Energy efficiency in WSN: IEEE 802.15.4

Hayfa AYADI, Ahmed Zouinkhi,
Boumedyen Boussaid, M Naceur Abdelkrim
MACS Laboratory: Modeling, Analysis and Control of Systems
National Engineering School of Gabes (ENIG)
University of Gabes, Tunisia
Email:ayadihayfa.ing@gmail.com,
ahmed.zouinkhi@enig.rnu.tn
boumedyen.boussaid@gmail.com

Thierry Val
Institut de Recherche en Informatique de Toulouse,
UMR 5505 - CNRS, Universite de Toulouse
IUT Blagnac, 1 pl. Georges Brassens
BP60073 F-31703 Blagnac Cedex France
Email:thierry.val@irit.fr

***Abstract*—Nowadays the energy consumption has become a critical challenge in Wireless Sensor Network (WSN). Wireless connection suffer from some weaknesse chiefly fault detection and energy efficiency which stay again the main problems in (WSN). Both was under the scope of research communities and industry engineers. We are interested to the IEEE 802.15.4 standard with beacon enabled mode. IEEE802.15.4 is a protocol designed to Physical (PHY) layer and Medium Access Control (MAC) for WSN. We intervene in the Superfame Duration (SD) which present the main private characteristic of the MAC frame in IEEE 802.15.4 in order to minimise the energy consumption when the energy level in a battery reach a critical level. INETMANET/OMNeT++ simulator is used to present our method.**

Keywords*—WSN, IEEE 802.15.4, Energy Consumption, Beacon Interval (BI), Superframe Duration (SD)

I. Introduction

Microelectronic progress and low radio technology gives birth to the wireless sensors devices with low cost and low power. Theses features give the opportunity to Wireless Sensor Network (WSN) specially the technology of IEEE 802.15.4 to be used in many fields and domains like military, environment monitoring [1], entertainments, security purposes, agriculture, medical field [2], [3], sports [4], [5].

Medical field is considered one of the most critical field at ever for all humanity. Implementation of sensor node in the body was really great development for WSN. It provides as very specific measurement in order to control vital organs status [6] .

Monitoring is considered an important application of WSN. Wireless Multimedia Sensor Networks (WMSNs) and image based sensor network [7], [8] can employ IEEE 802.15.4. So the data is send periodically to the base station with the low energy consumed possible. The accuracy of data transmission is an important issue in WSN that is why many methods was developed in order to detect all kinds of faults in WSN [9]. The IEEE 802.15.4 MAC still until now the subject for many research group which was motivating by such objectives witch consist of decreasing energy consumption, fault detection, increasing throughput, developing reliability, minimizing collision rate, and decreasing end-to-end delays [10]. Many other domains in it WSN could be used like the commercial application, control of industrial equipment, monitoring of greenhouse [11], [12] and communicating materials [12].

Although the WSN have many advantages that we could not omit, it suffers also from many challenges which are related to their wireless features and their hardware. We can cite some limitation such as Dynamic Network Nature, Traffic Asymmetry, Limited Resources, Scalability, Energy balancing, Multiple Sinks, Heterogeneous Traffic, Criticality Level and finally Security [11].

Our paper is organised by the way that section 1 presents an idea about energy efficiency in beacon enabled mode of IEEE 802.15.4. Section 2 introduces the IEEE 802.15.4. We demonstrate in section 3 our way to calculate The Superframe Duration. In next section the simulation results prove our method and we finish by small conclusion for our paper.

II. RELATED WORKS

Many works was interested to the adjustment of the Superframe Order (SO)/ Beacon Order (BO) which are private characteristic of IEEE 802.15.4 frame with regard to manage the active/inactive duration. Both kind of duration contributes in the energy consumption. In [13] the authors try to adjust the duty cycle to the data mouvement for minimum of energy consumption. In addition to that, according to this work the coordinator must also examine the collision rate and control the Channel Contention Access (CCA) in Contention Access Period (CAP) of the standard frame. However, a new methods ,which adjust the CAP duration to the actual traffic by resetting the SO, was proposed in [14]. So the writers try to study the access congestion problem and the collisions to avoid them.

In [15] the authors aims to adjust the duty cycle by proposing a new technique which is Dynamic Superframe Adjustment Algorithm (DSAA) with taking into account the channel opportunity and collision ratio. The research in [16] proposed a new algorithm: The Beacon Order Adaptive Algorithm (BOAA). The technique intervene only in the BO parameter of the superframe structure. It's about an algorithm that recalculate just BO parameter. The methods is applicable in star topology networks. Arshad Farhad et al, showed a new algorithm in [17] named A Traffic aware Dynamic Superframe Adaptation algorithm (TDSA) in which the writers try to make a link between BO and SO with reference to some criterion. Khanafer et al [18] try to give an analytical study based on Marckov chain. It is based on a modified prototypical presented by Park et al in [19].

The authors introduce a sleep state to the beacon-enabled mode after each successful transmission. Besides, a novel Duty Cycle Adaptation algorithm DCA was proposed for networks with beacon-enabled mode [20]. DCA control the duty-cycle flexibly conforming to the traffic of network.

III. Overview on IEEE 802.15.4 technology

This technology is destined to unwired networking protocol with specific characteristic such as low data. It includes the Medium Access Control (MAC) and Physical (PHY) layer. It is designed for Low Rate Wireless Personal Area Network LR WPAN. Its architechture is given by figure 1. So it is formed by Physical layer PHY. Also it contains the MAC sublayer which control the access to physical channel. The role of Specific Convergence Sublayer (SSCS) is to give access to Logical Link Control (LLC) of IEEE 802.2. The architecture is formed also by upper layers which is the responsible for manipulation, network configuration, and message routing [21].

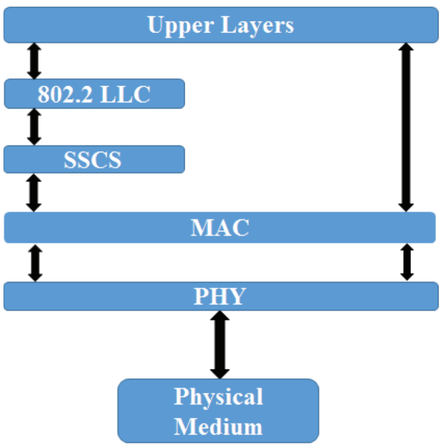

Fig. 1. Architecture of LR-WPAN device

While the MAC is responsible for MAC management service and MAC data service.The LR WPAN have many objective such as limited-area operation, cheeper, reliable data transfer, the ease of installation and a moderate battery activity [22].

Two kinds of nodes was established by IEEE 802.15.4 which are Full Function Device (FFD) and Reduced Function Device (RFD). FFD nodes could communicate with FFD and RFD, it can be a PAN Coordinator or an end device but the RFD is able to communicate only with the FFD associated. RFD nodes could be only end device. There is three topology could be formed by the node FFD and RFD which are star topology, mesh topology and peer to peer. In star topology, each FFD communicate with its associated RFD. In Mesh network coordinators initiate network parameters. It should enable full peer-to-peer link [22]. Besides in the third type, we integrate just one PAN coordinator (FFD) although there are many FFD associated to the network. As application of this topology we have the industrial monitoring and control also the Wireless Sensor Networks. Two operating styles are available in MAC sublayer either in beacon-enabled mechanism or non beacon-enabled behavior which are presented by figure 2.

In beacon-enabled, CSMA-CA slotted is allowed for transmis-

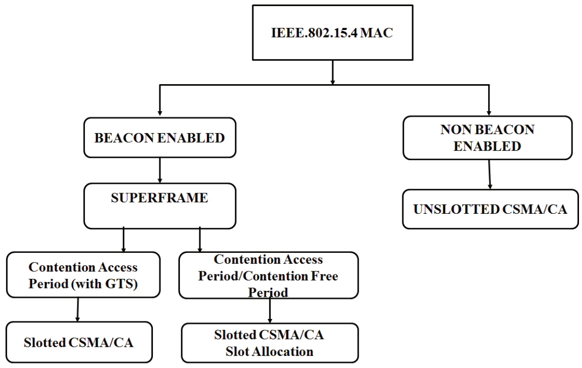

Fig. 2. MAC mecanism in IEEE.802.15.4

sion data. Although in non beacon-enabled style the unslotted CSMA-CA is enabled. The coordinator choose between the two modes. In the first mechanism, beacon frames are transmitted regularly by coordinator to synchronize the RFD associated with it, to determine its PAN and to describe the Superframe architecture. Two successive beacons are separated by a period of time which is named Beacon Interval (BI). It is divided in active period called also Superframe Duration (SD) and inactive duration as mentioned in figure 3.

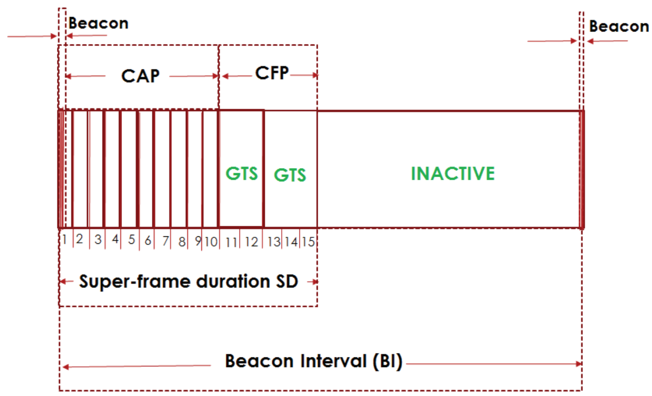

Fig. 3. Beacon Interval structure

The beacon is send in the first slot. The BI is formed by 16 slots with equal length, each slot is composed at minimum by 60 symbols in the case that the SO is set to 0. BI is get by formula (1) in which depend from BO. The Superframe Duration is composed by a beacon, Contention Access Period (CAP) and Contention Free Period (CFP). CSMA-CA is implemented in CAP part. It is explained by figure 4 and its parameters is mentioned in table I.

In the state that the beacon enabled mode is selected and the transmission will be throw the CAP, CSMA/CA slotted will be enabled. When the node has a data for transmission it begins by initializing BE to $macMinBE$ by default 3 and NB to 0. After waiting the selected period of time, it performs the CCA so as to explore the channel status. If it is idle, it is considered free and the node proceeds with data transmission. But in the case that the channel is unavailable, BE is elevated and the same for NB, it is incremented by 1

TABLE I. DESCRIPTION OF CSMA/CA PARAMETERS

CSMA/CA Parameters	Description
BE	Backoff Exponent
CW	Contention Window
macMinBE	The minimum value of the backoff exponent BE
macMaxBE	The maximum value of the backoff exponent BE
macMaxCSMABackoffs	The number of symbols forming the basic time period used by the CSMA-CA algorithm.
aUnitBackoffPeriod	Basic time period used by the CSMA-CA algorithm
CCA	Clear Channel Assessment

(NB = NB +1). The same procedure is repeated. In the case that $macMaxCSMABackoffs$ is inferior compared to NB value, so the algorithm of CSMA-CA finished with failure state of channel access. The algorithm is well described by figure 4

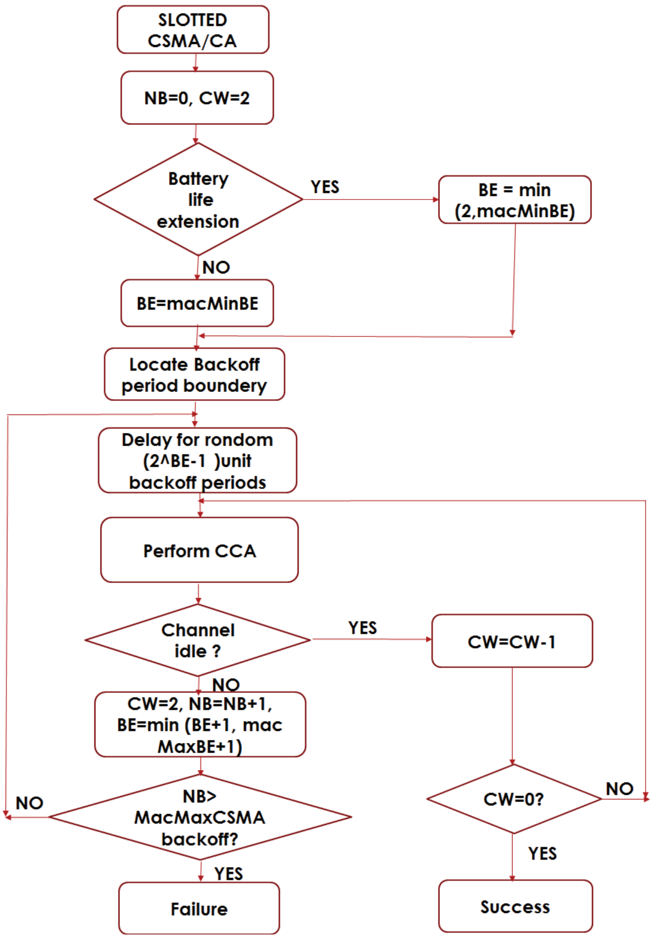

Fig. 4. CSMA/CA slotted algorithm

The beacon Interval is defined by equation (2) which depends from the $aBaseSuperframeDuration$.

$$BI = aBaseSuperframeDuration * 2^{BO}; 0 \leq \mathrm{BO} \leq 14 \quad (1)$$

The relation (2) gives as the definition of the $aBaseSuperframeDuration$ in the technology of IEEE 802.15.4 which is in direct relation with $aBaseSlotDuration$.

$$aBaseSuperFrameDuration = aBaseSlotDuration * anumSuperframeSlot \quad (2)$$

The $aBaseSlotDuration$ is given by relation (3).

$$\mathrm{aBaseSlotDuration} = 60 * \mathrm{symbolsaNumSuperFrameSlots} \quad (3)$$

Besides the Superframe Duration SD is defined by (4).

$$SD = ABaseSuperframeDuration {*} 2^{SO}; 0 \leq \mathrm{SO} \leq \mathrm{BO} \leq 14 \quad (4)$$

IV. SUPERFRAME DURATION ADJUSTMENT

Our work is interested basically on modifying the Superframe Interval when the energy consumed reach a specific threshold (avoid energy faults in the network). That is why we try to make a new link between the energy consumed and the way to get the Superframe Duration in order to minimise the duty cycle of the network and to extend the lifetime of the network. Many work was created in the energy field of the WSN. So many methods was developed in order to calculate the energy consumed in the state of transmission, energy in the reception phase and the energy consumed in the sleep state of the node.

A. *Energy Transmission*

Transmission energy (Etr) is the energy consumed by mote in data transmission. There is many way to calculate this kind of energy but in our work we will use an ordinary way in order to get the value of it. It is given by (5):

$$Etr = U * Itrans * \Delta t \quad (5)$$

with (Δt) is the time spend in the transmission period, ($Itrans$) is the current consumed by the CPU in order to enable the data transmission and (U) is the voltage needed by the mote in order to keep in work.

B. *Energy Reception*

In reception phase, very important quantity of energy (Er) is consumed. There are many way to calculate it. In our simulation we use a simple formula (6) to calculate it

$$Er = U * I_{recept} * \Delta t \quad (6)$$

with ($Irecept$) is the current consumed by the CPU in receiving data, (U) is the voltage needed by the mote and (Δt) is the period of reception data.

C. *Energy of Sleep Period*

In sleep phase the mote consumed very important quantity of energy (Es). This phase is very important to increase the lifetime of mote. In the 802.15.4 the sleep duration is calculated by (7):

$$\Delta t_{sleep} = BI - SD \quad (7)$$

So the Energy in sleep duration is given by this way (8):

$$Es = U * I * \Delta t_{sleep} \quad (8)$$

As we mentioned above our goal is to calculate a new Superframe Duration which depend from the energy remaining in the battery. The energy remaining (E_R), showed by (9), is the deference between the energy initial ($Eini$) and the energy consumed (Ec).

$$E_R = Eini - Ec \tag{9}$$

Ec is given by (10).

$$Ec = Es + Etr + Er \tag{10}$$

D. Superframe Duration (SD)

We try to adapt the level of energy with the activity of node which is described by the Duty Cycle percentage (DC). In the technology of IEEE 802.15.4 DC could be get by setting both macBeacon Order (BO) and macSuperframe order (SO). It is giving by equation (11) .

$$DC = 2^{(SO-BO)} * 100\% \tag{11}$$

When the energy consumed by the node is equal to 50% (as an example) of the energy initial, we intervane in the superframe duration in order to minimise the activity of the node. Therefore we decrease the duty cycle of the node. Our contribution is the new way is to make a direct link between energy and Superframe Duration. By this manner we can control the energy remaining in the battery.

We assume by assumption1 (equation (12)) that the energy wasted in (SD) is always inferior to the energy remaining. Assumption1:

$$E_{SD} \leq E_R \tag{12}$$

We propose that the energy consumed in the Superframe duration E_{SD} is expressed by relation (13) with the (E_R) is the Energy Remaining,(T_{tt}) presents the frame length, (E_T) is the Energy of frame and (SD_T) presents the size of Superframe period.

$$E_{SD} = (SD_T/T_{tt}) * E_T \tag{13}$$

So both relation (12) and (13) given as the formula (14).

$$(SD_T/T_{tt}) * E_T \leq E_R \tag{14}$$

We calculate the SD_T by equation (15).

$$(SD_T = ((16 * 960 * 10^{(-6)} * 2^{SO})/T_{tt}) \tag{15}$$

So equation (15) become by this way expression (16).

$$((16 * 960 * 10^{(-6)} * 2^{SO})/T_{tt}) * E_T \leq E_R \tag{16}$$

As 2^{SO} is calculate from equation (17).

$$2^{SO} \leq ((E_R * T_{tt})/(16 * 960 * 10^{(-6)} * E_T)) \tag{17}$$

Therefore the SO is expressed by the formula (18).

$$SO = log((E_R * T_{tt})/(16 * 960 * 10^{(-6)} * E_T))/log(2) \tag{18}$$

We propose that we use just 10% of the energy remaining in the node, giving by relation (19).

$$E_{R1} = E_R * 0.1 \tag{19}$$

That is why SO become (21):

$$SO = log((E_R * 0.1 * T_{tt})/(16 * 960 * 10^{(-6)} * E_T))/log(2) \tag{20}$$

V. Simulation results

We use INETMANET/OMNET++ for simulating. OMNeT++ simulator is adaptable and its component are based on C++ library. It is used for describing wired and unwired network for simulation. Despite many other WSN simulators accessible like as tinyOS and Opnet. INETMANET/OMNET++ serves practical wireless environment and mote behaviors. It is manipulated by scientific to test divers platform for specific roles [21]. Our simulation parameters are mentioned in table II.

TABLE II. Simulation Parameters

Parameters	Values
Simulation time	18000
Network size	(400,200)
E initial	18720
Nodes number	5
Channel frequency	2.4 GHz
Radio Type	IEEE 802.15.4 radio
dispersion	rondom

The simulation results (figures 5, 6 and 7) show as that energy reception decrease and also energy transmission decrease by the same way in the transmission period in contrary with the energy in the sleep period. The decrease of the energy in reception and transmission is the result of the decrease of the duty cycle DC so after change BO stays again 9 beacause we didn't touch it but SO decrease from 7 to 5 that is why CD become 6.25% given by equation (21) instead of 25 % given by formula (22) before our intervention.

$$2^{(SO-BO)} * 100 = (1/2^{(9-5)}) * 100 = (1/2^4) * 100 = 6,25 \tag{21}$$

$$2^{(SO-BO)} * 100 = (1/2^{(9-7)}) * 100 = (1/2^2) * 100 = 25 \tag{22}$$

While the increase of energy in sleep state is the result of the increase of the period of sleeping. Our intervention give results to the decrease of the DC in the network which present the principal cause of the change of the different period (active and inactive periods).

VI. Conclusion

We present a new w way for calculation of the Superframe Order which is characterised by its link to energy level We have calculated the three principal kind of energy consumption: energy transmission, energy reception and energy of sleep duration and we proved the effect of our new SO in the different energy types. Our new way gives as the opportunity to deal with the lifetime of the node by the well exploitation of the energy remaining in the battery. As perspective of this work we could set the life period of the node at the first use then change periodically the SD in order to get the lifetime set at the beginning .

o

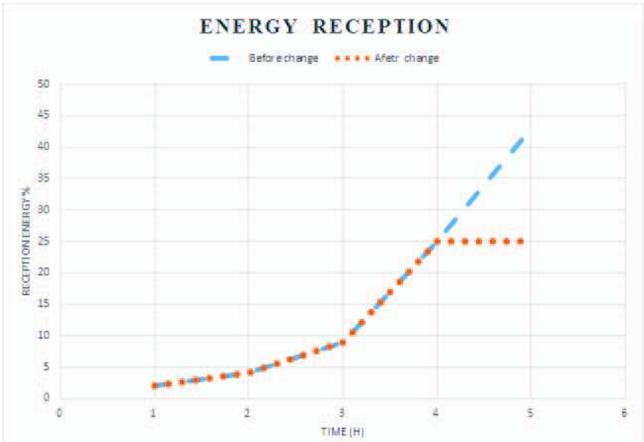

Fig. 5. Reception Energy

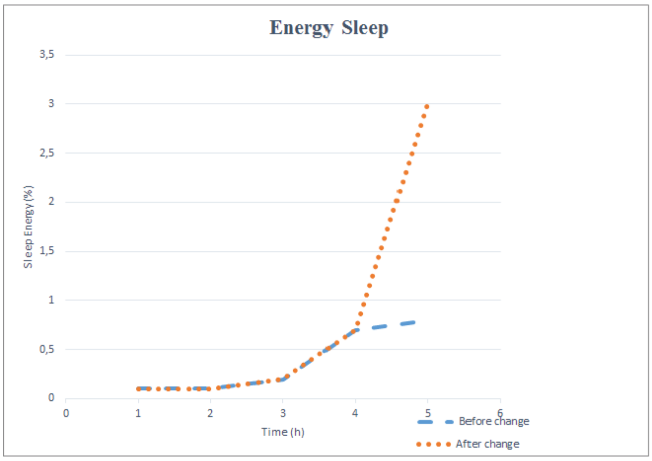

Fig. 6. Sleep Energy

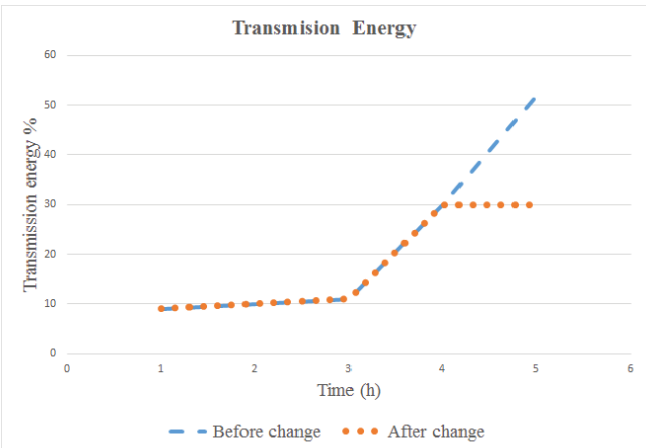

Fig. 7. Transmission Energy

VII. Acknowledgement

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

References

[1] K. Mekki, K. Mekki, and M. N. Abdelkrim, "Application and network layers design for wireless sensor network to supervise chemical active product warehouse," *International Journal of Computer Science, Engineering and Applications*, vol. 4, no. 6, 2015.

[2] N. A. Alrajeh, J. Lloret, and A. Canovas, "A framework for obesity control using a wireless body sensor network," *International Journal of Distributed Sensor Networks Sage*, vol. 10, 2014.

[3] N. Singh, A. K. Singh, and V. K. Singh, "Design and performance of wearable ultrawide band textile antenna for medical applications," *Microwave and optical technology Letters*, vol. 57, no. 7, pp. 1553–1557, 2015.

[4] M. Garcia, A. Catalá, J. Lloret, and J. J. Rodrigues, "A wireless sensor network for soccer team monitoring," in *IEEE International Conference on Distributed Computing in Sensor Systems and Workshops (DCOSS), June 27-29, Barcelona*, 2011, pp. 1–6.

[5] J. Lloret, M. Garcia, A. Catala, and J. Rodrigues, "A group-based wireless body sensors network using energy harvesting for soccer team monitoring," *International Journal of Sensor Networks*, vol. 21, no. 4, 2016.

[6] M. Patel and J. Wang, "Applications, challenges, and prospective in emerging body area networking technologies," *IEEE Wireless Communications Magazine*, vol. 17, no. 1, pp. 80–88, 2010.

[7] M. O. Farooq and T. Kunz, "Bandest: measurement-based available bandwidth estimation and flow admission control algorithm for ad hoc ieee 802.15. 4-based wireless multimedia networks," *International Journal of Distributed Sensor Networks*, vol. 2015, p. 2, 2015.

[8] C. Pham, V. Lecuire, and J.-M. Moureaux, "Performances of multi-hops image transmissions on ieee 802.15. 4 wireless sensor networks for surveillance applications," in *IEEE, 9th International Wireless Communications and Mobile Computing Conference (IWCMC), July 1-5, Sardinia, 2013*, pp. 477–484.

[9] 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.

[10] M. Khanafer, M. Guennoun, and H. T. Mouftah, "A survey of beacon-enabled ieee 802.15. 4 mac protocols in wireless sensor networks," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 2, pp. 856–876, 2014.

[11] J. Baviskar, A. Mulla, A. Baviskar, S. Ashtekar, and A. Chintawar, "Real time monitoring and control system for green house based on 802.15. 4 wireless sensor network," in *IEEE International Conference on Communication Systems and Network Technologies (CSNT),April 7-9, Bhopal India 2014*, pp. 98–103.

[12] L. Ruiz-Garcia, L. Lunadei, P. Barreiro, and I. Robla, "A review of wireless sensor technologies and applications in agriculture and food industry: state of the art and current trends," *sensors*, vol. 9, no. 6, pp. 4728–4750, 2009.

[13] 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.

[14] J. Hurtado-López and E. Casilari, "An adaptive algorithm to optimize the dynamics of ieee 802.15. 4 networks," in *Mobile Networks and Management chapter, Springer, pp 136-148.*

[15] B.-H. Lee and H.-K. Wu, "Study on a dynamic superframe adjustment algorithm for ieee 802.15. 4 lr-wpan," in *IEEE Vehicular Technology Conference (VTC 2010-Spring), June 16-19 Mai, Taiwan, 2010*, pp. 1–5.

[16] M. Neugebauer, J. Plonnigs, and K. Kabitzsch, "A new beacon order adaptation algorithm for ieee 802.15. 4 networks," in *Proceeedings of the Second IEEE European Workshop on Wireless Sensor Networks, Jan 31- Feb 02, Istanbul turkey 2005*, pp. 302–311.

[17] A. Farhad, Y. Zia, S. Farid, and F. B. Hussain, "A traffic aware dynamic super-frame adaptation algorithm for the ieee 802.15. 4 based networks," in *IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob), 27-29 Aug, Bandung Indonesia*, 2015, pp. 261–266.

[18] M. Khanafer, M. Guennoun, and H. T. Mouftah, "Adaptive sleeping periods in ieee 802.15. 4 for efficient energy savings: markov-based theoretical analysis," in *IEEE International Conference on Communications (ICC).*

[19] P. Park, C. Fischione, and K. H. Johansson, "Adaptive ieee 802.15. 4 protocol for energy efficient, reliable and timely communications," in *Proceedings of the 9th ACM/IEEE international conference on information processing in sensor networks, April 12-16, Sweeden*, 2010, pp. 327–338.

[20] J. Jeon, J. W. Lee, J. Y. Ha, and W. H. Kwon, "Dca: duty-cycle adaptation algorithm for ieee 802.15. 4 beacon-enabled networks," in *IEEE Vehicular Technology Conference (VTC2007), 22-25 April, Dublin Ireland*, 2007, pp. 110–113.

[21] A. Varga, "Omnet++," in *Modeling and Tools for Network Simulation*. Springer, 2010, pp. 35–59.

[22] 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.