GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

SURVEY ON ENERGY EFFICIENT REAL-TIME SERVICES FOR WIRELESS SENSOR NETWORKS WITH IEEE 802.15.4

R.Krishna kumar*1, K.Ramamoorthy2 and K.Batri3
PG Scholar, Department of Electronics and Communication Engineering, PSNA college of Engineering and Technology, Dindigul -624622, India*1
Assistant Professor, Department of Electronics and Communication Engineering, PSNA college of Engineering and Technology, Dindigul -624622, India2
Professor, Department of Electronics and Communication Engineering, PSNA college of Engineering and Technology, Dindigul -624619, India3

Abstract

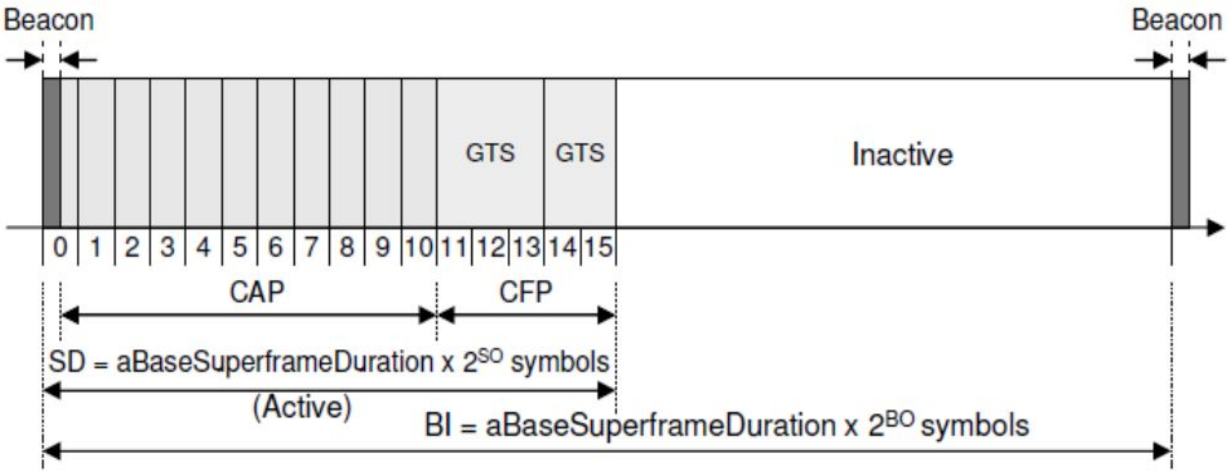
A Wireless Sensor Network (WSN) distinguishes from other wireless or wired networks through its capability of interaction with the environment. Such networks have been used under various applications like life safety, disaster relief, smart environments, and industrial monitoring systems, which require a large amount of wireless sensors which are battery-powered, and are generally designed for long-term deployments with no human intervention. Consequently, energy efficiency and reliability is the main design objectives for these sensor networks. Since reliability is highly application-dependent, it is possible to trade-off energy consumption and reliability in order to prolong the network lifetime, and also satisfying the application requirements (QoS). In order to reduce the energy consumption, beacon-enabled networks with long network inactive periods can be employed. However, , as some other configuration parameters are set to default values conventionally, the duration of these inactivity periods remain fixed during the whole network operation. This implies that if they are misconfigured the network will not adapt to variation in the QoS environment conditions, particularly to the traffic load. In this paper the trading off methodologies for optimizing the energy efficiency and reliability has been discussed.

Keywords: WSN, reliability, energy conservation, QoS, industrial monitoring system,

I. INTRODUCTION

WIRELESS sensor networks (WSNs) are being deployed in many real-life applications, such as health monitoring [1] and environmental, security [3] and surveillance, industrial automation and control [3]. This has been possible due to the advent of: (i) the IEEE 802.15.4 standard [2], which defines the physical and medium access control (MAC) layers of the protocol stack; and (ii) the ZigBee specifications [2], which cover the network and application layers. A major concern in WSNs is energy conservation [5], although reliability is also very critical [4]. Indeed, it has been shown that WSNs based on IEEE 802.15.4/ZigBee suffer from serious unreliability issues, especially when power management is enabled for conserving energy [5]. Therefore, effective and efficient mechanisms should be provided to achieve reliability with a low energy expenditure. Now, different WSN applications have different reliability requirements. For instance, industrial control or military applications might require nearly 100% reliability[4]. On the other hand, environmental monitoring applications might tolerate message, loss, leading to a trade-off between energy conservation and reliability [4]. For energy efficiency, the WSN protocol stack needs to be tuned according to the actual needs. The traffic and network conditions in a WSN are often very dynamic, due to both the noisy wireless channel and the failure probability of sensor nodes (e.g., when they run out of battery power). Thus, energy-aware and reliable data collection mechanisms should be able to adapt to the actual operating conditions [3]. In addition, they should be flexible enough to support a wide variety of operating scenarios, without any prior or global knowledge on the network topology and the traffic pattern. All these requirements make the design of energy-efficient adaptive schemes for reliable data collection a significant challenge.

Fig. 1. Superframe structure in IEEE 802.15.4



II. A) SUPERFRAME STRUCTURE

In beacon enabled mode, the time between two consecutive beacons is called the Beacon Interval (BI) and its structure is called Superframe (see Figure 1). The Superframe can be divided into two periods: an active and inactive period. All the communications between a coordinator and its 'children' must take place during the active portion of the Superframe, also known as Superframe Duration (SD). The active period of the superframe is divided into sixteen slots where slot (0) is reserved for the beacon. This frame must be received by all the associated devices so that they must be awake for this first slot. The Contention Access Period (CAP) extends between slot zero and the CFP. Within the CAP, devices contend for the channel and communications are regulated by slotted CSMA/CA. Up to seven Guaranteed Time Slots may be assigned to some nodes at the end of the SD in order to provide QoS (Quality of Service). This is called the Contention Free Period (CFP). Until the next Beacon, during the remaining time, the nodes will enter into a low consumption state or sleeping mode to reducing their duty cycle and consequently saving battery power. Although the beaconless operation mode is less complex and does not present any scalability problem (as far as it allows nodes to asynchronous transmission), it may force the nodes to be listening to the radio channel continuously. This leads to a useless waste of energy while GTS are not possible. On the other hand, the beaconenabled mode is more complex to configure and implement as it may demand a strict synchronization of the nodes. The whole structure of the Superframe is governed by the values of two MAC numerical parameters: the macBeaconOrder (BO) and the macSuperframeOrder (SO), which define the values of BI and SD as follows:

$BI = a \cdot 2BO$ for $0 \leq BO \leq 14$ **(1)**
$SD = a \cdot 2SO$ with $0 \leq SO \leq BO \leq 14$ **(2)**

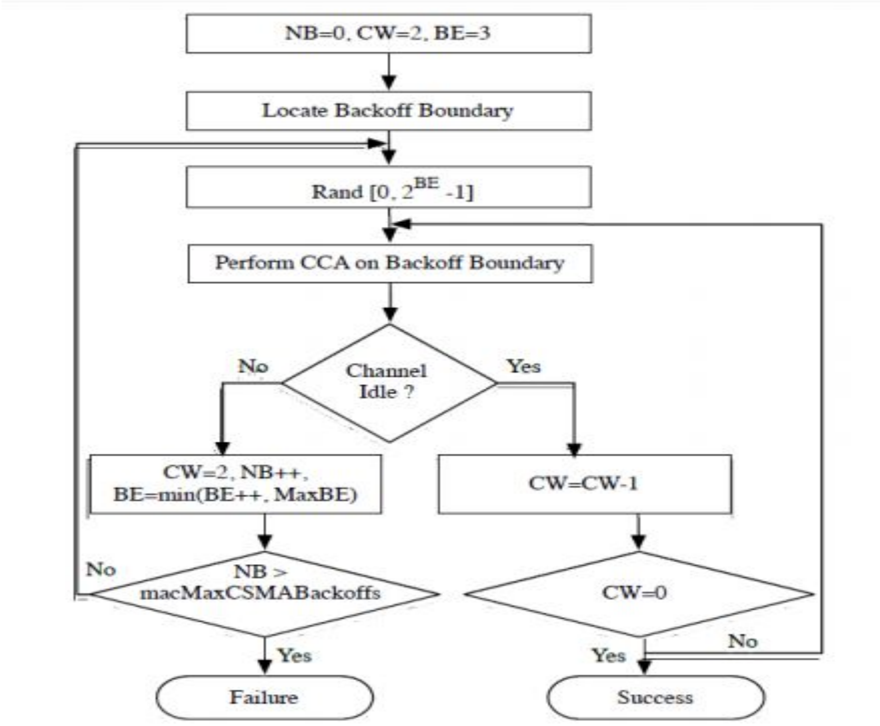
Where the time between two consecutive beacons is called the Beacon Interval and a is the Base Superframe duration (15.36, 24 or 48 ms depending on the employed bit rate: 250, 40 or 20 kbps respectively). The values of BO and SO are limited to the [0, 14] interval. The ratio SO/BO is called the duty-cycle. The lower the duty-cycle the larger the inactive period. If SO=BO (i.e. duty-cycle is 1) no inactive period would exist and the Superframe Duration would coincide with the whole Beacon Interval.

II. B) CSMA/CA ALGORITHM

Slotted CSMA/CA channel access algorithm shall be normally used in IEEE 802.15.4 beaconenabled networks to transmit data or commands within the CAP. Figure 2 illustrates the Slotted CSMA/CA algorithm flow chart.Upon receiving a data frame to be transmitted, the slotted CSMA/CA algorithm performs the following steps:-

1. State variables are initialized as follows. The contention window size (CW = 2), the number of backoff stages (NB = 0), and the backoff exponent (which is set to the default minimum value, i.e., BE = MACMINBE).
2. A backoff timer is initialized by using a random backoff time uniformly distributed in the range [0, 320 · (− 1)] µs.
3. The status of the wireless medium is checked through the Clear Channel Assessment (CCA).
4. If the medium is busy, the state variables are updated as follows: NB = NB + 1, BE = min (BE + 1, MACMAXBE) and CW = 2. If the number of backoff stages exceeds the maximum allowed value (i.e., NB > MACMAXCSMABACKOFFS), the frame is dropped. Otherwise, the algorithm falls back to Step 2.
5. If the medium is free, then CW = CW−1. If CW = 0 the frame is transmitted. Otherwise the algorithm falls back to Step 3 to perform a second CCA.

Fig. 2. Slotted CSMA/CA algorithm [16]



In the non-beacon enabled mode, the unslotted version of the CSMA/CA algorithm is used. Hence, operations are not aligned to the backoff period slots. In addition, the CCA operation is performed only once to check whether the channel is busy or not (i.e., CW = 1).In both cases, the CSMA/CA algorithm supports an optional re-transmission scheme based on acknowledgments. When re-transmissions are enabled, the destination node must send an acknowledgment just after receiving a data frame. Unacknowledged messages are retransmitted up to MACMAXFRAMERETRIES times, and then dropped. Every time the message is (re)transmitted, the CSMA/CA algorithm starts from Step 1.

III. RELATED WORKS

There exists literature about cross-layer frameworks and adaptive approaches to data collection in WSNs. This section briefly reviews the related work. Very few papers consider both data rate and jitter requirements for real-time traffic in TDMA based wireless sensor networks (WSNs).

A. Improvements in IEEE 802.15.4 Slotted CSMA/CA

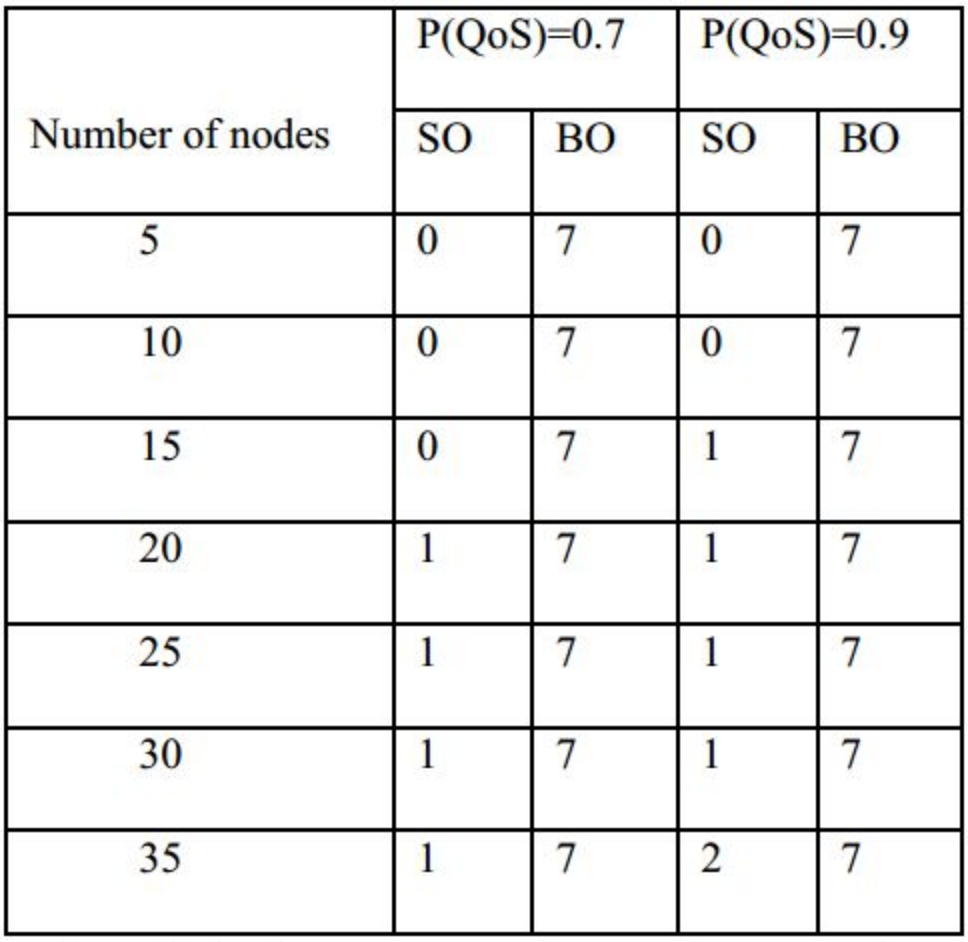
Song et al. [7] proposed a dynamic GTS (DGTS) allocation algorithm to reduce wasted bandwidth. To reduce the wasted part of GTS allocation, they proposed to allocate a D-GTS in the backoff period unit rather than a superframe slot unit. In [8] J. Zheng and M. J. Lee evaluated the general performance of this IEE802.15.4 standard, they developed an NS2 simulator model, which covers all the 802.15.4 PHY and MAC primitives, and carry out five sets of experiments, that is, experiments of:

- Comparing the performance between 802.15.4 and 802.11.
- Association and tree formation study.
- Orphaning and coordinator relocation investigation.
- Examination of unslotted CSMACA and slotted CSMACA behaviors; and
- comparing three different data transmissions, namely, direct, indirect and guaranteed time slot (GTS) data transmissions.

In [10] Feng Liu et al took the first attempt to obtain the optimal joint routing-and-sleepscheduling scheme for WSNs. They proposed a sleeping scheduling and routing scheme for energy efficiency. So that network life time will be maximized. They overcome the mathematical difficulty in solving joint optimization problems for joint routing-and-sleep scheduling schemes in current literature. the nonconvex nature constrain of optimization problem formulation in this work is a mathematical challenge tackle by transforming it into an equivalent Signomial Programming (SP) problem through the relaxation of an equality constraint. The SP problem then efficiently solved via an iterative convex approximation method, where a convex Geometric Programming (GP) problem is solved in each step. Here three algorithms are applied

1) An Iterative GP algorithm
2) Separate Routing and Sleep Scheduling
3) Fixed-Sleep-Time Routing. From numerical value obtained IGP algorithm provides 284% greater life time.

TABLE-1 Optimized SO & BO parameters for different QOS [10]



Number of nodes	P(QoS)=0.7		P(QoS)=0.9	
	SO	BO	SO	BO
5	0	7	0	7
10	0	7	0	7
15	0	7	1	7
20	1	7	1	7
25	1	7	1	7
30	1	7	1	7
35	1	7	2	7

The optimized BO & SO value are shown on above table that the parameter vary based on number of nodes and required QoS percentage.

Lopez et al. [11] proposed the AAOD algorithm. The coordinator calculates the number of packets received in each superframe and adjust the active period, and received packets compared with the previous superframe. If the amount of received packets increases from the threshold, the coordinator increasing the SO which increases the length of active period for the next superframe and vice versa. Based on this statistical value the SO order is modified. This solution is based on an optimization problem built on top of an analytical model of the IEEE

802.15.4 standard. As a result, the proposed approach has significant computational and storage overheads, which make it unsuitable for implementations on real sensors.

Huang et al. [12] developed an adaptive GTS allocation (AGA) scheme which considers low latency and fairness. Based on recent GTS usage, the algorithm assigns priority in priority assignment phase and in GTS scheduling phase a node with a higher priority will be allowed to use GTS. With a series of experiments, the proposed AGA scheme was evaluated and showed better wait time and fairness performance than the standard scheme.

In paper [14] Jie Zhang et al proposed a new MAC protocol explicitly designed for real-time wireless data acquisition. Adopting the TDMAFHSS schedule to control channel access, the protocol has collision and interference avoidance and low energy consumption capabilities. The synchronization is tightly coupled with TDMA scheme through periodically broadcasting beacons. Furthermore, to remove non-deterministic error caused by software overheads from the transmission path, hardware timers are used.

In addition to providing optimized solutions specific to a single layer of the protocol stack, various cross-layer approaches have been proposed in the literature [15], [16]. Most of these approaches focus on the joint optimization of the physical and MAC layers, or the MAC and networking (e.g., routing) layers. In [16] a cross-layer optimization framework is proposed based on an experimental analysis of interference in IEEE 802.15.4 networks. However, the focus of the paper is mostly on the physical layer in the form of power control. Finally, only limited literature jointly evaluates the impact of the network/application layer on the performance of IEEE 802.15.4 networks.

With special focus on ZigBee networks [15] investigates the impact of different sleep/wakeup scheduling policies in multihop WSN. Even though the authors provide hints on how to tune the IEEE 802.15.4 MAC layer, the investigated solution is not adaptive, nor does it support application-specific reliability requirements.

Alongside, relatively less attention has been paid to reliability guarantees in WSNs. In the context IEEE 802.15.4-based WSNs, many papers [17], [18],[19],[20],[21] highlighted that a significant share of transmitted messages may be lost due to contention, especially when the number of sensor nodes and the message size are large.

In [17] Jianxin Chen et al proposed EGSA scheme to increase the no of GTS allocation more than seven without modifying the existing standard. It is done by splitting the existing GTS slot into minislots. Each GTS act as bandwidth. In each bandwidth depending on packet size of nodes more than 7 number of nodes utilizes GTS. But due to low bandwidth the transmission time of each node will get increased.

In [18] Feng Xia et al, proposed a GTS allocation mechanism based on Data-based Priority and Rate-based Priority. In data based priority 3 level of priority (Low, Middle, and High) for a data is given. In rate based priority, by using statistical values based on packets received priorities for each node is assigned by coordinator. For that they define two new states GTS hit and GTS miss. The simulation result shows that probability of GTS allocation for node is vary based on their packet received state.

In paper [19], Anis Koubaa et al proposed a methodology for analyzing the Guaranteed Time Slot mechanism provided by the IEEE 802.15.4 protocol. Using Network Calculus formalism, two accurate models have proposed for the service curve provided by a GTS allocation and derived the delay bounds guaranteed by such an allocation. An expression of the duty cycle as a function of the delay was also presented. Based on those numerical results, the impact of the beacon order and the superframe order on the maximum throughput, delay bound and power-efficiency was analyzed. Based on numerical results typically with low arrival rates and low burst size, using low superframe orders is more convenient for providing low delay bounds. However, they lack of efficient utilization of the GTS capacity due to their short duration and to the impact of inter frame space (IFS). It has been also shown that, low superframe orders are more power-efficient while still satisfying a given delay bound requirement. IGAME [13] an implicit GTS allocation mechanism is later proposed by same author,

In [21] F. Chen et al has been implemented an IEEE 802.15.4 simulation model for OMNeT++. The main objective of this paper is to obtain the optimized BO, SO parameter to achieve high reliability, and energy conversation. The simulation is performed based on different traffic load and different number of nodes. Thus two different scenarios for the CSMA/CA operation mode has been analyzed: one with a small three-node star topology and the other with a 21-node star network modeling a typical industrial sensor network application with different data rates. In addition, the GTS mode that allows real-time operation based on a TDMA schedule was analyzed. The simulation done by varying the duty cycle, SO and BO parameters. End-to-end goodput on a logarithmic scale is increased with less traffic load.

In [22] Seong-eun Yoo et al proposed a realtime message-scheduling algorithm for IEEE 802.15.4- based industrial WSNs. The scheduling algorithm can schedule a given periodic real-time message set, and the algorithm determines the appropriate standard specific parameters such as BO, SO, and GTS descriptor to meet the timing constraints. The BO is determined based on minCAPlength. The proposed scheduling algorithm was analyzed with an extensive simulation study. The guaranteed time service was implemented in a real sensor node, namely, T-S–ink/Sensor node, and demonstrated, through experiments, and the implemented system runs accurately according to the schedule generated by the proposed algorithm.

To enhance and add functionality to IEEE 802.15.4-2006 for better support to the industrial WSNs, the IEEE 802.15 Task Group 4e [23] is charted to define a Media Access Control (MAC) amendment to the existing IEEE 802.15.4-2006. The proposals can be summarized as the following: 1) network-wide time synchronization; 2) beacon scheduling; 3) enhancing the existing superframe and GTS scheme; and 4) time-slotted channel hopping to support real-time communication under radio interference's. According to the proposals, the IEEE 802.15.4e standard is supposed to support industrial applications better in terms of real-time and reliable communication. But, a real-time message-scheduling algorithm to schedule periodic real-time messages is still requires.

B. ANALYTICAL MODELS

Most of the papers studying the slotted CSMA/CA algorithm employ a Markov chain model for their analysis [24],[25],[26],[27] to find better solution analytically. In paper [24] T. Lee proposed a new analytical model based on Markov chain model. It majorly focused to increase the throughput of IEEE 802.15.4 WPAN. The analytical results closely matches the simulation results.

The throughput and energy consumption of 802.15.4 network is analyzed under saturated [25] and unsaturated [26] traffic conditions and for a different number of nodes and simulated using NS2.
The analytical results closely matched to simulation. The results of both shows as the number of nodes increases, the Energy consumption per one slot payload (mJ/slot) also increases with decrease of Normalized throughput [25]. As well as the throughput decreases while the energy consumption per one slot payload increases [26].

IV. CONCLUSION AND PERSPECTIVES

In this paper the existing improvements for IEEE802.15.4 and optimizations for energy efficiency and reliability have discussed. From the results and parameters analyzed, it is observed that tuning or optimizing the superframeorder provides successful results on optimization. Mostly for Beacon order chosen above 7 provides better results. Since the Backoff period is already low in IEEE802.15.4 reducing the backoff period increases the energy consumption due to higher retransmission. So the tuning of BE won't provide significant improvement. So optimizing the BO and SO will provide significant improvement in energy conservation and reliability of WSN.

V. REFERENCES

1. *Ian F. Akyildiz and Mehmet Can Vuran, "Wireless Sensor Networks", 2010 John Wiley & Sons Ltd., 978-0470- 03601-3, August 2010.*
2. *Pei Huang, Li Xiao, Soroor Soltani, Matt W. Mutka, and Ning Xi, "The Evolution of MAC Protocols in Wireless Sensor Networks: A Survey", IEEE communications surveys & tutorials, vol. 15, no. 1, first quarter 2013.*
3. *S. Yoo, P. K. Chong, and D. Kim, "S3: School zone safety system based on wireless sensor network," Sensors, vol. 9, no. 8, pp. 5968–5988, Aug. 2009.*
4. *Rania Gomaa, Ihab Adly, Karam Sharshar "ZigBee Wireless Sensor Network for Radiation Monitoring at Nuclear Facilities", IEEE Transactions on Wireless Communications, 978-1-4673-5616-9/13, 2013.*
5. *S. Pollin, M. Ergen, and S. C. Ergen, "Performance analysis of slotted carrier sense IEEE 802.15.4 medium access layer," IEEE Transactions on Wireless Communications, vol. 7, no. 9, pp. 3359-3371, 2008.*
6. *L. Cheng, X. Zhang, and A. G. Bourgeois, "GTS allocation scheme revisited," Electron. Lett., vol. 43, no. 18, pp. 1005–1006, Aug. 2007.*
7. *J. Song, J.-D. Ryoo, S. Kim, J. Kim, H. Kim, and P. Mah, "A dynamic GTS allocation algorithm in IEEE 802.15.4 for QoS guaranteed real-time applications," in Proc. IEEE Int. Symp. Consum. Electron., Jun. 2007, pp. 1–6.*
8. *J. Zheng and M. J. Lee, "Will IEEE 802.15.4 make ubiquitous networking a reality? A discussion on a potential low power, low bit rate standard," IEEE Communications Magazine., vol. 42, no. 6, pp. 140-146, 2004.*
9. *Feng Liu, Chi-Ying Tsui, and Ying Jun (Angela) Zhang, "Joint Routing and Sleep Scheduling for Lifetime Maximization of Wireless Sensor Networks", IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 9, NO. 7, JULY 2010.*
10. *F. Shu, T. Sakurai, H. L. Vu, and M. Zukerman, "Optimizing the IEEE 802.15.4 MAC," Proceedings of IEEE Region 10 Conference (TENCON), pp. 1-4, 2006.*
11. *J. H. López and E. Casilari, "An adaptive algorithm to optimize the dynamics of IEEE 802.15. 4 networks," Mobile Networks and Management, pp.136-148, 2013.*
12. *Yu-Kai Huang, Ai-Chun Pang, and Hui-Nien Hung "An Adaptive GTS Allocation Scheme for IEEE 802.15.4", IEEE TRANSACTIONS ON PARALLEL AND DISTRIBUTED SYSTEMS, VOL. 19, NO. 5, MAY 2008.*
13. *Anis Koubaa, Mário Alves and Eduardo Tovar, "i-GAME: An Implicit GTS Allocation Mechanism in IEEE 802.15.4 for Time-Sensitive Wireless Sensor Networks", in proc. Of the 18 th euromicro conference on Real-Time systems, Dresden, Germany, July 2006, pp. 183-192.*
14. *Jie Zhang, Jie Wu, Zhao Han, Liefeng Liu, Kaiyun Tian, and Juan Dong, "Low Power, Accurate Time Synchronization MAC Protocol for Real-Time Wireless Data Acquisition", IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 60, NO. 5, OCTOBER 2013.*
15. *Francesca Cuomo , Anna Abbagnale and Emanuele Cipollone, "Cross-layer network formation for energy-efficient IEEE 802.15.4/ZigBee Wireless Sensor Networks", 1570-8705 _ 2011 Elsevier B.V. All rights reserved. doi:10.1016/j.adhoc.2011.11.006.*
16. *W. Ye, J. Heidemann, and D. Estrin, "Medium access control with coordinated adaptive sleeping for wireless sensor networks," IEEE/ACM Transactions on Wireless Communications, vol. 12, no. 3, pp. 493–506, 2004.*
17. *Jianxin Chen, Luis Lino Ferreira and Eduardo Tovar, "An Explicit GTS Allocation Algorithm for IEEE 802.15.4", Technical Report HURRAY-TR-120901.*
18. *Feng Xia, Ruonan Hao and Yang Cao, Lei Xue, "ART-GAS: An Adaptive and Real-Time GTS Allocation Scheme for IEEE 802.15.4", arXiv:1201.0215v1 [cs.NI] 31 Dec 2011.*
19. *Anis Koubaa, Mário Alves and Eduardo Tovar, "GTS Allocation Analysis in IEEE 802.15.4 for Real-Time Wireless Sensor Networks", TR-051204 Version: 1.0, 20 December 2005.*
20. *Anis Koubaa, Mário Alves, Bilel Nefzi and YeQiong Song, "Improving the IEEE 802.15.4 Slotted CSMA/CA MAC for Time-Critical Events in Wireless Sensor Networks", TR-060704 Version: 1.0 Jul 2006.*

21. F. Chen, N. Wang, R. German, and F. Dressler, *“Simulation study of IEEE 802.15.4 LR-WPAN for industrial applications,” Wireless Commun. Mobile Comput., vol. 10, no. 5, pp. 609–621, May 2010.*
22. *Seong-eun Yoo, Poh Kit Chong, Daeyoung Kim, Yoonmee Doh, Minh-Long Pham, Eunchang Choi, and Jaedoo Huh, “Guaranteeing RealTime Services for Industrial Wireless Sensor Networks with IEEE 802.15.4”, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 57, NO. 11, NOVEMBER 2010.*
23. *Pei Huang, Li Xiao, Soroor Soltani, Matt W. Mutka, and Ning Xi, “The Evolution of MAC Protocols in Wireless Sensor Networks: A Survey”, IEEE communications surveys & tutorials, vol. 15, no. 1, first quarter 2013.*
24. *T. Lee, H. R. Lee, and M. Y. Chung, “MAC throughput limit analysis of slotted CSMA/CA in IEEE 802.15.4 WPAN,” IEEE Communications Letters, vol. 10, no. 7, pp. 561-563, 2006.*
25. *T. Park, T. Kim, J. Choi, S. Choi, and W. Kwon, “Throughput and energy consumption analysis of IEEE 802.15.4 slotted CSMA/CA,” Electron. Lett., vol. 41, no. 18, pp. 1017–1019, 2005.*
26. *C. Y. Jung, H. Y. Hwang, D. K. Sung, and G. U. Hwang, “Enhanced Markov chain model and throughput analysis of the slotted CSMA/CA for IEEE 802.15.4 under unsaturated traffic conditions”, IEEE Transactions on Vehicular Technology, vol. 58, no. 1, pp. 473-478, 2009.*
27. *Alladi Ramesh, Dr.P.Sumithabhashini, “Analyzing the Performance of GTS Allocation Using Markov Model in IEEE 802.15.4”, (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 3 (2) , 2012,3382-3387.*