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RESEARCH ARTICLE

On Battery Energy Consumption in IEEE 802.15.4 for Wireless Sensor Networks with and without Guaranteed Time Slots

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*Abstract— **The main objective of this paper is to minimize the battery energy consumption in 802.15.4 for Wireless Sensor Networks (WSNs). This paper presents the simulation results of three scenarios: with Guaranteed Time Slot (GTS), Mixed and Without GTS for Fully Functional Devices (FFDs) and Reduced Functional Devices (RFDs). It is revealed that battery energy consumption is reduced to minimum in case of GTS enabled devices as compared to the non GTS devices.***

Keywords — GTS, FFD, RFD, IEEE 802.15.4, WSN, Battery Energy Consumed;

I. INTRODUCTION

Recent trend in networking is towards “Anywhere and Anytime Connectivity” with guarantee without the use of cables at low cost and low power consumption. IEEE 802.15.4 protocol is a flexible technology with great potential for WSN applications at low-rate and low-power which supports the information exchange via radio links in ISM 2.4 GHz frequency band for which no license is required. This protocol is quite flexible for wide range of applications if appropriate tuning of the parameters is carried out. A lot of work on 802.15.4 has been reported by the various researchers Ref [1-31]. They have investigated various performance issues like: Delay & Throughput evaluation of GTS mechanism, effects of direct and indirect transmission, impact of interferences, GTS delay bounds etc. but no comparative study has been done for various scenarios of IEEE 802.15.4 WPAN. In this paper we have compared the performance of three different scenarios of IEEE 802.15.4 protocol and effort has been done to design a two-tiered architecture for large scale WSN applications. Network Simulator OPNET® Modeler is used for designing the different scenarios: with GTS – which contains all GTS enabled nodes, secondly mixed scenario – which consists of equal number of GTS and Non-GTS nodes and third one is without GTS implementation in all nodes. The results have been obtained through simulation by considering the optimum values of parameters so that better performance of the protocol can be guaranteed.

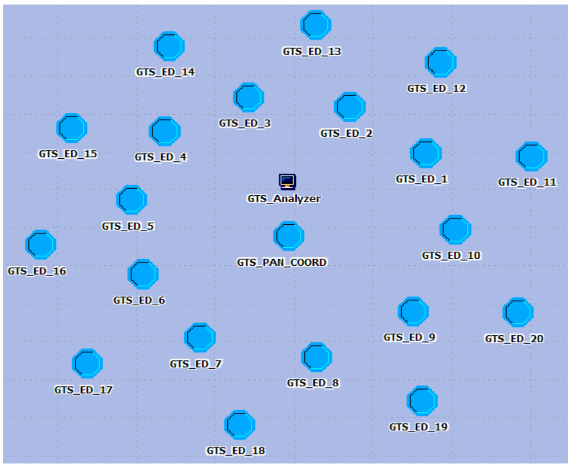
Most of those research studies have typically focused on evaluation/improvement of some characteristics of the standard protocol either analytically or by simulation. [1] addresses the performance evaluation of IEEE 802.15.4 GTS mechanism, and it is a research effort aiming at assessing IEEE 802.15.4/ZigBee protocol as a candidate technology within the ART-Wise framework. [2] describes the most important features of the IEEE 802.15.4 protocol that are relevant for WSNs, and discusses the ability of this protocol to fulfill the different requirements of WSNs and to resolve inherent paradoxes involving power-efficiency, timeliness guarantees and scalability issues. Sharath et al. [5] have classified and compared the GTS allocation and scheduling algorithms in IEEE 802.15.4 for WSNs. Authors of [6] have proposed a Multi-Factor Dynamic GTS Allocation Scheme (MFDGAS) to improve the utilization of GTS bandwidth. Also this MFDGAS scheme determines allocation of GTS by taking the data size, delay time and the utilization of GTS time slot into consideration. In [7] Naoki Hayashi and Shigemasa Takai have proposed a modified version of the standard IEEE 802.15.4 protocol where each agent communicates through a PAN coordinator with a superframe structure. Feng Xia et al. [8] have implemented an Adaptive and Real-Time GTS Allocation Scheme (ART-GAS) to provide differentiated services for devices with different priorities, which guarantees data transmissions for time sensitive and high-traffic devices. In [9] Feng Wang et al. have first analyzed the performance of the *contention access period* (CAP) specified in the IEEE 802.15.4 standard by integrating the discrete-time Markov chain models of the node states and the channel states. Then a modified CAP is analyzed, which could significantly improve the performance of the system. In [10] J. M. Cano Garcia and E. Casilari have presented an empirical study of the effects of the channel occupation on the consumption of actual IEEE 802.15.4/ZigBee motes. The study is focused on the current demanded by a sensor node in a simple beaconless star topology when the CSMA contention algorithm introduces idle times in the activity of the radio transceiver. Jonathan Edwards et al. [11] have proved the divergence between calculated, simulated and experimental results at higher throughput. Experimental results also highlight the limitations of the MoteWorks framework with regard to channel throughput measurements. [13] provides a methodology, based on the network calculus formalism, for evaluating the performance of real-time applications using GTS mechanism in one IEEE 802.15.4 cluster. [14] authors have synchronized a ZigBee cluster-tree network by proposing collision-free beacon frame scheduling algorithms. Authors of [15] evaluate the performance of slotted CSMA/CA in case of broadcast transmissions. [16] proposes two alternative models for the service curve provided by a GTS allocation, and derive the corresponding delay bounds, in addition to that expression of the duty cycle as a function of delay bound is also derived. [18] contributes an accurate Markov chain model based analytical model for evaluating IEEE 802.15.4 CSMA/CA. [19] investigates the reason of dropping a packet and then revising the original specifications with the minimum modification to enhance its reliability in 802.15.4. In [20 - 25] authors have worked on the performance investigations, evaluation and analysis of IEEE 802.15.4. [26] aims to access different parameter settings of the protocol with some basic queuing strategies (FIFO and Priority Queuing) for each traffic priority. [28] models a WSN in a cluster-tree topology, with a given number of nodes, a given number of routers, and a given depth, and provided that a minimum service is guaranteed to every node and a router and then answers: what are the delay bounds for flow originating from nodes at a given depth in the WSN, and what are the minimum resource requirements in each router? [29] represents the most relevant characteristics of the IEEE 802.15.4 protocol, in the context of WSNs. [31] has discussed certain techniques that results in decreasing the power consumed by WSNs.

The main contribution of this paper is the comprehensive evaluation and analysis of IEEE 802.15.4 for converting it into WSN from the simple WPAN at the cost of performance. Three different scenarios: With GTS (all GTS enabled nodes), Without GTS (All non GTS nodes) and Mixed (GTS & non GTS nodes) have been developed. Performance parameters are evaluated and analyzed at Fully Functional Device (FFD) and Reduced Functional Device (RFD) at physical, MAC and application layers of IEEE protocol stack.

This paper is outlined as: Section [I] gives the brief introduction of the IEEE 802.15.4/ZigBee and extensive literature survey. Section [II] constitutes the system description which contains node model, process model, and parametric tables of the model. Section [III] shows the results and discussions derived from the experiments carried out on different 802.15.4 scenarios. Finally Section [IV] concludes the paper.

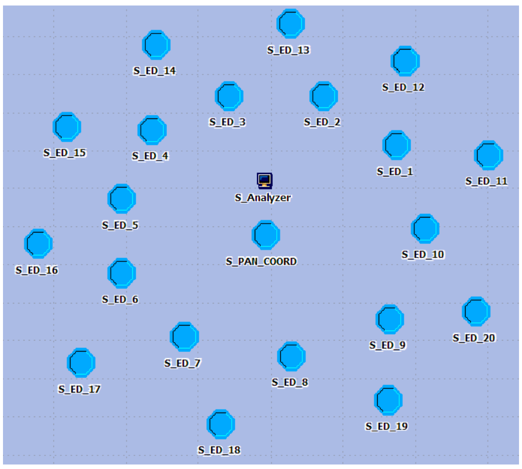
II. SYSTEM DESCRIPTION

The simulation model implements physical and medium access layer defined in IEEE 802.15.4 standard. The OPNET® Modeler has been used for developing three different variants of 802.15.4 i.e. With GTS – which contains all Guaranteed Time Slot (GTS) enabled nodes, Without GTS - which contains nodes that can handle unacknowledged non GTS traffic, Mixed – which consists of With GTS and Without GTS nodes to handle both type of traffic.



(a)

(b)

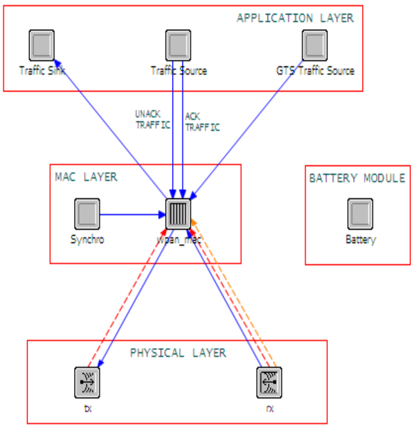


(c)

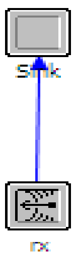
Fig. 1: Network Scenarios (a) With GTS (b) Mixed (c) Without GTS

Fig. 1(a) shows the With GTS scenario which contains one PAN Coordinator, one Analyzer and twenty End Devices (all GTS enabled). Similarly Fig. 1(b) shows Mixed scenario which contains one PAN Coordinator, one Analyzer and twenty End Devices (ten GTS enabled and ten non GTS). Fig. 1(c) shows Without GTS scenario which contains one PAN Coordinator, one analyzer and twenty End Devices (all non GTS). PAN Coordinator is a FFD which manages functioning of the whole network. Analyzer is a routing device which routes the data between PAN coordinator and the End Devices. End Devices are the RFDs that communicate to the PAN Coordinator in Peer to Peer mode and can support both GTS and non GTS traffic.

Fig. 2 shows the node models for the 802.15.4 WPAN devices used for modeling three different scenarios. PAN Coordinator, GTS and Non GTS End Device have the same node model as shown in Fig. 2 (a) while the node model for analyzer is depicted in Fig. 2 (b).



(a)

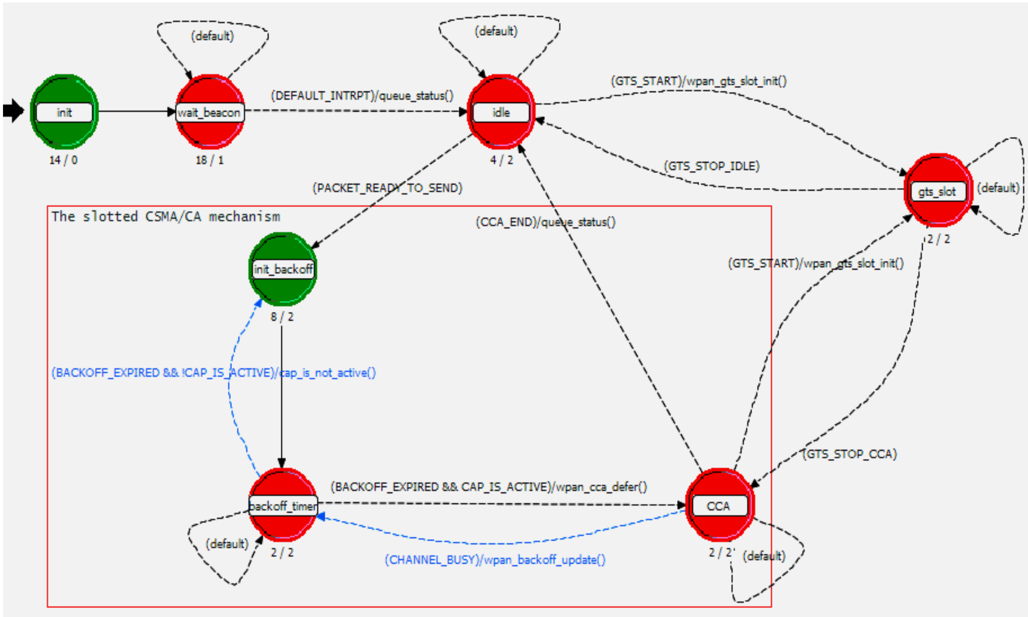


(b)

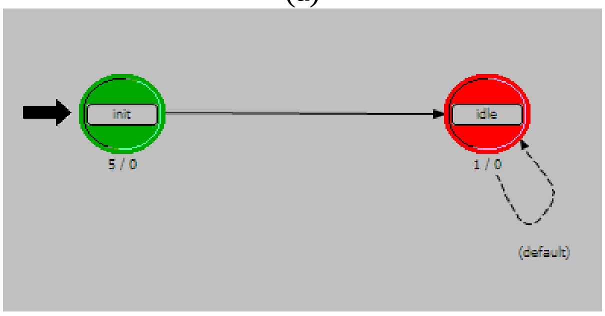
Fig. 2: Node Model (a) PAN Coordinator, GTS and Non GTS end device (b) Analyzer

As it has been observed from the Fig. 2(a), a node model for PAN Coordinator, GTS End Device and Non GTS End Device has three layers: physical, MAC and application layers. Physical layer consists of a transmitter and a receiver compliant to the IEEE 802.15.4 specification, operating at 2.4 GHz frequency band and data rate equal to 250 kbps. MAC layer implements slotted CSMA/CA and GTS mechanisms. The GTS data traffic coming from the application layer is stored in a buffer with a specified capacity and dispatched to the network when the corresponding GTS is active. The non time-critical data frames are stored in an unbounded buffer and based on slotted CSMA/CA algorithm are transmitted to the network during the active Contention Access Period (CAP). This layer is also responsible for the generation of beacon frames and synchronizing the network when a given node acts as a PAN Coordinator. Finally is the topmost application layer which is responsible for generation and reception of traffic consists of two data traffic generators (i.e. Traffic Source and GTS Traffic Source) and one traffic sink. The traffic source generates acknowledged and unacknowledged data frames transmitted during CAP. GTS traffic source can produce acknowledged and unacknowledged time-critical data frames using GTS mechanism. The traffic sink module receives frames forwarded from lower layers. Fig. 2(b) shows the node model for the analyzer which consists of sink and a radio receiver.

Corresponding process models for PAN Coordinator, GTS End Device, Non GTS End Device and analyzer that deals with each and every operation on the data are depicted in Fig. 3:



(a)



(b)

Fig. 3: Process model (a) PAN Coordinator, GTS and Non GTS end device (b) Analyzer

Fig. 3(a) shows the process model for the PAN Coordinator, GTS and Non GTS End Device. It consists of the various states: Init whose function is to initialize MAC and GTS scheduling; Wait_beacon which is responsible for synchronizing the traffic of the node with rest of the WPAN in order to minimize the collisions; Idle which is responsible for introducing delays in order to make the maximum use of the resources; gts_slot which is responsible for generation, reception and management of GTS traffic; Backoff_timer used for sensing the medium and transfer of data, CCA - for interrupt processing. Similarly Fig. 3(b) shows the process model for analyzer which consists of init and idle states. Basically the process model explains how the data is sent from the generating node to the PAN Coordinator, taking into consideration the availability of PAN Coordinator as it has to communicate with the other similar nodes.

Here three different Scenarios have been created in which total number of nodes is same but with different number of GTS and Non GTS nodes. Appropriate values have been given to the different parameters in different scenarios. For example: Maximum Size Data Unit (MSDU) Interarrival Time is exponential (2) for all type of devices in all scenarios; Similarly destination MAC Address for PAN Coordinator is Broadcast and for End Device is PAN Coordinator.

III. RESULTS AND DISCUSSIONS

Simulation has been carried out for three different scenarios of 802.15.4 for WSNs: With GTS, Mixed (With & Without GTS nodes) and Without GTS. In this section the results have been presented and discussed for the battery energy consumed at the FFD i.e. PAN Coordinator and RFD i.e. End Device.

A. Battery Energy Consumed at the FFD

Fig. 4 shows that the battery energy consumed is 18.19463, 15.17164 and 12.68574 joules respectively for without GTS, mixed and with GTS scenarios at the PAN coordinator. It is observed that minimum energy is consumed in case of with GTS scenario because in case of with GTS scenario all nodes are GTS enabled and whenever the data is to be transmitted, enough bandwidth is reserved in advance for that particular data transmission to provide Guarantee of Service (GoS) and data to be transmitted suffers least from delays, retransmission attempts, transmission failures ([30], [31]). Also it has been observed that battery energy consumed is maximum in case of without GTS scenario as in case of without GTS scenario all nodes support ordinary traffic (i.e. non GTS) and PAN coordinator being FFD receives data from all the nodes in the 802.15.4 wireless personal area network (WPAN), since there is no bandwidth reservation for any type of data, it suffers from delays, jitters, comparatively more retransmission attempts and more transmission failures as a result of which more battery energy is consumed as compared to with GTS and mixed GTS scenarios which contain GTS feature ([30], [31]).

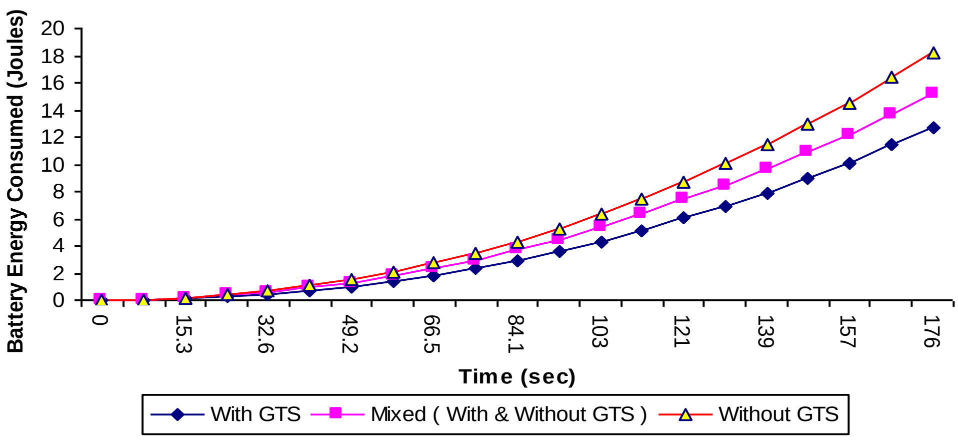


Fig. 4: Battery Energy Consumed at PAN coordinator

B. Battery Energy Consumed at the RFD

Fig. 5 below indicates that the battery energy consumed is: 13.34305, 12.59223 and 11.09392 joules respectively for without GTS, with GTS and mixed scenarios at the End Device. It is observed that minimum energy is consumed in case of mixed scenario as it is a combination of GTS and non GTS nodes and is responsible for handling its own traffic only, so depending on the type of data, it can decide whether to make the bandwidth reservations or not which further reduces the delays in getting the channel access ([30], [31]). It has also been observed that battery energy is consumed maximum in case of without GTS scenario as it is a End Device and is responsible for its own traffic only and there is no bandwidth reservation for any type of data, it suffers from delays, jitters, comparatively more retransmission attempts and more transmission failures as a result of which more battery energy is consumed as compared to with GTS and mixed GTS scenarios which contain GTS feature ([30], [31]).

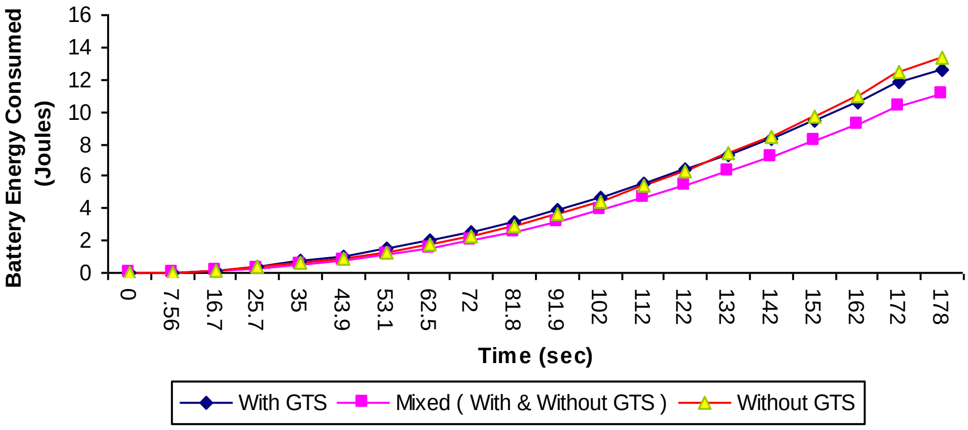


Fig. 5: Battery Energy Consumed at End device

From the Fig. 4 & 5 is observed that if we make bandwidth reservations for any type of traffic in advance then comparatively less battery energy is consumed as data is quickly transmitted from the transmitter to the receiver because of bandwidth (channel) reservation in advance. Variations in the minimum energy consumed at the PAN coordinator and End Device is because PAN coordinator is FFD and handles traffic from whole of the network while End Device is a RFD responsible for its own traffic only so comparatively less traffic, less collisions, less retransmission attempts required and also lesser transmission failures.

IV. CONCLUSIONS

The focus of this paper is on the battery energy consumption at the FFD and RFD with and without GTS. The results achieved show that the battery energy consumption at the PAN Coordinator and the End Device is: {18.19463, 15.17164, 12.68574} and {13.34305, 11.09392, 12.59223} joules respectively for Without GTS, Mixed and With GTS scenarios. From the results, it is proved that battery energy consumed is minimum in case of With GTS scenario at the PAN Coordinator and Mixed scenario at the End Device. It has also been observed that maximum energy consumption in case of Without GTS scenario in both types of devices. Therefore from the results obtained, it is concluded that if battery energy consumption at the PAN coordinator is to be taken into consideration then all devices in 802.15.4 for WSN should be GTS enabled. On the other hand if battery energy consumed at the End Device is to be taken into consideration then combination of GTS enabled and non GTS devices should be preferred. Further it is concluded that in 802.15.4 if all nodes are non GTS, it results in more consumption of battery energy.

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