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Quality of Service Trade-off at the Application Layer with Guaranteed Time Slots in IEEE 802.15.4 for Wireless Sensor Networks

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Abstract - The impact of Guaranteed Time Slots (GTS) mechanism on Traffic Received and End to End Delay at FFD (Fully Functional Device) and RFD (Reduced Functional Device) at the application layer level directly impacts the Quality of Service (QoS). The GTS mechanism provides guarantee of service to real-time data using superframe structure but only at the cost of significant performance effecting parameters like: throughput and end to end delay. The results of this work may pave the way for provisioning of simple and effective methodology to determine the performance cost for converting 802.15.4 Wireless Personal Area Network (WPAN) into Wireless Sensor Network (WSN).

Keywords - ***Wireless Sensor Networks, superframe, Wireless Personal Area Network (WPAN), Quality of Service.***

1. Introduction

The application layer of the 802.15.4 protocol is responsible for interacting with the end users. The end user in case of WSN can be a human being or the environment surrounding that end user. One of the main features of WSN is that the end user can be in the remote area where it can remain unattended for months or years for which low-power consumption and low-cost nodes (end users) are required [2]. For this research work ZigBee protocol has been used. ZigBee specifications [3] relies on the IEEE 802.15.4 physical and data link layers, building up the network and application layers, thus defining a full protocol stack for Low Rate - WPANs (LR-WPANs) for converting it into WSN using GTS feature.

The IEEE 802.15.4 protocol has been researched widely [1-24] for its suitability and adaptability for the WSNs. Most of the researches works have focused on evaluation/improvement of standard protocol either analytically or by simulation. Authors of [1] evaluates the performance of IEEE 802.15.4 GTS mechanism within the ART-Wise framework. Researchers in [2] have identified the most significant features of the IEEE 802.15.4 protocol that are suitable for WSNs, and have also explained the ability of this protocol to meet the different requirements of WSNs. [6] on the basis of network calculus formalism evaluates the performance of real-time applications using GTS mechanism in IEEE 802.15.4 cluster. Authors in [9] have proposed two alternative models for the service curve of GTS allocation, and have also derived the corresponding delay bounds and additionally the duty cycle as a function of delay bound has also been derived. Researchers of [11] have contributed Markov chain based analytical model for evaluating IEEE 802.15.4 CSMA/CA. [12] enhances the reliability of 802.15.4 by investigates the reason of dropping a packet and then revising the original specifications. In [13 - 18] authors have investigated, evaluated and analysed IEEE 802.15.4. Authors of [19] have worked on some basic queuing strategies (FIFO and Priority Queuing) for each traffic priority. [21] models a WSN in a cluster-tree topology, with a given number of nodes, routers, depth and then minimum service is guaranteed to every node and a router and then determines: what are the delay bounds and what are the minimum resource requirements in each router? [22] determines the most relevant characteristics of the IEEE 802.15.4 protocol as required by WSNs. Authors of [24] has discussed some methods that decreases the power consumed by WSNs.

This paper deals with the evaluation and analysis of IEEE 802.15.4 at the application layer for converting it into WSN from the simple WPAN at the cost of performance. Three different scenarios: With GTS having all GTS enabled nodes, Without GTS having all non GTS nodes and Mixed containing both GTS & non GTS nodes, have been developed. Performance parameters are evaluated and analyzed at Fully Functional Device (FFD) and Reduced Functional Device (RFD) at application layers of IEEE 802.15.4 protocol stack. The rest of the paper is organized as follows. Section 2 gives the brief description of IEEE 802.15.4 protocol. In section 3, we simulate and analyze the impact of the protocol parameters on different devices in three different scenarios at the application layer. Finally, section 4 concludes this paper.

II. System Description

The open ZigBee has been used for implementing physical and Medium Access Layer (MAC) defined in IEEE 802.15.4 standard and application layer defined by Zigbee. The OPNET® Modeler 14.5 is used for developing three different variants of 802.15.4 i.e. With GTS, Without GTS and. Here the Superframe is responsible for differentiating and carrying the GTS and Non GTS data from the End Device to the PAN coordinator.

2.1 The Superframe Structure

Superframe is a beacon-enabled structure which consists of time-interval between the two beacon frames, one marks the beginning and the other marks the end. Beacon frames are periodically sent by the PAN coordinator to identify its PAN and to synchronize nodes that are associated with it. The time between two consecutive beacon frames called Beacon Interval (BI) includes an active period and, optionally, an inactive period as shown in the figure 1. The active period, called superframe, is divided into equally-sized 16 time slots, during which frame transmissions are allowed. During the inactive period (if it exists), all nodes may enter in a sleep mode, thus saving energy.

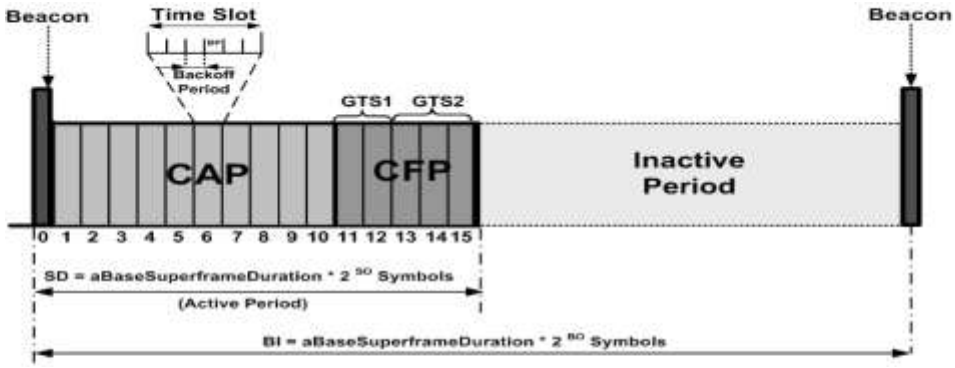

Figure 1: Structure of Superframe [2]

The Beacon Interval (BI) and the Superframe Duration (SD) are calculated using: Beacon Order (BO) and the Superframe Order (SO) respectively. The Beacon Interval is defined as follows:

$$BI = aBaseSuperframeDuration \cdot 2^{BO}, \quad \text{for } 0 \leq BO \leq 14 \quad (1)$$

$$SD = aBaseSuperframeDuration \cdot 2^{SO}, \quad \text{for } 0 \leq SO \leq BO \leq 14 \quad (2)$$

The nodes compete for medium access using slotted CSMA/CA during the Contention Access period (CAP). The IEEE 802.15.4 protocol also defines a Contention Free Period (CFP) within the Superframe. The CFP, being optional, is activated at the request of a node to the PAN Coordinator for allocating GTS depending on the node's requirements. The information on BI and SD is embedded in each beacon frame sent by the PAN Coordinator in the superframe specification field. Therefore, each node receiving the beacon frame must correctly decode the information on the superframe structure, and synchronize itself with PAN coordinator and consequently with other nodes. After the beacon frame, the CAP starts immediately and ends before the CFP (if it exists) begins. Otherwise, the end of active period of superframe marks the end of CAP. The CFP starts immediately after the end of the CAP and must complete before the start of the nest beacon frame. All the GTSs that may be allocated by the PAN Coordinator are located in the CFP and must occupy contiguous time slots. Maximum of 7 time slots of a superframe can be allotted to CFP. The transmissions in the CFP are contention-free and therefore do not use the CSMA/CA mechanism.

2.2 Parametric Table

Table 1 shows the values of the various parameters the scenarios: With GTS, Mixed and Without GTS at the PAN coordinator and at the End device respectively:

Table 1
Parametric values for PAN Coordinator and End Devices in three different scenarios.

Device Type	PAN Coordinator				End Device			
Parameter / Scenario	With GTS	Mixed		Without GTS	With GTS	Mixed		Without GTS
		With GTS	Without GTS			With GTS	Without GTS	
Acknowledged Traffic Parameters								
MSDU Interarrival Time (sec)	Exponential (2)							

MSDU Size (bits)	Exponential (912)			
Start Time (sec)	0.1			
Stop Time (sec)	180			
Destination MAC Address	Broadcast		PAN Coordinator	
Unacknowledged Traffic Parameters				
MSDU Interarrival Time (sec)	Exponential (2)			
MSDU Size (bits)	Exponential (912)			
Start Time (sec)	0.1			
Stop Time (sec)	180			
CSMA Parameters				
Maximum Backoff Number	4			
Minimum Backoff Exponent	3			
IEEE 802.15.4				
Device Mode	PAN Coordinator		End Device	
MAC Address	Auto Assigned			
WPAN Settings				
Beacon Order	3			
Superframe Order	2			
PAN ID	0			
Logging				
Enable Logging	Enabled			
GTS Settings				
GTS Permit	Enabled	Disabled	Enabled	Disabled
Start Time (sec)	0.1	Infinity	0.1	Infinity
Stop Time (sec)	180	Infinity	180	Infinity
Length (slots)	2	0	2	0
Direction	Receive	Transmit	Transmit	Transmit
Buffer Capacity (bits)	10,000	1000	1000	1000
GTS Traffic Parameters				
MSDU Interarrival Time (sec)	Exponential (2)	Constant (1.0)	Exponential (2)	Constant (1.0)
MSDU Size (bits)	Exponential (912)	Constant (0.0)	Exponential (912)	Constant (0.0)
Acknowledgement	Enabled	Disabled	Enabled	Disabled

III. Results and Discussion

The results have been derived and discussed for the Traffic Received (Throughput) and End to End Delay (Delay) at the Application layer as both have the direct impact on the QoS being provided by the WSN enabled FFDs & RFDs. The Application layer handles two types of traffic: ordinary traffic and the GTS traffic. Moreover, at the Application layer the higher throughput and minimum delays are preferred to improve QoS. The results below show that if QoS has to be improved then certain tradeoffs have to be done like: sensing capability has to be reduced to improve QoS in terms of throughput delay etc.

3.1 Throughput (Traffic Sink Traffic Received)

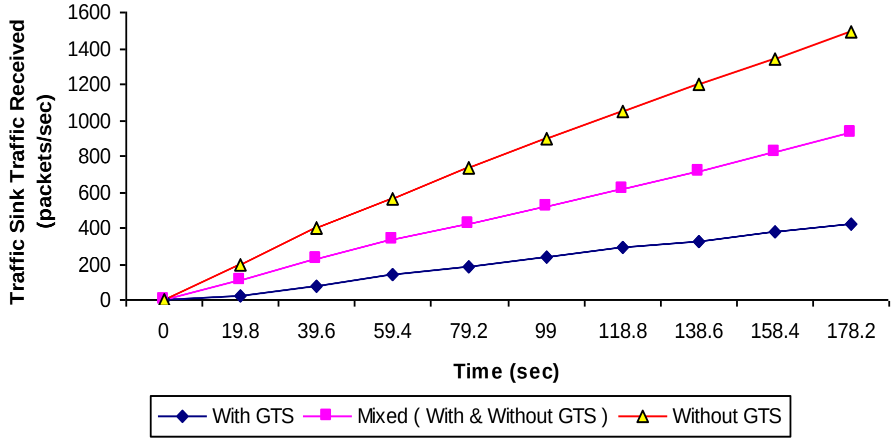

Figure 2(a): Traffic Sink Traffic Received - PAN coordinator

Figure 2(a) evaluates and analyzes that the traffic received by the traffic sink at the PAN coordinator is: 1494, 929 and 424 packets/sec for Without GTS, Mixed and With GTS scenarios respectively [(2), 8, 12]. It has been analyzed that traffic received (Throughput) is minimum in case of With GTS scenario because all the nodes are GTS enabled and each reserves the 07 out of 16 time slots at a time from the Superframe for the real-time data and thus leaving only 07 time slots for the transmission of data. As a result of which the GTS enabled node suffers maximum from Bit Errors, maximum Collisions, maximum Packet Losses as long queues are formed but provides guarantee and reliability of transmission to the GTS data as the resources (time slots) are reserved in advance.

It is further observed that traffic received is maximum in case of Without GTS scenario because all 14 data carrying time slots are free as none is reserved for the GTS data as a result of which there are minimum Collisions, Packet Losses & Bit Errors because the data to be transmitted has not to wait for long [(2), 8, 12].

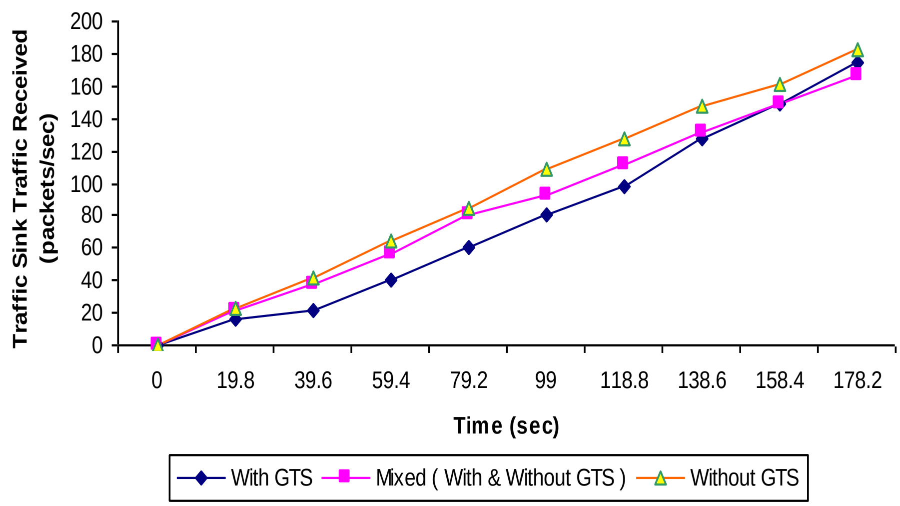

Figure 2(b): Traffic Sink Traffic Received - End device

Figure 2(b) evaluates and analyzes that the traffic received by the traffic sink at the End device is: 182, 175 and 167 packets / sec for Without GTS, With GTS and Mixed scenario respectively [(2), 8, 12]. It is analyzed that traffic received is moderate in case of With GTS scenario as it is a collection of GTS and Non GTS nodes and half of the nodes reserve the resources in advance while the another half do not reserve any time slot for the data transmission.

From the figure 2 (a & b), it is observed that traffic received by the traffic sink in case of Sensor nodes in 802.15.4 for WSNs is at the cost of the performance metrics like: Lesser throughput, more collisions, more packet losses etc.

3.2 Traffic Sink End to End Delay

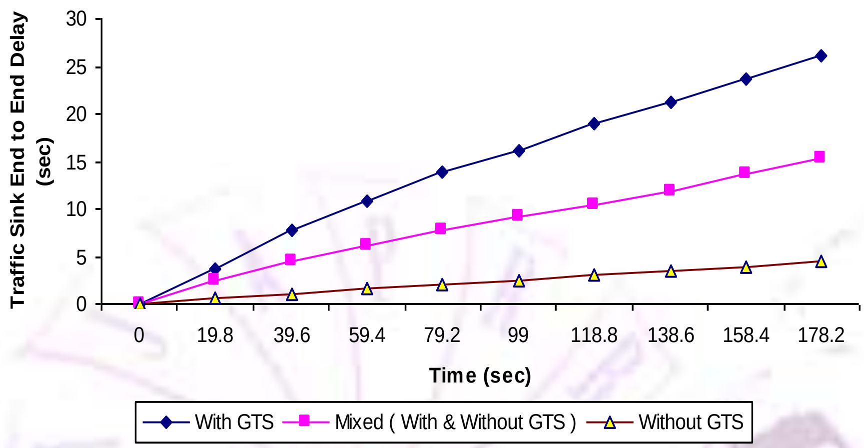

Figure 3(a): Traffic Sink End to End Delay - PAN coordinator.

Figure 3(a) evaluates and analyzes that End to End delay at the traffic sink of a PAN coordinator is: 26.0333, 15.26329 and 4.427471 sec for With GTS, Mixed and Without GTS scenario respectively. It is analyzed that End to End delay is maximum in case of With GTS scenario for the reason that radio receiver at PAN coordinator suffers from maximum BER, maximum collisions and maximum Packet losses [(2), 8, 19]. It has also been observed that End to End delay is minimum in case of Without GTS scenario for the reason that radio receiver at PAN coordinator suffers from minimum BER, minimum collisions and minimum Packet losses [(2), 8, 19].

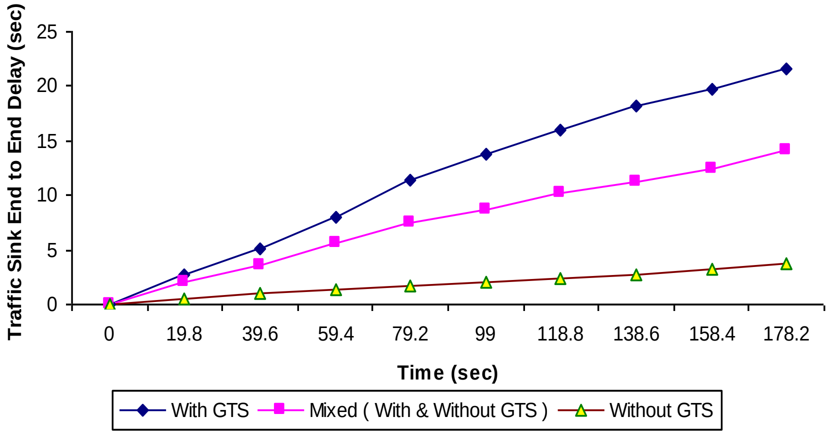

Figure 3(b) Traffic Sink End to End Delay - End device

Figure 3(b) indicates that the End to End delay at the traffic sink of End device is: 21.57049, 14.05457 and 3.715252 sec for With GTS, Mixed and Without GTS scenario respectively. It is observed that End to End delay is maximum in case of With GTS scenario for the reason that radio receiver at the End device suffers from maximum BER, maximum collisions and maximum packet loss ratio [(2), 8, 19]. It has also been observed that end to end delay is minimum in case of Without GTS scenario at the end device for the reason that radio receiver suffers from least BER, minimum collisions and minimum packet loss ratio [(2), 8, 19].

From the Figure 3 (a & b), it is observed that End to End delay at the traffic sink of any type of device in 802.15.4 for WSNs is minimum in case of Without GTS scenario while it is maximum in case of With GTS scenario for any type of device in 802.15.4 for WSNs.

IV. Conclusion

Research work carried out at the application layer concludes that if the QoS has to be improved then the tradeoff has to be done with the performance metrics like: throughput, delay etc. Research done proves that if the node does not reserve the resources in advance then it cannot be converted in WSN node as it does not fulfill the requirements. But if the node reserves the resources in advance like: bandwidth for the transmission of data from one place to another place, then it leads to the lowering of performance metrics like: throughput and increases the parameters like: End to End Delay. All this lowers the QoS at the application layer as it directly interacts with the end user. And the end users are intolerant towards the increased delays and decreased throughput.

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