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Performance Analysis of Guaranteed Time Slots Allocation in IEEE 802.15.4 Protocol over Radio

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Abstract: IEEE 802.15.4 protocol is designed for low-rate Wireless Personal Area Networks with very low cost and power consumption. IEEE 802.15.4 provides Guaranteed Time Slots (GTSs) which allow a device to operate on the channel within a portion of the superframe that is dedicated exclusively to that device. The GTSs always appear at the end of the active superframe starting at a slot boundary immediately following the Contention Access Period (CAP). The Personal Area Network (PAN) coordinator may allocate up to seven of these GTSs and a GTS can occupy more than one slot period. This paper has investigated the impact of varying the number of slots allocated for GTS on the IEEE 802.15.4 protocol performance on the radio level. We have observed the relationship between the interference in the radio channel and the number of slots allocated for GTS. Additionally, the measurements have been implemented when we are having a wireless channel that exhibits path loss variation versus one that it does not. The results have revealed that the IEEE 802.15.4 protocol is significantly affected by the variation of the GTS and the wireless environment. Better performance is achieved when the number of slots allocated for GTS equals three where the number of packet failed to be received due to the interference was at its lowest value. We have carried out our experiments by using Omnet++ and Castalia simulation packages.

Key words: IEEE 802.15.4 · Zigbee · MAC · Guaranteed Time Slot (GTS) · Omnet++ · Castalia · Radio and Interference

INTRODUCTION

Wireless Networks are a promising technology and are becoming an important feature of many aspects of our life. Ultimately each device will have one or several wireless interfaces such as laptops, phones etc. [1]. In some cases these devices and even fixed stations require to communicate with each other without requiring an infrastructure or they may costly or time consuming. In such a case, there is a need for ad-hoc wireless networks to provide an effective network communication between different wireless devices. This type of network has a number of applications such as conferences, emergency operations and military operations etc. In ad-hoc networks, those devices need to be within the transmission range of each other in order to be able to establish a direct communication and to compete between each other to access the wireless medium. If those devices are out the transmission range of each other due to lack of transmitted power, long distances between the wireless devices, interference, noise or due to mobility, it becomes essential to have an intermediary node between them. The presence of an intermediary node performs a multi-hop ad-hoc network. In this type of network a routing protocol is required and the MAC protocol has to share the media with fairness between different devices for different applications. For all these reasons, Wireless Personal Area Networks (WPANs) are becoming very important since they are focused on a short range wireless communication up to 10m in all directions [2]. Additionally, the WPANs are considered low-cost, low power, short range, small data rates and very small size networks. The IEEE 802.15 working group is formed to create WPAN standard [3]. The creation of WPAN standard is divided into three classes IEEE 802.15.3, IEEE 802.15.1/Bluetooth and the IEEE 802.15.4/LR-WPAN).

The IEEE 802.15.3 is appropriate for multimedia transmission because it requires a high QoS where throughput has to be high and packet latency and jtter have to be low [4]. The IEEE 802.15.1/Blueetooth WPANs class is considered as a medium data rate [5]. The IEEE 802.15.1 deals with a diversity of tasks ranging from cell

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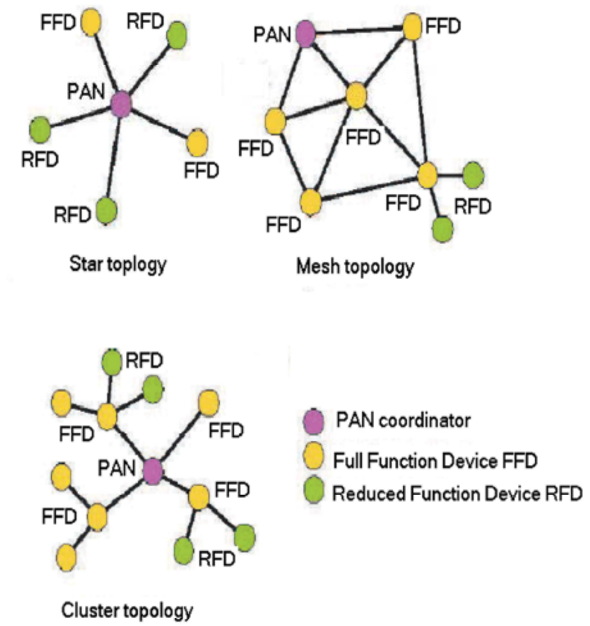

Fig. 1: Zigbee Topology Models

phones to Personal Digital Assistants (PDA) communications and have QoS requirements for voice transmission and communication. The IEEE 802.15.4/LR-WPAN is considered as a low data rate WPANs up to 250kbps at 2.4GHz band [6]. This class is proposed to provide a set of industrial, residential and medical applications with very low power consumption.

ZigBee alliance and the IEEE 802.15.4 group join their efforts to have a new technology named commercially by Zigbee technology that is described by a low data rate, low power consumption and low cost [7]. This technology is implemented in different types of networking known as ”star, mesh and cluster tree”. It is designed towards automation and remote control applications for a wider coverage area ranging from 10 to 75 meters according to Radio Frequency (RF) environment and the power consumption. Compared to Bluetooth technology, Zigbee technology has smaller data rate, less power consumption, wider coverage area and simpler protocol.

Theory and Related Work: Zigbee system consists of several components. A Zigbee device can be a Full-Function Device (FFD) or Reduced-Function Device (RFD) [4]. With respect to the network flexibility feature, Zigbee system has several network topologies these are: star topology, peer to peer topology (i.e. mesh) and cluster tree topology. A network shall include at least one FFD, operating as a Personal Area Network (PAN) coordinator as shown in Figure 1.

The IEEE 802.15.4 provides two services: the MAC data service and the MAC management service. The MAC data service enables the transmission and reception of MAC Protocol Data Units (MPDU) across the PHY data service [4]. The MAC management service interfacing to the MAC sublayer Management Entity (MLME) Service Access Point (SAP) (known as MLME-SAP) [4].

The IEEE 802.15.4 has two different medium-access modes: Non Beacon-enabled mode and Beacon-enabled mode. In a beacon-enabled network with superframes, a Slotted Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) mechanism is used. In networks without beacons, unslotted or standard CSMA-CA is used.

The IEEE 802.15.4 can operate in an optional superframe mode to support data transfers generated by repetitive low-latency applications. A network coordinator called the PAN coordinator is used to transmit superframe beacons in predetermined intervals. The duration between two beacons is divided into 16 equal time slots independent of the duration of the superframe. Although, the channel access in the time slots is contention-based, the PAN coordinator provides time slots to a single device that needs low-latency transmissions or dedicated bandwidth. These assigned time slots are called Guaranteed Time Slots (GTS).

The superframe structure adopted by the IEEE 802.15.4 beacon-enabled mode is shown in figure 2 [3]. The coordinator shall not interact with its PAN and may enter a low-power mode during the inactive portion.

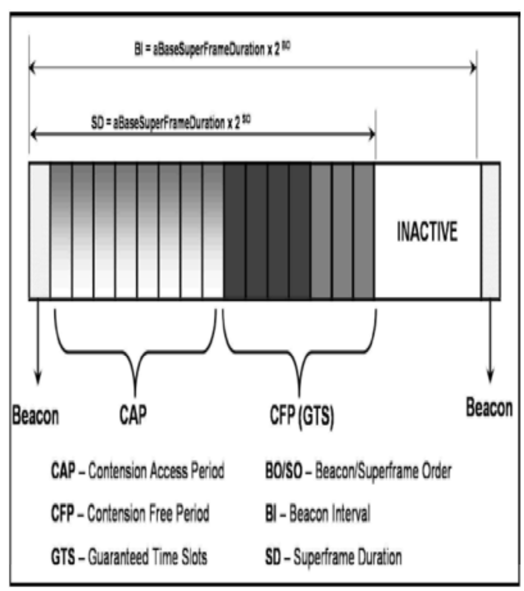

Fig. 2: Superframe structure in IEEE 802.15.4.

The active portion consists of Contention Access Period (CAP) and Contention Free Period (CFP). Any device requires to communicate during the CAP shall compete with other devices using a slotted CSMA/CA mechanism. On the other hand, the CFP contains Guaranteed Time Slots (GTS) which appears at the end of the active superframe starting at a slot boundary immediately following the CAP. A GTS is only used for communications between the device and the PAN coordinator.

There are many papers have been published studying the efficiency of GTS allocation mechanism IEEE 802.15.4. An implicit GTS allocation mechanism (i-GAME) to improve the GTS utilization efficiency is proposed in [10]. The authors of [11] have studied the energy-cost analysis of IEEE 802.15.4 beacon-enabled and non beacon-enabled transmission modes In [12], the authors have studied the IEEE 802.15.4 standard over ubiquitous networks. In [13], the system throughput and the probability distribution of access delay for a beacon-enabled WPAN was presented. A performance analysis of IEEE 802.15.4-based Body Area Networks (BANs) for medical sensors was presented [14].

This paper has studied the performance of the IEEE 802.15.4 protocol over radio. The focus of this paper is on the interference that occurs in the wireless communication channel. Any two nodes that communicate with each other might by affected from the other nodes that comes between them causing an interference. We have experimented with a certain number of nodes that each of them sends various number of packet to a sink node. The remaining nodes cause interferences and reduce the number of the packets that are received by the sink node. This paper illustrates how Zigbee make a more efficient use of the wireless medium and is reducing the effect of the interference. The PAN coordinator may allocate up to seven of GTS slots. We experimented with various number of GTS slots: 1, 3, 5 and 7 slots. We used Omnet++ simulator [8] in addition to Castalia [9] simulation model to study the impact of varying the time slots allocated for GTS such that more packets are received despite the existence of the interference in the wireless medium channel. The experiments were implemented when we were having a wireless channel that exhibits path loss variation versus one that it does not. For all of these experiments, we will vary the packet rate of the sending nodes.

The Rest of this Paper Is Organized as Follows: Section two presents the research methodology and simulation overview. In section three, our simulation results are presented after conducting a series of experiments. Section four is the conclusion.

Research Methodology and Simulation Overview: There are three mechanisms for performance evaluation, these are: simulation, analytical modeling and measurement [15]. It was not practical to use the analytical modeling technique in this paper because of the nature of wireless medium that varies in time and space. Measurements from real systems are also excluded since the implementation of real networks would have been too time consuming for this paper. Therefore, simulation was chosen as the most appropriate approach. Within the simulation process, data were collected from simulation runs then quantitatively analyzed.

In order to simulate wireless networks with realistic topologies a simulation tool was required. There were several simulation tools that could have been used. The most well known tools are Global Mobile Information Systems Information Library (*GloMoSim*) [16 and 17], Optimised Network Engineering Tools (*OPNET*) [18], Network Simulator (*NS-2*) [19] and Objective Modular Network Test-bed in C++ (Omnet++) [8]. These tools have oriented to wireless domain. *GloMoSim* was not used for purpose of this paper since its model libraries are not open source and so cannot be easily modified. Although *OPNET* is well oriented to wireless models particularly the new versions, it is not open source and it imposes high level of complexity when modifications are required. *NS-2,* Omnet++ and Castalia are open source and freely available simulation tool that run on different platforms. Omnet++ and Castalia are comprehensive platforms and can deal with number of network issues e.g. different applications, protocols and traffic models. They can be extended by modifying the *C++* code. They have also been widely validated; giving confidence in most of the functionality of the simulator. Additionally, Omnet++ simulation tool is a component-based and modular simulation structure. It is mainly useful for the domain of network simulation and other distributed systems. The Omnet++ model is composed of hierarchically nested modules. The top-level module is called the Network Module, which contains one or more sub-modules. Each could contain other sub-modules.

Different protocols such as Internet protocol model have been built on the top of Omnet++ such as the Omnet++ Mobility structure [9] and Castalia [20]. Castalia can be used to examine distributed algorithms and/or protocols in practical wireless channel and radio models

[20]. It can also be used to assess different platform characteristics for specific applications, since it is highly parametric and can simulate a wide range of platforms. For more details about the internal structure of the node in Castalia simulation package are described in [20]. For these features, they have been used in this paper to evaluate the impact of varying the GTS value of the IEEE 802.15.4 standard on the radio level.

Simulation Results: The network model used employs the star topology as shown in figure 1. The simulations were performed in order to evaluate the performance of the Zigbee protocol with the existence of the interference and path loss conditions. The scenarios were carried out for various values of slots allocated for GTS.

The lognormal shadowing model has been used to give accurate estimates for average path loss. The received signal strength (*Pr*) at a distance *d* is the output power of the transmitter minus *PL*(*d*).

$$PL(d)=PL(d_0)+10\eta.\log\left(\frac{d}{d_0}\right)+X_\sigma$$

Where d is the transmitter-receiver distance, d_0 a reference distance, η the path loss exponent (rate at which signal decays) and X_σ a zero-mean Gaussian RV (in dB) with standard deviation σ (shadowing effects). These parameters are given the following values according to [20]:

$\eta = 4$ $\sigma = 4$, $PL(d_0) = 55$, dB, $d_0 = 1$.

The number of nodes that we experimented with was 6 and node 0 is the sink node. The sink node receives packets from the other nodes and the number of the packets varied from 14 packets/sec to 30 packets/sec. Each node is sending the packets to the sink node for 50 seconds. Therefore, if we had perfect reception we would reach 1500 packets per node for the 30 packets/sec. The packets received by the sink node can be classified into four different categories: "Success, with interference", "Success without interference", "Fail, with interference" and "Fail, below sensitivity".

For the results obtained with the existence of the path loss in the wireless channel, the highest values of the received packets with no interference was achieved at GTS equals 3 as shown in figure 3.a. It is obvious that the IEEE 802.15.4 protocol performs better when the GTS is turned on. We found that with a zero slot allocated for GTS the lowest percentage of packets are received with interference.

We also measured the number of the packets that is received despite interference. We found that the highest values of packets that is received despite interference when the GTS is off (0 slots for GTS). This is expected as the GTS is reducing interference. Additionally, with three slots allocated for GTS the lowest value of packets are received despite interference.

We have also measured the number of packets that have not been received by the sink node because of the interference as shown in figure 4.a.

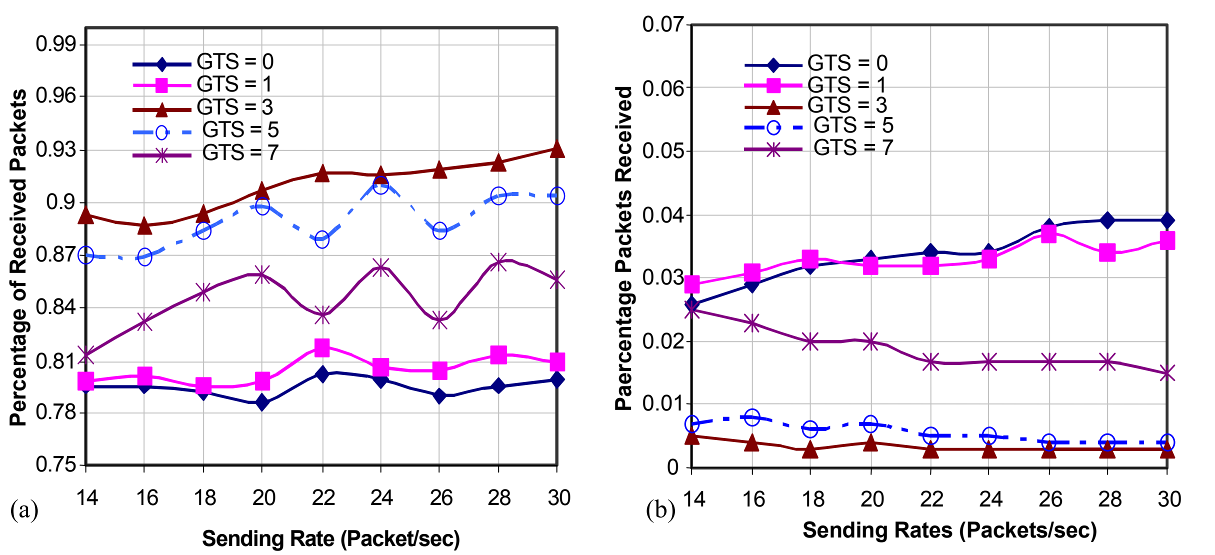

Fig. 3: a) Comparing the percentage of received packets for different values of GTS when path loss is considered: a) without Interference and b) despite Interference

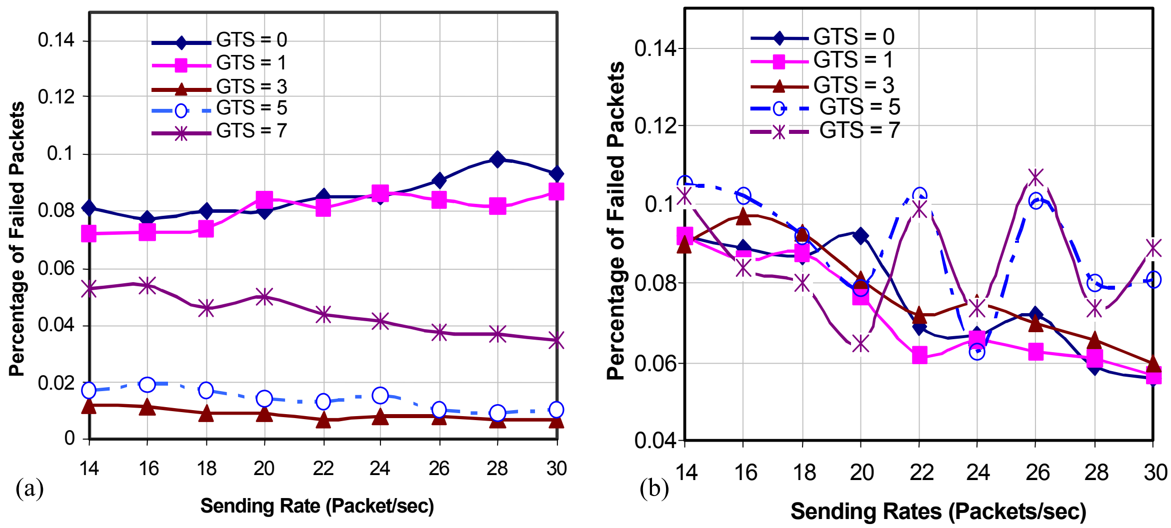

Fig. 4: a) Comparing the percentage of failed packets for different values of GTS when path loss is considered: a) failed packets with interference and b) failed packets below sensitivity.

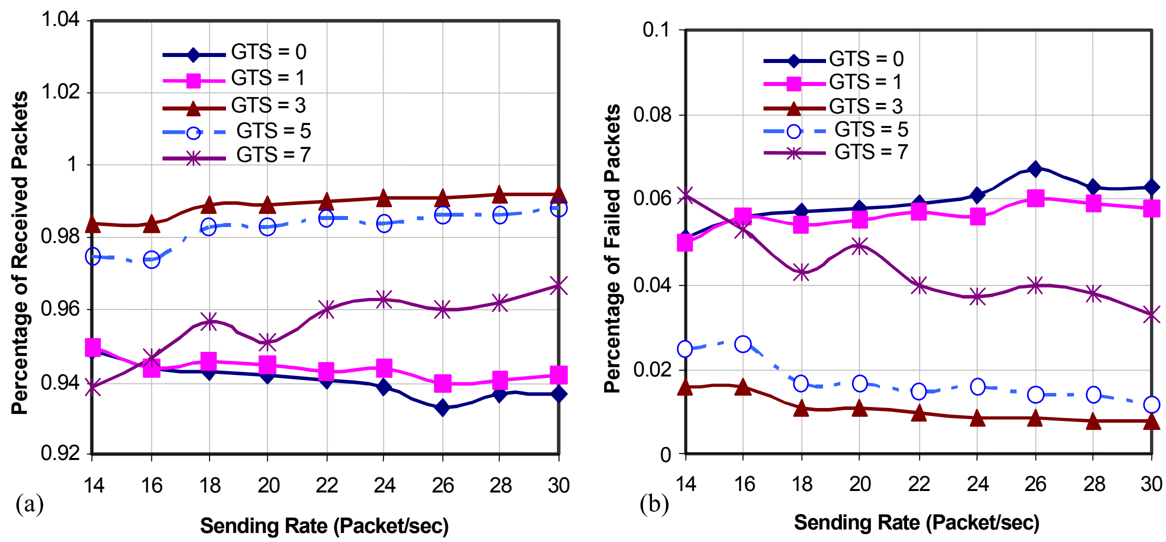

Fig. 5: The percentage of received and failed packets without path loss in the communication channel: a) Comparing the percentage of received packets without interference and b) Comparing the percentage of failed packets with interference.

We found that allocating three slots for GTS has minimized the number of packets failed to be received due to the interference. It is obvious that when GTS is off the highest percentage of packets have failed due to the interference.

There are packets that have not been received by the sink node because it is below the sensitivity. The sensitivity was considered because receiving a packet irrespective of how weak they are will be a waste of resources. We have considered in our simulations a packet strength threshold that beneath it a packet will be ignored. If two packets are received by the sink node, one is at the sensitivity threshold, the other is 1dB smaller. The first one would be processed and the packet that it carried would be received with no problems. The weaker one would be ignored. If we deliver both packets a collision would probably occur. The sensitivity threshold was set of value equals 5 dB throughout our simulation. Any packet that has a power less than 5 dB will be ignored. Figure 4.b shows the percentage of packets failed because they are below sensitivity and exhibit similar characteristics as we varied the number of slots allocated for GTS.

Figures 5.a and 5.b show our simulation results without having a path loss in the wireless communication channel. Figure 5.a shows the percentage of received packets without interference as we varied the number of packets. In comparison to figure 4.a, the percentage of received packets has increased and this is expected because the path loss does not exist. It is clear that having three slots allocated for GTS is showing better characteristics. The least percentage was obtained when the GTS is off. The failure of the packet to be received will be only due to the interference. The sensitivity will not be considered because we are not experimenting with a path loss. When the GTS is off the percentage of failed packets was the highest as shown in figure 5.b. For three slots allocated for GTS, the lowest percentage of failed packets due to the interference was obtained.

CONCLUSIONS

IEEE 802.15.4 provides a Guaranteed Time Slots (GTS) mechanism to allocate a specific duration within a superframe in beacon-enabled mode. We carried out several experiments by using Omnet++ simulator and Castalia to observe the performance of the IEEE 802.15.4 on the radio level as we varied the number of slots allocated for GTS.

We carried out our experiments with the existence of the path loss and without path loss in addition to the interference. The findings revealed that with three slots allocated for GTSs more packets are received by the sink node from the sender nodes despite the presence of the interference in the wireless communication channel. Additionally, the lowest number of packets have failed with interference with three slots allocated for GTS.

It can be concluded that varying the value of GTS in the contention free period has a significant impact on the performance of the IEEE 802.15.4 protocol, where a better performance is achieved when the number of slots allocated for GTS equals three.

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