The International Journal of Soft Computing and Software Engineering [JSCSE], Vol. 3, No. 3, Special Issue:
The Proceeding of International Conference on Soft Computing and Software Engineering 2013 [SCSE'13],
San Francisco State University, CA, U.S.A., March 2013
Doi: 10.7321/jscse.v3.n3.102 e-ISSN: 2251-7545

Soft Computing Tehnique Based Throughput Optimization of GTS mechanism for IEEE 802.15.4 Standard

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Abstract—**Real time application and QOS are important services provided by IEEE 802.15.4 standard for Wireless Sensor Network (WSN). By providing Guaranteed Time Slot (GTS) mechanism, time critical application can be fulfilled by the IEEE 802.15.4 standard. This paper explores the under utilization of bandwidth in WSN and analyzed GTS mechanism by evaluating throughput using Artificial Neural Network (ANN) soft computing technique in OPNET Modeler. Our focus is for better GTS throughput, which can be achieved due to the packet size based on data rate and Interarrival rate using ANN soft computing technique.**

Keywords-Wireless sensor network (WSN), OPNET, Artificial Neural Network, IEEE 802.15.4, GTS, Packet Medium Access Delay

I. INTRODUCTION

WSN is a network of distributed autonomous devices that monitor physical or environmental conditions cooperatively [1]. WSN are intended for monitoring environmental phenomena in a given physical space; such networks find increasing use in areas as diverse as military applications, object surveillance, structural health monitoring, and agriculture and forestry, among others. With the emergence of new WSN applications under timing constraints, the provision of deterministic guarantees may be more crucial than saving energy during critical situations. These applications of WSN requires real time QOS. IEEE 802.15.4 standard provides GTS mechanism for resource reservation for those applications [2,3]. This paper evaluates the performance of GTS mechanism using Traditional method and Soft Computing method. Traditional method includes the simulation results, carried out by IEEE 802.15.4 OPNET simulation model and Soft Computing method includes the Artificial Neural Network (ANN). The results are obtained in terms of comparison of traditional method and proposed method using soft computing techniques.

The remainder of this article is organized as follows. Section II and section III give a brief overview of the IEEE 802.15.4 protocol and its MAC layer specifications. In section IV, Soft GTS mechanism and traditional GTS mechanism are organized. Simulation results are discussed in section 5. Finally it is concluded in conclusion.

II. IEEE 802.15.4 STANDARD

Recently IEEE 802.15.4[4] has widely adopted for wireless sensor network WSN because of its low Data Rate, Low Power Consumption, and Low Cost Capabilities. This protocol is quite flexible for a wide range of applications by adequately tuning its parameters and it also provides real time guarantees by using the Guaranteed Time Slot (GTS) mechanism. This feature is quite attractive for time-sensitive WSN applications [5]. The IEEE 802.15.4 standard specifies the physical layer and MAC sub-layer for Low-Rate Wireless Personal Area Networks (LR-WPANs). The ZigBee [6] standard is close associated with the IEEE 802.15.4 protocol and specifies the network (including security services) and application (including objects and profiles) layers. The ZigBee/IEEE 802.15.4 protocol architecture is presented in Figure 1.

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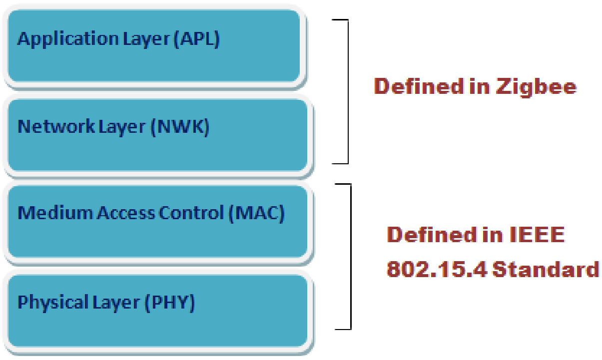

Figure 1. IEEE 802.15.4/ZigBee protocol stack architecture

Two different types of devices are defined by IEEE 802.15.4 standard viz. Full Function Device (FFD), Reduced Function Device (RFD). FFD can be a pan coordinator, a coordinator or simply an end device. The FFD can communicate with either type of device while RFD can be only an end device and can talk only through the pan coordinator or coordinator.

The different topologies are also can be considered for IEEE 802.15.4 standard viz. Star Topology, Peer to Peer Topology. In the star topology communication from one device to another device can be done only through the centralized node which is known as PAN coordinator. This type of topology is simple. In peer to peer topology all the end device can communicate with any other type of device within its radio range. The cluster tree topology is a special case of a peer to peer topology with a distributed synchronization mechanism.

IEEE 802.15.4 standard can operate in Beacon Enable mode and Non Beacon Enabled Mode. In the beacon enabled mode beacon frames are generated regularly by PAN coordinator, to identify its personal area network, to synchronize the end devices associated with it and to describe the Superframe Structure. The device simply sends their data by using Unslotted CSMA/CA algorithm in the Non Beacon Enabled mode. There is no use of Superframe structure. The advantages of this mode are scalability and self organization. However, the non beacon-enabled mode cannot provide any time guarantees to deliver data frames.

III. SUPERFRAME STRUCTURE

When the PAN Coordinator selects the beacon-enabled mode, it forces the use of a Superframe structure which is shown in Figure 2 to manage communication between the devices that are associated to that PAN. The format of the superframe is defined by the PAN Coordinator. The superframe, corresponding to the Beacon Interval (BI), is defined by the time between two consecutive beacons, and includes an active period and, optionally, a following inactive period. The active period, corresponding to the Superframe Duration (SD), is divided into 16 equally sized time slots, during which data transmission is allowed. Each active period can be further divided into a Contention Access Period (CAP) and an optional Contention Free Period (CFP). Slotted CSMA/CA is used within the CAP. The CFP is activated by the request sent from a device to the PAN Coordinator. Upon receiving this request, the PAN Coordinator checks whether there are sufficient resources and, if possible, allocates the requested time slots. This requested group of time slots is called Guaranteed Time Slot (GTS) and is dedicated exclusively to a given device. A CFP support up to 7 GTSs and each GTS may contain multiple time slots. The allocation of the GTS cannot reduce the length of the CAP to less than the value specified by aMinCAPLength constant.

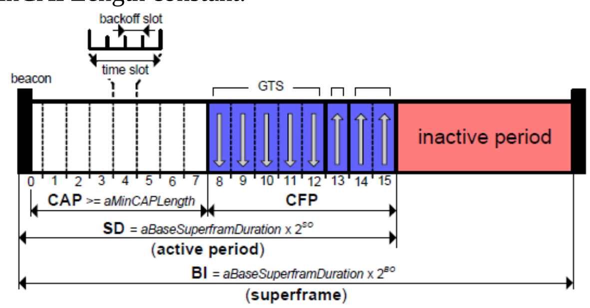

Figure 2. The IEEE 802.15.4 Super frame structure[5]

The structure of the superframe is defined by two parameters, the Beacon Order (BO) and the Superframe Order (SO), which determine the length of the superframe and its active period. The setting of BO and SO must satisfy the relationship $0 \leq SO \leq BO \leq 14$. The length of the superframe (BI) and the length of its active period (SD) are defined as follows:

$$BI = aBaseSuperframeDuration \times 2^{BO},$$

$$SD = aBaseSuperframeDuration \times 2^{SO}.$$

The aBaseSuperframeDuration constant denotes the minimum length of the superframe when BO is equal to 0. The IEEE 802.15.4 standard fixes this duration to 960 symbols. If SO = BO then SD = BI and the superframe is always active. According to the standard, if SO = 15, the Superframe will not be active following the beacon. If BO = 15, then the superframe shall not exist and the network will operate in the non beacon-enabled mode. In this case, the value of SO is ignored. As a result, a PAN that wishes to use the superframe structure must set Beacon Order to a value between 0 and 14 and Superframe Order to a value between 0 and the value of Beacon Order. Each independent PAN selects a unique identifier. This PAN identifier (PAN ID) allows communication between devices within a network using short addresses and enables transmissions between devices across independent networks. Thus, all networks can operate independently from all others currently in operation.

The PAN Coordinator may accept or reject the GTS allocation request from the End Device according to the value of the user defined attribute ***GTS Permit*** [5]. The End Device can specify the time when the GTS allocation and deallocation requests are sent to the PAN Coordinator (***Start Time*** and ***Stop Time*** attributes). This allocation request also includes the number of required time slots (***GTS Length*** attribute) and their direction, transmit or receive (***GTS Direction*** attribute).

The GTS mechanism packet flow structure is shown in figure 3. When the requested GTS is assigned to a given device, its application layer starts generating data blocks that correspond to the MAC frame payload (i.e. MAC Service Data Unit (MSDU)). The size of the frame payload is specified by the probability distribution function of the ***MSDU Size*** attribute.

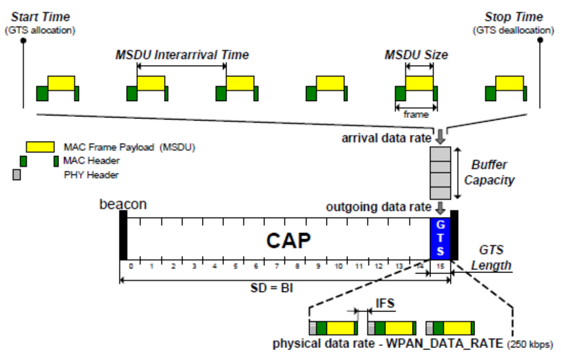

Figure 3. Packet flow structure in GTS enabled mode [7]

The probability distribution function, specified in the ***MSDU Interarrival Time*** attribute, defines the inter-arrival time between two consecutive frame payloads. Then, the frame payload is wrapped in the MAC header and stored as a frame in the buffer with a given capacity (***Buffer Capacity*** attribute). The default size of the MAC header (*MAC_HEADER_SIZE*) is 104 bits, since only 16-bit short addresses are used for communication (according to standard specification). The maximum allowed size of the overall frame (i.e. frame payload plus the MAC header) is equal to *aMaxPHYPacketSize* (1016 bits). The generated frames exceeding the buffer capacity are dropped. When the requested GTS is active, the frames are removed from the buffer, wrapped in the PHY headers and dispatched to the network with an outgoing data rate equal to physical data rate *WPAN_DATA_RATE* (250 kbps).

IV. PROPOSED SOFT GTS MECHANISM

Analysis of GTS mechanism is evaluated for enhanced GTS throughput using Artificial Neural Network (ANN) [11, 12] soft computing technique in OPNET Modeler, which can be achieved due to the packet size based on data rate and Interarrival rate.

Neural computing is a new approach to information processing. It is the fast, vital alternative to normal sequential processing. The large computing power lies in parallel processing architecture. It is capable of imitating brain's ability to make decisions and draw conclusions when presented with complex, noisy, irrelevant or partial information. Thus it is the domain in which an attempt is made to make compute think, react and compute. Neural networks are constructed with neurons that connected to each other. ANN can be used for complex relationships between inputs and outputs. ANN in most cases is adaptive systems that change their structure based on external or internal information flowing through them and use a connectionist approach to process information [13]. Back propagation feed forward networks are standard neural networks for any supervised learning pattern recognition. The error between the network output and target output is back propagated through the network and used to update the weights.

Here two inputs are considered to ANN for optimizing the GTS throughput as shown in figure 4. A packet interarrival time and data rate input decides the best packet size output through trained ANN. Since it is possible to generate I/O training pairs from the existing environment and classical procedures, we have selected a feed forward ANN with multi layers Perception model, with 2 nodes in the input Layer, 10 nodes in hidden layer and 1 node in the output layer. The input layer, hidden and output layers have a sigmoid tan-type activation function to produce outputs.

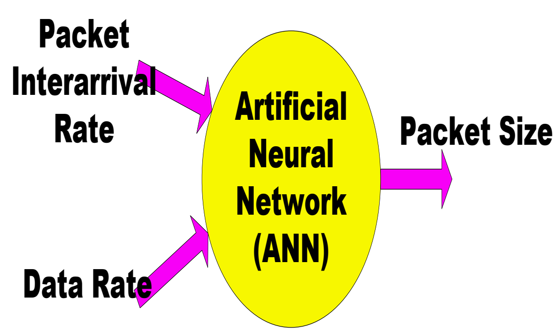

Figure 4. ANN with respective inputs and outputs

Training of neural network tries to achieve the goal of 1E-5 within 20 epochs; the goal performance is 9.95 e-5.The figure 5 shows the training of the neural network.

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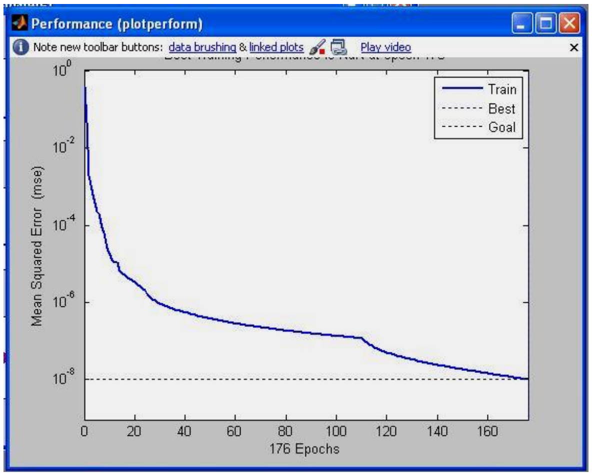

Figure 5. Training of Artificial Neural Network for Packet size

V. SIMULATION SETUP

Simulation model has one pan coordinator and one end device (GTS enabled). This configuration is sufficient to evaluate GTS mechanism because the medium is contention free and adding new device does not affect the GTS throughput of considered node. For the sake of simplicity, and without loss of generality, it is assume that only one time slot of GTS is occupied by any node and the duty cycle of a superframe is 100% (SO = BO).

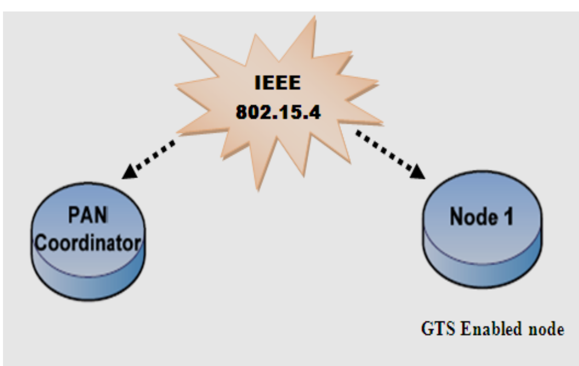

Figure 6. Simulation Set up

Figure 6 shows the simulation setup of the Traditional GTS Mechanism.

For the evaluation of the GTS throughput, GTS is set to 1 time slot and acknowledgement traffic is disabled.The buffer capacity is 4kbits for simulation and simulation time is 5 sec. 4 kbits is the real buffer size in MicaZ architecture. Table 1 shows the attributes taken under simulation consideration.

Table 1 Simulation Parameters

Parameters	Values	Units
Packet size	50-912	Bits (constant type)
Packet Interarrival Time	0.001824	Sec
Buffer size	4 K	Bits (constant type)
Distance	25	Meters

VI. SIMULATION RESULTS

The impact of data Rate, Packet Size , Packet Interarrival Rate, Buffer Size is evaluated on GTS throughput using traditional and soft computing method for different values of SO (=BO)[8]. The intense of this section is to optimize the GTS throughput during one time slot of GTS when inter arrival time is set to 0.001824 and for different values of the SO. Since the frames are transmitted without acknowledgements, the underutilized bandwidth can only result from IFS or from intermittent data arrival at the buffer.

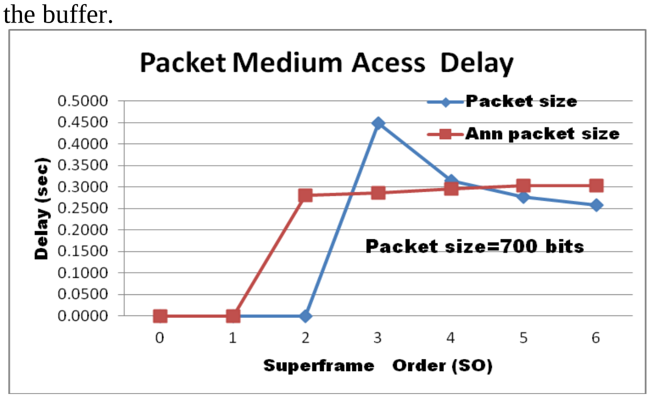

Figure 7(a). Packet Medium Access Delay v/s Superframe Order for 700 bits Packet Size

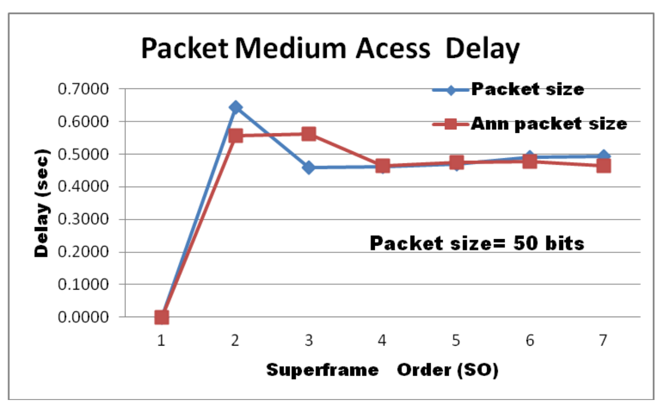

Figure 7(b). Packet Medium Access Delay v/s Superframe Order for 50 bits Packet Size

Figure 7(a) and (b) plot the packet medium access delay (sec). In these graphs, observe that the delay depends

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neither on the arrival data rate nor on the initial size of the buffer for higher values of arrival data rate. The lowest delay is achieved for SO values equal to 2,3. For SO values higher or equal to 5, all frames stored in the buffer and transmitted during one GTS and the delay grows with SO. For higher values of SO, delay will increase.

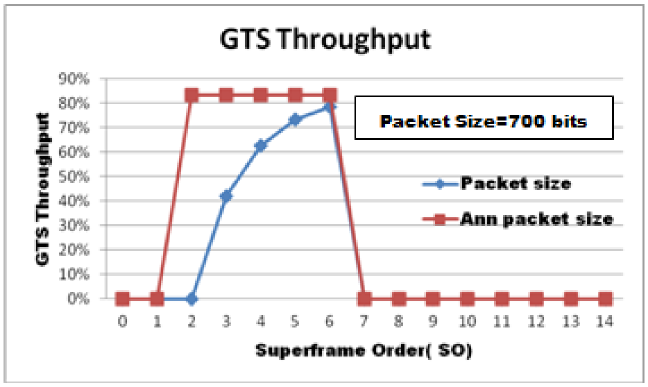

Figure 8(a). GTS Throughput v/s Superframe Order for 700 bits Packet Size

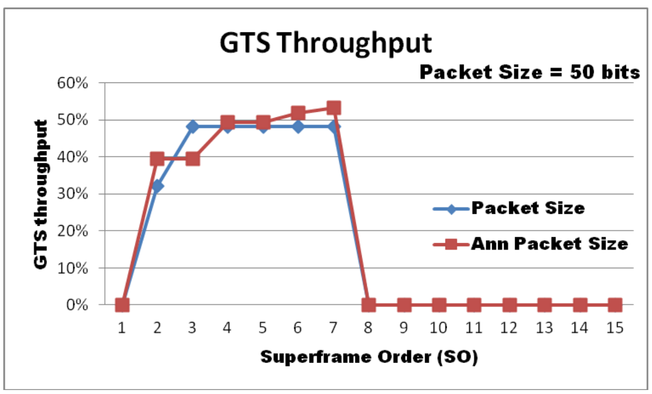

Figure 8(b). GTS Throughput v/s Superframe Order for 50 bits Packet Size

Figures 8(a) and (b) plot the GTS throughput for traditional GTS mechanism and Soft GTS mechanism. In these graphs, the corresponding packet size has reached its saturation throughput when the curve reaches its maximum peak value and plateaus. Throughput gradually decreases after reaching certain SO. The higher the SO, the larger the SD is. This creates unproductive service in a time slot window duration with the corresponding buffer size and packet generation. This can be observed for SO beyond 7. Also higher SO values are not suitable for WSN application because as Higher SO values, SD will be higher. This will provide more time duration to transmit the data but simultaneously delay will increase and throughput will decrease. At the lower SO, the duration of the superframe is very small so that only a packet size of 40 bits can conform.

We can also observe that when we apply Soft GTS mechanism, GTS throughput is increased for different SO values. That means we get optimized (greater) GTS throughput after applying the soft computing method to predict the packet size.

VII. CONCLUSION

This paper presents the evaluation of WSN beacon enabled mode operating the GTS mechanism. The evaluation was performed using IEEE 802.15.4 OPNET simulation model and soft computing technique (ANN). Here, data throughput has been considered as a function of the packet size for various SO. In this paper, it is concluded that Higher SO values i.e., greater than 7 are not supported by WSN application. Selection of SO must be done carefully to ensure that the GTS in a superframe can accommodate at least one packet size. The GTS throughput is increased and delay (sec) is decreased for the proposed Soft GTS mechanism (ANN) for different values of packet size and SO values.

ACKNOWLEDGMENT

Authors are thankful to Dept. of Elect. Engg., Faculty of Tech. & Engg., M.S.University of Baroda for technical help in doing this work.

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