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ANFIS Based Soft GTS Mechanism For IEEE 802.15.4 WSN

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Abstract: *IEEE 802.15.4 Standard is used for low rate, low power consumption and low cost wireless sensor network applications. This standard has an attractive feature for real time application by providing Guaranteed Time Slot (GTS) Mechanism. By applying this mechanism, this standard gives real time guaranty to deliver the time critical data. The GTS is started in the Beacon-enabled mode based on the superframe structure which is defined by PAN-Coordinator. A node has to use at least one whole GTS in a transmission. However, it is not necessary that each node fully utilise its transmission capacity in a particular time slot if the packet arrival rate is too small. Hence, bandwidth utilisation is reduced. This paper explores the underutilization of bandwidth in WSN,the performance optimization of the GTS Mechanismand analyzes GTS mechanism by evaluating throughput using conventional method and proposed adaptive method (Adaptive Neuro Fuzzy Inference System (ANFIS)-soft computing technique) in OPNET Modeler.*

Keywords: *Wireless sensor network (WSN), OPNET, Adaptive Neuro Fuzzy Inference System, IEEE 802.15.4, GTS, GTS Throughput, Packet Medium Access Delay, Wasted Bandwidth.*

I. Introduction

IEEE 802.15.4 standard defines the protocol connection orientation of a personal area network (PAN). The standard uses carrier sense multiple access with a collision avoidance medium access (CSMA/CA) mechanism and supports varieties of topologies for the network viz. star as well as peer-to-peer topologies. The IEEE 802.15.4 [1] Medium Access Control (MAC) protocol supports beacon enabled and non beacon mode. In the beacon enabled mode beacon frames are sent by coordinator periodically for synchronization of sensor nodes. The advantage of beacon enabled mode is that all nodes can wake up and sleep at the same time allowing very low duty cycles and hence save energy. Using the optional superframe structure, time slots can be allocated by the PAN coordinator to devices with time critical data, known as Guaranteed Time Slots (GTS) to fulfill Quality of Service requirements [2]. The primary goal of GTS allocation is providingcommunication services to time critical data, i.e., make certain guarantees on eventual delivery and delivery times of packets to be transmitted by local devices to the network coordinator. In this paper mainly focus is on uplink scenario, which is more relevant for WSNs applications. Adaptive Neuro-Fuzzy Inference System (ANFIS) is used here to decide the number of packets to be transmitted for optimization of throughput of GTS mechanism based on Packet Interarrival time and Data rate.

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

II. IEEE 802.15.4 Mac Layer

IEEE 802.15.4 MAC layer protocol [3] can work in two modes viz. non beacon enabled and beacon enabled mode. The non beacon enabled mode is same as non slotted CSMA/CA which provides scalability and self organization to the network while beacon enabled mode uses the superframe structure which defines a time interval during the frames are exchanged between PAN coordinator and associated nodes for the synchronization purpose. Beacon enabled mode works as a slotted CSMA/CA and it enables the allocation of time slots in superframe which is known as Guaranteed Time Slots (GTSs) for the nodes which guaranteed the data frames.

Each superframe is divided into Contention Access Period (CAP), where nodes contend among each other to send packets, and a Contention Free Period (CFP), where nodes have GTSs to send packets without contention and thus with guaranteed transmission. The Beacon Order (BO) and Superframe Order (SO) decide the length of the superframe structure and its active period.

Real-time guarantees can be achieved by using the GTS mechanism [4, 5] in beacon-enabled mode. The node allocates GTS with a minimum service guarantee, enabling the prediction of the worst-case timing performance of the network. Power-efficiency can be achieved by operating at low duty cycles (down to 0.1%) as power efficiency and timeliness guarantees are often two opposite requirements in wireless sensor networks.

Analysis of GTS mechanism is evaluated for GTS throughput using OPNET Modeller [6], which can be achieved due to the packet size based on data rate and Interarrival time.

III. Superframe Structure

When the PAN Coordinator selects the beacon-enabled mode [7], it forces the use of a Superframe structure which is shown in Figure 1 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 lengthof the CAP to less than the value specified by aMinCAPLength constant.

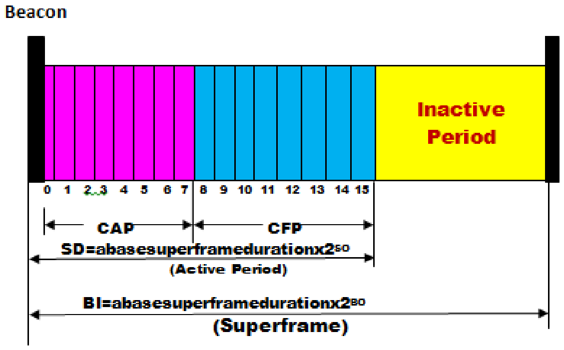


Figure 1:The IEEE 802.15.4 Super frame structure [6]

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 [8]. The End Device can specify the time when the GTS allocation and deallocation requests are sentto 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 2. 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.

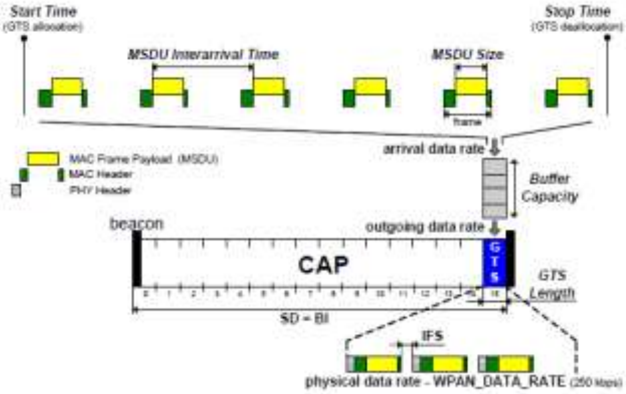


Figure 2: Packet flow structure in GTS enabled mode [8]

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 Computing Method

Soft Computing is an innovative approach to constructing computationally intelligent systems, which tries to mimic natural creatures. In this sense soft computing is the name of a family of problem-solving methods that have analogy with biological reasoning and problem solving and sometimes referred to as cognitive computing. The basic methods included in cognitive computing are fuzzy logic (FL), neural networks (NN), Artificial Neuro Fuzzy Inference System (ANFIS) and genetic algorithms (GA).

ANFIS (Adaptive Neuro-Fuzzy Inference System) is the combination of Neural Network and Fuzzy inference System (FIS) [9,10]. In ANFIS Neural Network can be trained by FIS and having characteristic of both. Here ANFIS is used to determine the MSDU packet size based on the data rate and MSDU Interarrival time. Here best Packet Size is decided depending upon two inputs, given to ANFIS for optimizing the GTS throughputas shown in Figure 3.

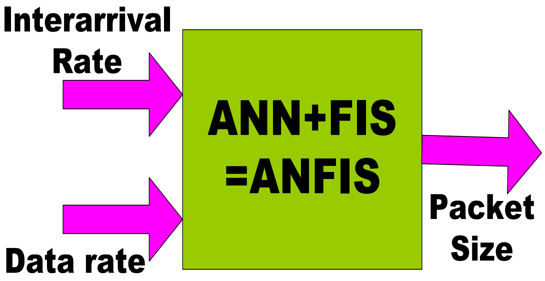
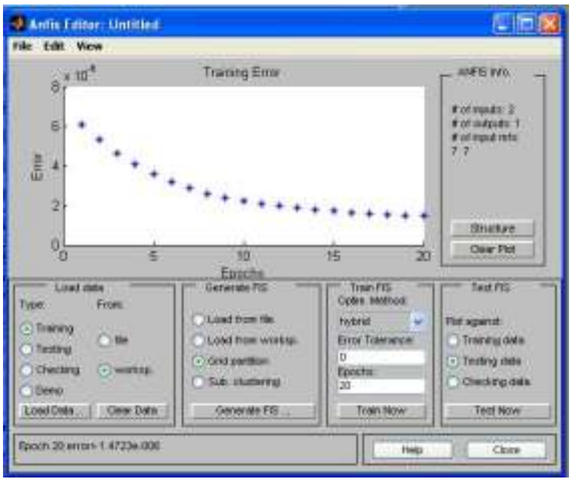


Figure 3: Internal architecture of ANN with respective inputs and outputs

A packet Interarrival time and data rate input decides the best packet size output through trained ANFIS. ANFIS (using 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) is used offline with OPNET modeler for IEEE 802.15.4GTS mechanism and evaluated the performance. Total (53x53) 2809 pairs are used to minimize the error between trained output and desired output as shown in Figure 4.



\# of inputs: 2
\# of outputs: 1
\# of input mfs:
7 7

Load data Type: ● Training ○ Testing ○ Checking ○ Demo
From: ○ file ● worksp.

Generate FIS: ○ Load from file ○ Load from worksp. ● Grid partition ○ Sub. clustering

Optim. Method: hybrid
Error Tolerance: 0
Epochs: 20

Plot against: ○ Training data ● Testing data ○ Checking data

Epoch 20:error= 1.4723e-006

Figure 4: ANFIS training

ANFIS architecture was trained with Number of nodes are 131 with training data pairs of 2809 using 49 fuzzy rules.

V. Simulation Setup & Results

The Simulation Setup consists of one PAN Coordinator and one associated devices (GTS enabled) within it coverage. There is no medium access contention so devices would not have any influence on the simulation results due to that two devices are enough to evaluate the performance of GTS mechanism. 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).

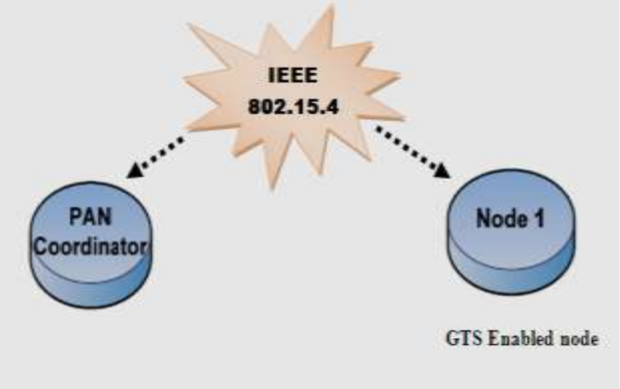


Figure 5: Wireless Sensor Network for GTS Mechanism

Figure 5 shows the simulation setup of the Conventional 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. The simulation was carried out by varying packet size and keeping packet Interarrival time constant (0.001824 sec). The distance between the two nodes is 25meters.

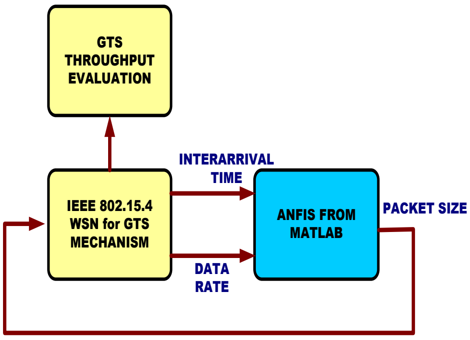


Figure 6: System Setup for ANFIS based GTS Mechanism

The system setup for evaluation of performance of GTS mechanism for WSN using ANFIS in OPNET and MATLAB [11-14] is shown in Figure 6.

The impact of data Rate, Packet Size , Packet Interarrival Time, Buffer Size is evaluated on GTS throughput using conventional and soft computing method for different values of SO (=BO). The intense of this section is to optimize the GTS throughput during one time slot of GTS when inter arrival time is set to 0.001824sec 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.

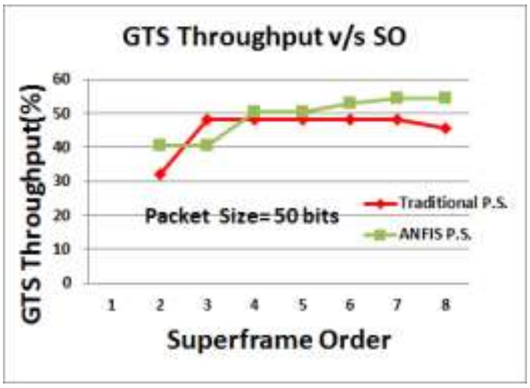


Figure 7: GTS Throughput v/s Superframe Order

Figure 7 describes the GTS throughput for conventional GTS mechanism and Proposed Soft GTS mechanism for packet size of 50 bits. In these graphs, the GTS Throughput 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 time slot window duration with the corresponding buffer size and packet generation. This can be observed for SO beyond 7.

High values of SO values are not suitable for WSN application because as the SO value is high, SD also will be higher. This will provide more time duration to transmit the data but simultaneously delay will increase and throughput will decrease.

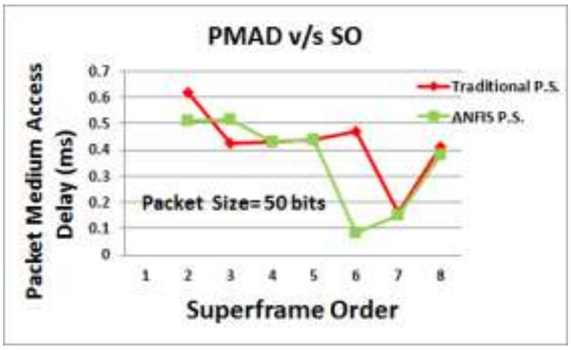


Figure 8: Packet Medium Access Delay (PMAD) v/s Superframe Order

Figure 8 plots the packet medium access delay (sec). When SO increases, 0.001824 s inter-arrival time records a bigger range of Packet Medium Access Delay (PMAD). This indicates the significant relationship of inter-arrival time, packet size and buffer size. As shown in Figure 8 initially PMAD is somewhat stable and then starts to decrease slightly. The point at which the PMAD decreases slightly indicates that the PMAD contribution originates from the long SD produced by the SO. The PMAD measurement is similar for the same SO regardless of the buffer size until it reaches that slightly decreased point. Also for higher SO values, 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.

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 9: Wasted Bandwidth v/s Superframe Order

From Figure 9, it is observed that wasted bandwidth is less in proposed method compare to conventional method. A device with a low arrival rate that has been allocated one time slot of GTS, may use it only partially. This leads to underutilization of the GTS band width resources. Due to the prefixed time slot duration in a superframe, it is practically impossible to balance the arrival rate of a device and its guaranteed GTS bandwidth. The amount of wasted bandwidth increases with the variance between the guaranteed bandwidth and the arrival rate. However, wasted bandwidth decreases in proposed adaptive method by applying ANFIS soft computing technique.

VI. Conclusion

In this paper, GTS Mechanism in the IEEE 802.15.4 Standard is evaluated in beacon enabled mode, widely used in WSN application. The evaluation was performed using IEEE 802.15.4 OPNET simulation model and soft computing technique (ANFIS). 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 Packet Medium Access Delay, Wasted bandwidth are decreased for the proposed Adaptive GTS mechanism (ANFIS) for different values of packet size and SO values. The evaluation results that were obtained provide excellent statistics to pursue our future work. The performance of GTS mechanism can be more improved by applying fuzzy as well as genetic algorithm.

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