Priority based Adaptive Scheduling Algorithm for IoT Sensor Systems

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***Abstract*--In IoT sensor systems, the existing scheduling approaches fail to satisfy the varying Quality-of-Service (QoS) requirements of heterogeneous applications and their demands. This paper proposes a priority based adaptive scheduling algorithm (PASA) for IoT sensor systems. Unlike the existing scheduling techniques, the proposed PASA considers the requirements of heterogeneous applications such as data rate, minimum delay, transmitting power, remaining energy, remaining buffer size of devices etc. The base station allocates collison-free time slots for each node based on their traffic priority. The duty-cycle (ST) of each node will be adaptively assigned based on the Priority of traffic, remaining buffer size of queue level (RBS), remaining energy (RE) and required transmitting power (TP). The proposed PASA is compared with the Energy Efficient Context Aware Traffic Scheduling (EE-CATS) algorithm. Simulation results have shown that PASA outperforms EE-CATS in terms of packet delivery ratio (PDR), average residual energy and throughput.**

Keywords--IoT, Scheduling, Priority, Adaptive, WSN

I. INTRODUCTION

The Internet of Things (IoT) is a wordwide developed technology which provides multiple services. IoT interconnects people with various devices through Internet oriented services. Wireless Sensor Networks (WSN) is an essential component of an IoT application. Normally, WSNs are equipped with controlled devices and the corresponding IoT applications [1].Smart IoT devices are growing popular in our day-to-day activities. It is estimated that the number of such devices will grow into billions within few years [2].]. IoT is being used by WSN transmissions and radio frequency identification (RFID) to attain reliability and robust processing.

IoT supports various applications such as smart home, smart cities, industrial automation and intelligent transportation. IoT is also used in 5G wireless communication to provide heterogeneous services to the users. In 5G networks, if some packets are lost, the application loss tolerance can be utilized to reduce the average power consumption of the devices [4]. The main challenges in the data collection of IoT networks involve scheduling the data transmission of massive number of IoT nodes. In IoT event-driven applications, it is very crucial to send data with low latency, so that an appropriate action can be initiated. Hence, the network design for IoT based on WSN's should aim to minimize the data collection delay and energy consumption. [5].

In IoT, designing an optimal scheduling algorithm should maximize the CPU utilization and throughput and minimize the latency and power consumption [6] [7]. Generally, IoT applications have repeated tasks executed in various sensor nodes which may result in higher sensing cost and reduced network lifetime. In some of the approaches, this problem can be solved by assigning the similar tasks within a specific region to a single system. But selecting that single system for execution was a challenging issue. Also, an efficient scheduling of tasks avoids repeated execution of the same task which leads to unnecessary inter-node communication.[1].

Duty cycle scheduling of limited energy IoT sensors is a main concern in various IoT applications.

In [9], the nodes are put into sleep mode when their queues become empty. The energy efficient scheduling [11] considers node's life time (least residual energy) for deciding the active set of nodes. DeTAS [12] and optimal duty-cycle scheduling technique [13] consider traffic load of nodes in terms of queue size for determining the duty-cycle length. Interference aware scheduling has been discussed in [10] and [13]. But these approaches to satisfy the varying QoS requirements of heterogeneous applications and their demands [9]. It should consider the data rate or bandwidth requirements, minimum delay, transmitting power, buffer size of devices etc.

Based on these issues, the duty cycle of the scheduling algorithm should be assigned meeting the following objectives:

- ✓ Conflict free time slots should be assigned
- ✓ Priority of traffic should be derived based on the data rate and delay requirements
- ✓ The duty cycle should be adjusted based on the priority of traffic, remaining buffer size, remaining energy and required transmitting power.

To meet these objectives, a priority based adaptive scheduling algorithm for IoT sensor systems is designed.

The paper is organized as follows. Section II presents the related works done on scheduling in IoT. Section III presents the detailed methodology of PASA. Section IV presents the experimental results along with analysis. Finally, section V concludes the paper.

II. Related Works

Baranidharan et al [1] have proposed an Efficient Task Scheduling in Internet of Things (ETSI) algorithm. It schedules different tasks to the suitable nodes. The ETSI algorithm was said be effective with respect to task execution when compared to related algorithms.

Zheng Jiang et al [2] have proposed two schemes for improving the IoT communication: The preconfigured access and joint spatial and code domain. They are actually extension of multiuser shared access (MUSA) scheme to the spatial domain.

Sathish Kumar et al [8] have utilized bankers algorithm for resource scheduling to yield best resource utilization. The algorithm provides better utilization in terms of fairness and execution time when compared to traditional FCFS approach. Bilal Afzal et al [9] have proposed an energy efficient context aware traffic scheduling (EE-CATS) algorithm. The EE-CATS algorithm allocates resources to the IoT devices by reducing the awake period of sensors using an adaptive duty cycle scheduling technique.

Sourav Kumar Dhar et al [10] have proposed an interference aware scheduling for IoT sensors-based health care system. It considers the sampling rate and data size parameters for scheduling. It significantly reduces the interference among the sensors and prevents data loss. Taewoon Kim et al [11] have studied the problem of energy efficient scheduling of clustered IoT devices. An optimal node activation scheduling algorithm has been proposed. It ensures the accuracy of collected reports and adaptive report updation.

Nicola Accettura et al [12] have presented a new Decentralized Traffic-Aware Scheduling algorithm. It generates optimum distributed schedules for multi-hop networks. This distributed algorithm provides effective queue management and minimizes the network duty cycle.

Maria Rita Palattella et al [13] have designed standardized IoT architecture by applying the traffic aware scheduling algorithm (TASA). TASA determines the schedules based on the topology and the traffic load of IEEE802.15.4e network. They have derived the minimum required active slots and duty-cycle period.

III. Priority based Adaptive Scheduling Algorithm (PASA)

In this paper, we propose to design a priority based adaptive scheduling algorithm (PASA) for IoT sensor systems. In this algorithm, the IoT sensors having heterogeneous applications were considered. The base station allocates collison-free time slots for each node based on their traffic priority. The duty-cycle (ST) of each node will be adaptively fixed based on the Priority of traffic, remaining buffer size of queue level (RBS), remaining energy (RE) and required transmitting power (TP).

A. Traffic Type Classification

Consider the following parameters:

TC - traffic class
DR - data rate
DTL - delay tolerance level (L1 and L2 are minimum and maximum tolerance levels)
Pr – traffic priority

The traffic classes were categorized and prioritized as shown in Table 1.

TABLE I. Priority of Different Traffic Classes

Pr	*TC*	*DR*	*DTL*
1	Emergency	Low	No Tolerance Level
2	Real-Time (RT) Traffic	Medium	L1 – L2
3	Real-Time (RT) Traffic	High	L1
4	Non-Real-Time (NRT) Traffic	Low	L2

B. Time Slot Allocation

The base station allocates collision-free time slots for each node based on their priority. The steps involved in this traffic aware scheduling algorithm are as follows:

Algorithm

Notations	*Definitions*
X_i	duplex-conflict links
Y_i	interference conflict links
T	time slot
Z	channel offset

1. BS uses Matching procedure to select X_i for T
2. Schedule each Yi $\subset$ X_i on different Z
3. To select Y_i, a graph G {U, V} is built
   Where U is the set of transmitters containing X_i links
   V is the set of interfering links
4. Using the Coloring technique, BS selects Y_i which have been scheduled on same Z.

5. Only a small sub set of links in X_i will be scheduled, keeping the other links for next step of procedure.
6. At the end of each iteration, local and global queue levels are updated based on the schedule of slot T.
7. Based on the update, the links to be scheduled in the (T + 1), will be selected based on the traffic priority.
8. The execution of the algorithm will be terminated when the schedules for all the network traffic has been determined.

C. Estimating the Duty Cycle

The duty-cycle (ST) of each node will be adaptively determined based on the

- Priority of traffic (PR)
- Remaining Buffer size of Queue level (RBS)
- Remaining energy (RE)
- Required transmitting power (TP)

a. Remaining Buffer size of Queue level (RBS)

The remaining buffer space of queue level is estimated based on the following equation:

$$RBS = pr * (TBS / ND) \quad (1)$$

where,
pr is the priority of traffic
TBS is the total buffer size
ND is the neighbor density

b. Remaining energy (RE)

The remaining energy of each node (RE) after a data transmission is estimated using Eq (2)

$$RE = E_i - (E_{tx} + E_{rx}) \quad (2)$$

where E_i is the initial energy
E_{tx} is the transmitting energy
E_{rx} is receiving energy

c. Required transmitting power (TP)

The deviation in the TP value is obtained by comparing with reference value as follows:

$$\Delta P_{tx}^{\,i}(t) = P_{txi}(t) - P_{ref}(t) \quad (3)$$

$P_{ref}(t)$ = pre-defined reference power value.

d. Adaptive Policy for ST Adjustment

The adaptive policy for fixing ST will be as shown in Table 2.

TABLE II. ADAPTIVE POLICY FOR FIXING ST

PR	RBS	RE	TP	ST
1	NA	NA	NA	0 (i.e. the node will be immediately activated)
2	High	Low	High	High
	Low	High	Low	Low
3	High	Low	High	High
	Medium	Medium	Medium	Medium
	Low	High	Low	Low
4	High	Low	High	High
	Medium	Medium	Medium	High
	Low	High	Low	Low

The table content is explained in the below algorithm

Algorithm for Adaptive ST Adjustment

1. Start
2. If PR= 1, Then
   ST=0
   End if
3. If PR=2 Then
   If (RBS=HIGH) OR (RE=LOW) OR (TP=HIGH) Then
   ST = HIGH
   Else If (RBS=LOW) OR (RE=HIGH) OR (TP=LOW) Then
   ST=LOW
   End if
   End if
4. If PR=3 Then
   If (RBS=HIGH) OR (RE=LOW) OR (TP=HIGH) Then
   ST = HIGH
   Else If (RBS=MEDIUM) OR (RE=MEDIUM) OR (TP=MED) Then
   ST = MEDIUM
   Else if (RBS=LOW) OR (RE=HIGH) OR (TP=LOW) Then
   ST=LOW
   End if
   End if
5. If PR=4 Then
   If (RBS=HIGH) OR (RE=LOW) OR (TP=HIGH) Then
   ST = HIGH
   Else if (RBS=MEDIUM) OR (RE=MEDIUM) OR (TP=MED) Then
   ST = HIGH
   Else if (RBS=LOW) OR (RE=HIGH) OR| (TP=LOW) Then
   ST=LOW
   End if
   End if
6. Stop

IV. Experimental Results

A. Simulation Settings

The Priority based Adaptive Scheduling Algorithm (PASA) has been implemented in NS2 and compared with the Energy efficient context aware traffic scheduling (EE-CATS) [9] algorithm. The performances of these two algorithms are evaluated in terms of packet delivery ratio (PDR), average packets dropped, average residual energy and throughput. The simulation settings are presented in Table 3.

TABLE III. Simulation Parameters

Number of Nodes	21,41,61,81 and 101
Size of the topology	50 X 50m
MAC Protocol	IEEE 802.15.4
Traffic type	Constant Bit Rate
Number of traffic flows	2 to 10
Antenna model	Omni Antenna
Initial Energy	10 Joules
Transmission Power	0.7 watts
Reception Power	0.5 watts

B. Results & Analysis

a. Performance on Network Size

In order to analyze the performance of the two algorithms on network size, the number of nodes has been varied as 21,41,61,81 and 101.

TABLE IV. Result Table for Delivery Ratio

Nodes Vs Delivery Ratio		
Nodes	*PASA*	*EE-CATS*
21	0.936114	0.90461
41	0.91122	0.8717
61	0.8478	0.8121
81	0.8429	0.7755
101	0.81268	0.7146

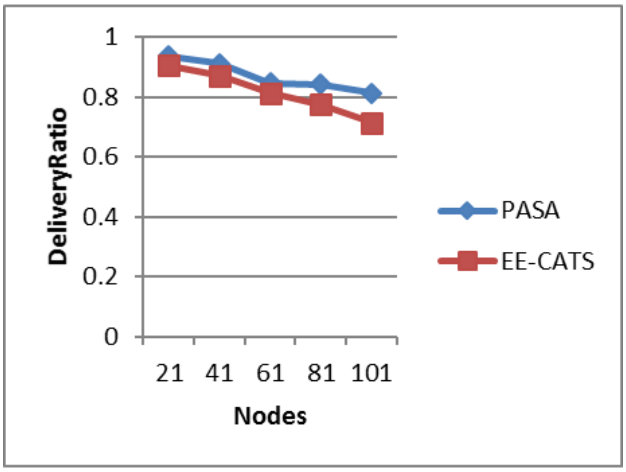

Fig. 1. Nodes Vs Delivery Ratio

The packet delivery ratio of PASA and EE-CATS are shown in Figure 1. From the figure, it can be seen that PASA has 6% higher delivery ratio than EE-CATS, for varying the nodes.

TABLE V. Result Table for Drop

Nodes Vs Drop		
Nodes	*PASA*	*EE-CATS*
21	7875	16636
41	9399	18366
61	9499	19738
81	10384	20300
101	11168	20660

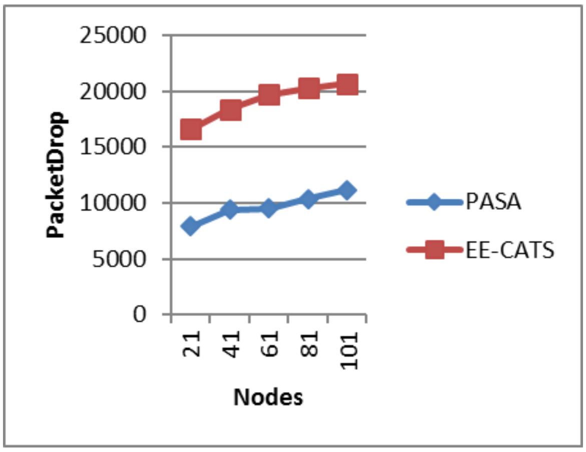

Fig. 2. Nodes Vs Packet Drop

The average packet drop of PASA and EE-CATS are shown in Figure 2. From the figure, it can be seen that PASA has 49% lesser packet drop than EE-CATS, for varying the nodes.

TABLE VI. Result Table for Residual Energy

Nodes Vs Residual Energy		
Nodes	*PASA*	*EE-CATS*
21	7.973537	6.977645
41	7.9804	6.82741
61	7.6511	6.470199
81	7.50442	6.302507
101	7.48596	6.086805

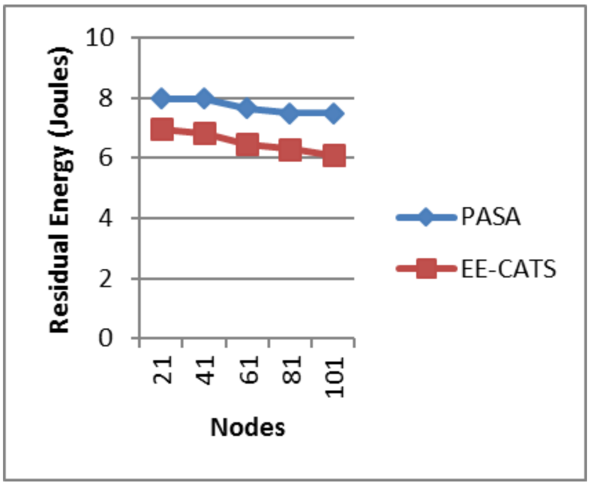

Fig. 3. Nodes Vs Residual Energy

The average residual energy of PASA and EE-CATS are shown in Figure 3. From the figure, it can be seen that PASA has 15% higher residual energy than EE-CATS, for varying the nodes.

TABLE VII: RESULT TABLE FOR THROUGHPUT

Nodes Vs Throughput		
Nodes	*PASA*	*EE-CATS*
21	1.8591	0.8392
41	1.2756	0.8676
61	0.8891	0.6304
81	0.829	0.5724
101	0.803	0.5108

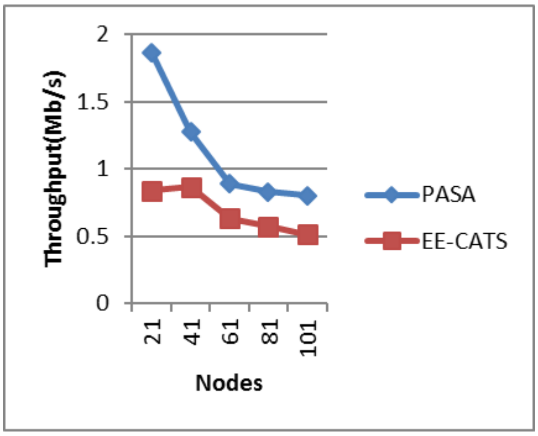

Fig. 4. Nodes Vs Throughput

The throughput measured for PASA and EE-CATS are shown in Figure 4. From the figure, it can be seen that PASA has 36% higher throughput than EE-CATS, for varying the nodes

b. Performance on Traffic Flows

In order to analyze the performance of the two algorithms on various traffic flows, the number of traffic flows has been varied from 2 to 10.

TABLE VIII. RESULT TABLE FOR DELIVERY RATIO

Flows Vs Delivery Ratio		
Flows	*PASA*	*EE-CATS*
2	0.84539	0.76842
4	0.8524	0.71662
6	0.8268	0.71946
8	0.8184	0.70069
10	0.8037	0.64973

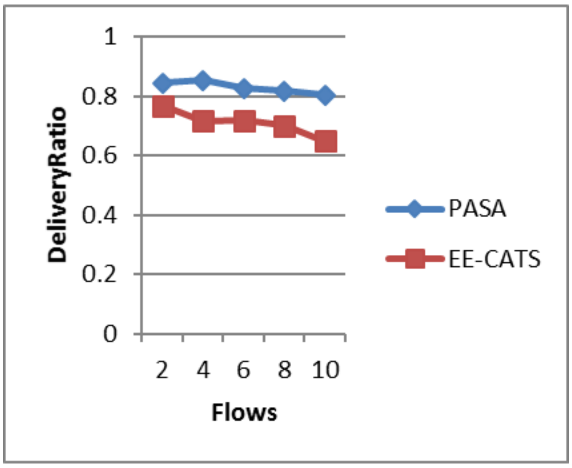

Fig. 5. Flows Vs Delivery Ratio

The packet delivery ratio of PASA and EE-CATS are shown in Figure 5. From the figure, it can be seen that PASA has 14% higher delivery ratio than EE-CATS, for varying the flows.

TABLE IX. RESULT TABLE FOR DROP

Flows Vs Drop		
Flows	*PASA*	*EE-CATS*
2	3298	6099
4	5856	11906
6	8168	19060
8	11553	25859
10	12968	33076

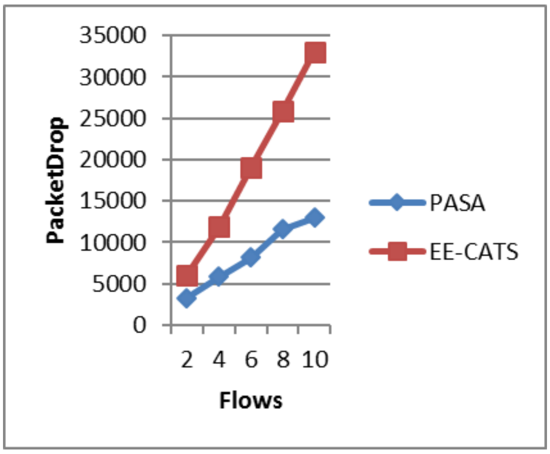

Fig. 6. Flows Vs Packet Drop

The average packet drop of PASA and EE-CATS are shown in Figure 6. From the figure, it can be seen that PASA has 54% lesser packet drop than EE-CATS, for varying the flows.

TABLE X. RESULT TABLE FOR RESIDUAL ENERGY

Flows Vs Residual Energy		
Flows	*PASA*	*EE-CATS*
2	9.225198	7.204388
4	8.957757	6.150896
6	7.648596	6.086805
8	8.09958	6.042425
10	7.823334	6.10074

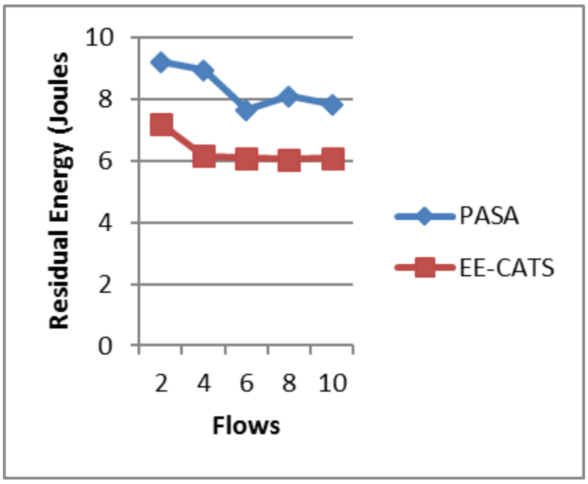

Fig. 7. Flows Vs Residual Energy

The average residual energy of PASA and EE-CATS are shown in Figure 7. From the figure, it can be seen that PASA has 24% higher residual energy than EE-CATS, for varying the flows.

TABLE XI. RESULT TABLE FOR THROUGHPUT

Flows Vs Throughput		
Flows	*PASA*	*EE-CATS*
2	0.272	0.29
4	0.84	0.5864
6	1.0104	0.5108
8	1.0124	0.5012
10	1.1908	0.5008

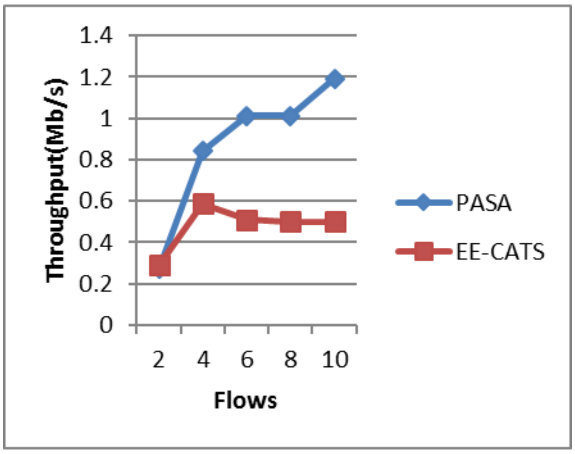

Fig. 8. Flows Vs Throughput

The throughput measured for PASA and EE-CATS are shown in Figure 4. From the figure, it can be seen that PASA has 36% higher throughput than EE-CATS, for varying the flows.

V. CONCLUSION

In this paper, a priority based adaptive scheduling algorithm for IoT sensor systems has been proposed. In this algorithm, the IoT sensors having heterogeneous applications were considered. The base station allocates collison-free time slots for each node based on their traffic priority. The duty-cycle (ST) of each node will be adaptively fixed based on the Priority of traffic, remaining buffer size of queue level (RBS), remaining energy (RE) and required transmitting power (TP). By experimental results, the performance of PASA has been found to be improved in terms of PDR, throughput and residual energy of nodes.

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