Energy and Priority Aware Scheduling Scheme for Wireless Sensor Networks

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Abstract — Wireless sensor networks (WSNs) are playing a vital role in automation, sensing and commercial applications. Key issues in WSNs are to satisfy Quality of service (QoS) parameters and to conserve energy. Some of the sensor nodes in WSN act as a single communication link to connect one group of sensor nodes to other in multi-hop environment. If nodes acting as a single communication link become dead due to low energy then this can cause network failure and nodes causing failure are called bottleneck nodes. This paper proposes an Energy and Priority Aware Scheduling (EPAS) scheme for bottleneck node avoidance. Every node has three priority queues to place packets of different priorities. Scheduling of packets is performed based on energy level threshold and priority level marked. Proposed scheme avoids bottleneck problem by scheduling packets of high priority based on energy level thresholds, if energy is critically low then low priority packets are dropped but sensor node still keep transmitting high priority packets in order to keep network alive. Proposed scheme is implemented using Network Simulator-2 (NS-2). Simulation results show that the scheme achieves 96% packet delivery ratio for highest priority packets and gives 52% improvement in packet delivery ratio, 0.309 Kbits/sec improved throughput and 5.16s less delay as compared to priority queuing.

Index Terms — QoS: Quality of service, WSN, NS-2

I. INTRODUCTION

Wireless Sensor Networks (WSN) are group of sensor devices which collaborate to monitor any environmental or physical phenomenon such as temperature, humidity level, pressure while working at diverse locations. Considering that most of wireless sensor nodes are battery operated, energy conservation is one of biggest challenges as sensors once deployed in an environment remain there for years and it is difficult to recharge or replace batteries. Besides overall energy consumption, Quality of Service (QoS) differentiation and reliability are also important features demanded by today’s WSN environment [2]. QoS is capacity of network to fulfill certain requirements of a user or an application; requirements can be minimum bandwidth, packet delay, packet loss etc. QoS differentiation for WSNs can be defined as different sensors require different level of QoS to perform different tasks in a system. For example, in surveillance system status of an anomaly or intruder must be updated within few seconds of detection. Similarly status of fire alarm is more prior to water level in a home automation system. Thus applications requiring QoS are gaining more and more importance in field of WSNs. Many researchers designed routing protocols, Medium Access Control (MAC) protocols and scheduling schemes to provide energy efficiency and ensure QoS to WSNs. Scheduling schemes play a vital role at sensor nodes since they guarantee delivery of different data types based on their priority and ensure minimum delay for each type of packet. Literature review shows that very fewer studies exist on packet scheduling that schedule data processing at sensor nodes and also reduce energy consumption. In fact most operating systems for WSNs use First in First out (FIFO) scheduling which process packets as per arrival time i.e. packets received first are transmitted first. However packets at sensor nodes must be delivered considering different constraints like deadline, delay, queue length and priority levels. Most of scheduling schemes available in literature are not designed considering dynamic requirements of WSNs.

In this paper a new energy and QoS aware scheduling scheme named Energy and Priority Aware Scheduling (EPAS) scheme is proposed. It uses priority marking to provide QoS among nodes. Scheduling is performed considering energy of node and priority level marked. Rest of paper is organized as follows. In section II an overview of related research work is given. Section III explains proposed EPAS scheme in detail while section IV gives performance evaluation of proposed scheme using Network Simulator (NS-2). In the end section V concludes the paper.

II. RELATED WORK

This section gives an overview of literature related to Quality of Service (QoS) aware MAC protocols, scheduling schemes and bottleneck nodes. N. Saxena et al. presented idea of a MAC protocol designed specifically for multimedia transmission over WSNs [4]. Aim is to conserve energy and provide QoS support. It varies duty cycle and Congestion Window (CW) based on network parameters such as transmission failure rate and priority of traffic class. Differentiation of QoS among different traffic classes is provided by varying CW sizes using different multiplicative coefficients among traffic classes. There is no centralized control so early sleeping as well as idle channel listening are main drawbacks. Also protocol cause high latencies for packets of low priority type.

Priority Reservation Medium Access Control (PR-MAC) is a MAC protocol which assigns priorities to sensors based on the event monitored by that sensor node e.g. in a home automation system a sensor for fire alarm is more important than a sensor for water level [5]. Different priorities are assigned to sensors for every event under observation by sensor node and differentiation between events is provided by changing Congestion Window (CW) size and varying Inter Frame Space (IFS) per event. Sender
node communicates a small duration pulse instead of using RTS-CTS messages for medium reservation. Later M.A Yigitel et al. proposed Q-MAC [6], protocol is designed to provide QoS among nodes and energy conservation for multi-hop networks. It is a scheduling based protocol and schedule priorities of packets considering their hop count, remaining energy and node’s queuing load. Q-MAC uses intra-node scheduling to choose next packet to service among different priority queues and medium access among neighboring nodes is provided by inter-node scheduling. Packets are queued at their respective nodes, as per their priority in FIFO manner and then from respective nodes highest priority packet is transmitted towards receiver using different algorithms for intra-node and inter node scheduling. However computing transmission urgency for any sensor is complex and also leads to higher latencies.

Congestion avoiding algorithms for multi-hop wireless environment are proposed to work at different layers of OSI model [9, 10, 11]. B. Ngo et al. proposed a scheme to address congestion at relay nodes by balancing its relaying activities. [12]. Relay node tries to balance its incoming and outgoing traffic. If receiving rate is too high relay node starts dropping RTS frames. Whenever there is an imbalance between incoming and outgoing traffic, relay node drops RTS frames, it entains next packet only when buffered queue is empty. This scheme achieves 100% throughput increase as compared to IEEE 802.11 RTS/CTS strategy. High dropping rate of Channel request frames provides feedback to nodes at every hop. Thus packet sending rate of nodes is limited by relay nodes leading to stabilize the system.

Later R. K Tripathi et al. propose an algorithm for bottleneck nodes detection and critical level of a node [13]. In this algorithm nodes are divided into two types, root nodes who initiate flooding and those which are used to forward signals of root node. Root nodes are determined from number of neighboring nodes, a node having least number of neighbors is considered a root node. Reason of this criterion is nodes having least number of neighbors have more chances of being at border of network. Thus being at border of network can act as bottleneck. If any node receive flooding messages from other than one root node in that case it is critical node of network, i-e it can be considered bottleneck. Criticality of a node increases as number of root nodes connected to it increases. Thus in this way bottleneck node detection is done in this algorithm.

Later on authors reported the concept of a congestion control scheme for WSNs named ECODA (Enhanced Congestion Detection and Avoidance) [14]. It is designed to operate at both MAC and network layer and works for multiple traffic classes. Scheme proposed uses cross layer design, detects congestion using buffer and weighted buffer difference. Packet transfer is done using flexible queue scheduler, packets are assigned static and dynamic priorities and packet scheduler selects next packet as per priority. Queuing strategy used commonly for WSNs is FIFO, it schedules packets in their order of arrival i-e packets which come first are served first but it does not consider constraints like deadline, delay or priority. Scheduling packets in a priority based method involves use of Priority Queuing (PQ). It can use single queue architecture with high priority packets placed at top of queue or multiple queues can be used for queuing packets of different priority in different queues. Every queue is a FIFO queue. High priority values are assigned to control packets mostly while data packets are assigned low priority values. Packets from high priority queues are served first. If congestion occurs low priority packets are dropped first while there is no fair distribution of resources for all types of packets [15]. In faire queuing (FQ), data packets are identified as flows and every flow is stored in a particular queue. It uses round robin algorithm to ensure equal sharing of resources among flows. Weighted Fair Queuing (WFQ) is a combination of PQ and FQ. Just like FQ method, all queues are served to avoid bandwidth starvation, but weights are assigned to queues so a queue with high weight use network for longer duration or it is served first. Thus assigning weight is just like giving different priorities to queues. Thus classification of packets is done and then they are assigned different queues accordingly [15] but these scheduling schemes are not designed considering dynamic requirements of WSNs. Nidal Nasser et al. proposed Dynamic Multi Priority (DMP) scheduling scheme for WSNs, it differentiates packets into real and non-real time data [16]. It uses multiple variable length queues, real time packets which are of highest priority so placed in high priority queue while non-real time packets are placed in low priority queues considering certain threshold of time. Real time packets can preempt transmission of low priority packets. It improves QoS by delivering real packets fast and reducing delay. A performance analysis of DMP is presented by S. Bansode et al. using NS-2 [22]. Overview of literature suggest that most of QoS related research work assigns priorities to nodes either by adjusting CW size or varying duty cycle but they have drawback like complex cost function, high latencies and starvation of low priority packets. Scheduling schemes are designed considering traffic classes, single queue and multiple queue architecture, priority levels and deadlines. There is research space to design a scheduling scheme considering dynamic requirements of WSNs to avoid bottleneck node problem.

III. PROPOSED SCHEDULING SCHEME

Proposed Energy and Priority Aware (EPAS) Scheduling scheme provides QoS to wireless sensor nodes while efficiently using energy resources. It uses prioritization to provide QoS, multi-queue architecture and energy aware decision making to avoid bottleneck problem. System model for proposed scheduling scheme consists of a group of wireless sensor nodes connected by a single communication link named bottleneck link as shown in Fig. 1. Sensor nodes within group can communicate from one end to other as long as bottleneck link is active. If this link is broken or down because of low energy then network will be partitioned and there will be no communication between different parts of network. Let sensor nodes have different data sending rates and there is no priority based classification of packets and nodes. If bottleneck nodes use simple scheduling techniques like first come first serve then a low priority sensor node with
high data sending rate may occupy channel for a long duration causing starvation for other sensor nodes and bottleneck node may drain its energy sending low priority packets. Thus there is a need of priority based classification of data packets and prioritize scheduling to address the problem of bottleneck nodes.

Proposed scheduling scheme consists of following phases
1) Priority marking
2) Priority queue assignment
3) Energy and priority aware scheduling

A. Priority Marking
Every node mark data packets with static priorities depending upon importance of task assigned to them. Every packet is assigned a priority level and a priority queue as per priority of packet, in this scheme we have three priority levels for packets
1) High
2) Mid
3) Low

Every packet is marked with a priority level and when it is received by a node it is assigned a particular queue as per its priority. In this scheme packets are assigned three priority levels, packets having highest priority are marked as P1, then comparatively low priority packets are marked with P2 and lowest priority packets are given priority of P3. Table I gives details of priority assignment in tabular form. Main advantage is that QoS differentiation among packets is achieved by marking priority levels.

<table>
<thead>
<tr>
<th>Priority value</th>
<th>Packet status</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Highest priority packet</td>
</tr>
<tr>
<td>P2</td>
<td>Mid level Priority</td>
</tr>
<tr>
<td>P3</td>
<td>Low priority</td>
</tr>
</tbody>
</table>

B. Priority Queue Assignment
In this scheme we have used approach of multiple priority queues. Typical PQ uses a single queue with high priority packets placed at the top of queue but in this scheme every node has three FIFO queues. Three priority queues are used as number of priority levels of packets is three, scheduler checks priority level marked on packet and assigns every packet its particular queue. The proposed scheme uses following notation for all the three queues.

- HPQ-1 represents queue containing packets of highest priority i.e. packet of type P1.
- HPQ-2 represents queue with packets of mid-level priority i.e. packets of type P2.
- LPQ denotes queue containing lowest priority packets i.e. packets of type P3.

C. Energy and Priority Aware Scheduling
It is most important phase of proposed scheduling scheme as packets are differentiated into different types as per importance of task and energy level of node. This scheme uses three energy levels as decision thresholds. Initial energy of node is compared with remaining energy of node. Every node whenever receives a packet it checks packet’s priority level marked in its header and its own energy level. We have used three energy thresholds.

1) Threshold 1: Remaining Energy of node > 70% of initial energy
2) Threshold 2: Remaining Energy of node > (30% and < 70%) of initial energy
3) Threshold 3: Remaining Energy of node < 30% of initial energy

Scheduling of packets is performed considering these thresholds and priority levels, detailed process is explained in next section.

D. Working Principle
In this section we explain working of proposed EPAS scheduling scheme. All nodes assign priority levels to packets as per importance of task assigned as discussed in priority assignment block. When a bottleneck node receives any packet it examines priority level of packet marked in its header and it checks its own remaining energy. If energy level of node is greater than 70% of initial energy then it will allow all priority packets i.e. P1, P2 and P3 to transmit with packets of priority level P1 are transmitted first, then P2 and at the end packets of priority P3 are transmitted. If energy level is less than 70% but greater than 30% of initial energy then only packets of priority P1 and P2 will pass through and remaining packets are queued. If high priority queues (HPQ-1 and HPQ-2) are empty then packets from low priority queue are allowed to pass through. If energy of node becomes less than above two thresholds and drops below 30% of initial energy then packets of highest priority P1 are transmitted only while low priority packets are queued. If high priority queue is empty then packets from low priority queues are transmitted but if high priority queue HPQ-1 is not empty then low priority packets are dropped in case of critically low energy state i.e less than 30%. Thus using this scheme bottleneck problem is avoided as even if energy of node is critically low still it can pass high priority packets so that network is alive. Proposed scheme improves overall network lifetime, uses energy intelligently and provides QoS
Proposed scheduling scheme uses algorithm given in Table II and parameters for algorithm are:

- **LE** = initial energy of node
- **E** = current energy of node
- Priority levels for packets: i.e., P1, P2, and P3
  - HPQ-1 queue = High Priority Queue for packet of priority P1.
  - HPQ-2 queue = Mid Priority Queue for packet of priority P2.

### Table 2. Algorithm of Proposed EPAS scheme

```plaintext
Proposed Algorithm

Initialize priority levels to packets
P1 for high priority
P2 for mid priority
P3 for low priority
When a bottleneck node receives a packet
{ check priority level of packet & update energy status
  if ( E > 0.7*LE)
    allow all priority packets to pass
  else if ( E >= 0.3*LE & < 0.7*LE)
    [ if (HPQ-1 || HPQ-2 queue is not empty)
      transmit packets of priority P1 and P2.
    else transmit P3 packets.]
  } else if (HPQ-1 queue is not empty)
    Allow packets of priority P1 only.
  else
    Allow packets of priority P2 or P3.
end if }
```

### IV. PERFORMANCE ANALYSIS

Performance analysis of proposed scheduling scheme in terms of data delivery probability, throughput and delay is performed in this section. Simulation of proposed scheme has been performed using NS-2.35 [19]. It is evaluated for metrics of packet delivery ratio, throughput and delay.

#### A. Simulation Setup

Simulation setup consists of 25 mobile sensor nodes placed randomly in an area of 500*500. CBR traffic is used to send data over nodes. Every sensor node uses three priority queues to place packets of priority level P1, P2, and P3 respectively. Simulation parameters used for proposed EPAS scheme are given in detail in Table 3.

### Table 3. Simulation Parameters

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Simulator</td>
<td>NS-2.35</td>
</tr>
<tr>
<td>Routing Protocols</td>
<td>AODV</td>
</tr>
<tr>
<td>Size of Network</td>
<td>500m*500m</td>
</tr>
<tr>
<td>Number of sensors</td>
<td>25</td>
</tr>
<tr>
<td>Ifq-length</td>
<td>50 packets</td>
</tr>
<tr>
<td>Packet Size</td>
<td>512</td>
</tr>
<tr>
<td>Data Type</td>
<td>CBR</td>
</tr>
<tr>
<td>Mac protocol</td>
<td>802.11</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>10-100 Joule</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>100s</td>
</tr>
<tr>
<td>Propagation</td>
<td>Two Ray Ground</td>
</tr>
</tbody>
</table>

### Table 4. Mobility Pattern files

<table>
<thead>
<tr>
<th>Mobility pattern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>mob-00</td>
<td>Mobility pattern file with zero pause time i-e continuously moving</td>
</tr>
<tr>
<td>mob-03</td>
<td>Mobility pattern with pause time = 3 sec</td>
</tr>
<tr>
<td>mob-07</td>
<td>Mobility pattern with pause time = 7 sec</td>
</tr>
<tr>
<td>mob-10</td>
<td>Mobility pattern with pause time = 10 sec</td>
</tr>
</tbody>
</table>

#### B. Packet Delivery Ratio (PDR)

Packet delivery ratio (PDR) is a measure of successful transmission rate and it is an important parameter to determine effectiveness of system. PDR of packets is denoted by P1-EPAS, P2-EPAS and P3-EPAS for high priority packets, mid level priority packets and low level priority packets. PDR is computed experimentally for all mobility scenarios mob-00, mob-03, mob-07 and mob-10 separately as shown in Fig. 2. PDR is calculated as a function of number of connections also called traffic flows. Results show that packets of highest priority P1 in proposed EPAS scheme achieves maximum data delivery for all mobility scenarios while PDR is low for low priority packets. Comparison of proposed scheme results with PQ [21] for all mobility scenarios show that proposed scheme performs better as compared to PQ. Optimum results are obtained for mobility scenario mob-07 with pause time equal to 7 sec because movement of sensor nodes is moderate. In case of mob-00 nodes are continuously moving so chances of collisions are high as shown in Fig. 2 (a). Overall results show proposed scheme achieves maximum PDR for packets of priority P1 i.e. 95-96 % while low priority packets have comparatively low data delivery ratio. Average results for all mobility patterns are given in tabulated form in Table V. Comparing values of P1 type packets in proposed scheme and PQ for mob-07 in Table V shows that proposed scheme achieves 52% improvement in PDR.

### Table 5. Average PDR of Proposed Scheme and PQ for all mobility patterns

<table>
<thead>
<tr>
<th>Priority Queue Type</th>
<th>mob-00</th>
<th>mob-03</th>
<th>mob-07</th>
<th>mob-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1-EPAS</td>
<td>92.3</td>
<td>88.33</td>
<td>95</td>
<td>93.3</td>
</tr>
<tr>
<td>P2-EPAS</td>
<td>77</td>
<td>85</td>
<td>79</td>
<td>82.6</td>
</tr>
<tr>
<td>P3-EPAS</td>
<td>71</td>
<td>66</td>
<td>55</td>
<td>69</td>
</tr>
<tr>
<td>PQ</td>
<td>25</td>
<td>31</td>
<td>43</td>
<td>22</td>
</tr>
</tbody>
</table>
C. Throughput

Throughput depends on number of packets received for a particular node, performance plot of throughput versus no. of connections for all mobility scenarios is given in Fig. 3. Highest priority packets are denoted by P1-EPAS, mid level priority packets are denoted by P2-EPAS and lowest priority packets are denoted by P3-EPAS. Throughput graphs show that proposed queuing scheme achieve different throughput for all types of priority packets. With an increase in number of connections also called traffic flow patterns throughput increases for proposed scheme. Packets of type P1 have maximum throughput as compared to low priority packets and PQ in all mobility scenarios. Mobility pattern mob-07 achieves best results for throughput as compared to other mobility scenarios while mob-03 scenario performs better as compared to mob-00 because in mob-00 sensor nodes are continuously moving so chances of collisions are more. Overall results show that proposed scheduling scheme performs better as compared to PQ scheduling while highest priority packets P1 achieve maximum throughput.

D. Average Delay

Table 4 shows average delay computed for proposed scheduling scheme and PQ for all mobility patterns. It shows that proposed scheme gives minimum delay of 0.01sec for mob-00 and maximum value of 8.6sec for mob-10 with 6.99sec average delay for all mobility patterns. Comparison of average values of proposed scheduling scheme and PQ shows it gives 5.16sec decrease in delay.

In Fig. 4 simulation results are shown in graphical form, it is a plot of average value of delay for all mobility patterns where each mobility pattern is simulated by varying no. of connections. Fig. 4 shows that average delay is minimum for highest priority packets i.e. P1 while for low priority packets delay is more for proposed scheduling scheme. PQ gives low value of delay in case of mob-00 while for remaining scenarios it gives high delay values. Thus overall simulation results show that proposed schemes gives better results as compared to PQ scheduling in terms of PDR, throughput and delay and avoids bottleneck problem by sending highest priority packets in case of extreme low battery conditions.

![Fig. 2 Packet delivery ratio for all mobility patterns.](image)

(a) PDR as a function of No. of connections for mob-00.

(b) PDR as a function of No. of connections for mob-03.

(c) PDR as a function of No. of connections for mob-07.

(d) PDR as a function of No. of connections for mob-10.
V. CONCLUSION AND FUTURE WORK

In this paper, a new scheduling scheme considering energy and priority marking for bottleneck nodes is proposed for WSNs. It is proposed as a solution to bottleneck node problem for WSNs. Proposed scheduling scheme is designed to satisfy QoS needs of a network in terms of priority marking while energy constraints are satisfied using threshold. It avoids bottleneck node problem by dropping low priority packets if energy is critically low but transmission of high priority packets is maintained. This is the main advantage of this scheme that it utilizes energy resources intelligently.

Proposed scheme has been implemented using NS-2. Performance is evaluated based on various metrics including PDR, throughput and delay under different mobility scenarios. Experimental results show that proposed scheme gives PDR of 96%, throughput of 2.785 Kbits/sec and minimum delay of 0.01 sec for highest priority packets i.e. of type P1. PQ achieves PDR of 43 %, throughput of 2.476 Kbits and minimum delay of 3.99 sec for same simulation scenarios. Thus the proposed scheme out performs PQ in terms of packet delivery ratio, throughput and delay. Through detailed simulation analysis, it can be concluded that the proposed scheme gives promising results in a dense wireless deployment, minimize chances of bottleneck node development and improves overall network performance. The proposed scheme implementation for Destination Sequenced Distance Vector (DSDV) and Dynamic Source Routing (DSR) can be investigated as a future work. Implementation as a real time scenario is another milestone envisaged in near future.

REFERENCES


