Chapter 7

Implementation of Prioritized MAC

7.1 Introduction

Chapter 6 covers the details of proposed IPCAP and EPCAP protocols. Both the protocols configure the MAC layer parameters based on information they receive from the application layer. To verify the working of IPCAP and EPCAP, we have implemented both the protocols in Qualnet Network simulator. This chapter covers the implementation details of our protocols. It shows the conceptual representation of both the protocols in CLAPDAWN architecture. Further, major results that we have found in the course of simulation of both the protocols are shown in this chapter.

7.2 Implementation

Figure 7.1 shows framework for our implementation. Application layer provides priority information to control interface. MAC layer provides the channel and beacon details to control interface. On arrival of events application layer generates the message and puts priority information in control interface. This will trigger the event in control interface and it propagates them to execution engine. On getting events, execution engine fetches rules from rule base and executes them. Here rule base contains rules for implicit priority mechanism and explicit priority mechanism.
7.2 Implementation

7.2.1 IPCAP implementation

Implicit priority rules contain the information about the parameters of CSMA-CA algorithm. Using this information execution engine generates the messages to set the parameter at MAC layer. It puts these messages into notification layer. Notification layer sends these messages to MAC layer, which at the end updates its parameters.

7.2.2 EPCAP implementation

Explicit priority rules contain the information about the secondary beacon. Execution engine gets this information and generates the messages to send secondary beacon. It puts these messages into notification layer. Notification layer sends these messages to MAC layer, which at the end sends the secondary beacon.

At the coordinator node priority rule generates the messages for energy scan. Execution engine puts these messages on notification layer, that triggers the MAC layer to go for energy scan for each priority slot. After energy scan the detected energy readings are updated on CNI, based on which the execution engine decides the priority level for the
In IPCAP and EPCAP, MAC layer is itself not deciding about CSMA-CA parameter or secondary beacon. In IPCAP it configures the CSMA-CA parameter and in EPCAP it transmits the secondary beacon based on the notification messages received from notification layer. The knowledge base and the inference engine control the overall working. That makes the conventional layer mechanism untouched from the cross layer implementations.

### 7.3 Simulation Results

#### 7.3.1 IPCAP

QualNet is a network simulator from scalable network technology. We have implemented IPCAP protocol in QualNet and compared it with the standard IEEE 802.15.4 MAC protocol. Both the protocols are evaluated considering different network conditions. In our simulation we have changed network traffic and one hop neighbor density. With these network conditions we have compared IPCAP and standard protocol for packet delivery, prioritized packet delivery, throughput and energy consumption. In all the cases we have considered network as star topology with percentage of nodes rounded to the nearest integer value. Following subsections highlight our major findings.

**Packet delivery ratio**

The proposed prioritized protocol works with application specific prioritized classes. A network node defines its class based on application data. Nodes belonging to high priority class should get higher chances of getting channel than nodes with lower priority classes. In our simulation we have considered five priority classes. Each priority class comes with the set of CSMA-CA parameters defined in chapter 6. Node selects its priority class based on application layer specification.

To analyze the packet delivery ratio of different priority classes, we have tested our network by varying the number of one hop neighboring nodes and network traffic. Each priority class generates the same amount of packets in the network. Figure 7.2 shows
simulation results for one hop contending nodes ranging from 5 nodes to 25 nodes. In the result, X-axis represents the network traffic and Y-axis represents the packet delivery ratio. In our simulation we have increased network traffic from 0.4 Kbps to 51.2 Kbps. Here each packet consists of 50 bytes.

Figure 7.2(a) shows the simulation result for the network having 5 nodes as one hop neighbor nodes. Simulation result shows that set 1 which represents the priority class 1 has higher packet delivery ratio than the other priority classes. Priority class 1 is getting more chances of sending packets. So it has higher packet delivery than the other priority classes. Next we have priority class 2, which has packet delivery less than the priority class 1 and greater than the priority class 3, 4 and 5. As priority class 2 gets more chances of packet access than the priority class 3, 4 and 5 it has higher packet delivery than the priority class 3, 4 and 5. But, it has lower chances of channel access than the priority class 1 so its packet delivery count is less than the priority class 1. Priority class 3, 4 and 5 follow the same pattern.

Figure 7.2(a) shows that as the network traffic increases the number of packets delivered increases for each priority class. As the traffic increases, soon the network reaches its limit (transition point) and gets congested. After that the network nodes start dropping packets. This decreases the packet delivery in the network. This particular pattern can be seen in all the simulation results from figure 7.2(a) to 7.2(e). As number of nodes increases this transition point shifts from high traffic to low traffic.

**Prioritized packet delivery**

Figure 7.3 and 7.4 show the next set of simulation results. It covers the result for prioritized packet delivery in given priority class. The previous set of results shows how nodes falling in same priority class compete for the channel. There, the high priority class has more success in channel access compared to low priority class and all the priority classes have same number of nodes. Here, we analyze the packet delivery ratio of nodes for network having two priority classes. Lower priority nodes are considered as normal nodes and higher priority nodes are considered as prioritized nodes. In simulation we
7.3 Simulation Results

Figure 7.2: Packet Delivery Ratio for Different Priority Classes
have analyzed the effect of prioritized nodes on the normal nodes. We also analyzed the effect of increasing the number of nodes in the given priority class.

To analyze the prioritized packet delivery of different priority classes, we have tested our network with varying one hop neighboring nodes and network traffic. Each node in given priority class delivers the same number of packets in the network. We have tested our network for 10 and 15 one hop neighbor nodes. With increasing traffic we have measured the packet delivery ratio on Y-axis.

Figure 7.3 and 7.4 show the simulation results for the prioritized packet delivery for 10 and 15 one hop neighbor nodes respectively. We have increased the number of nodes in higher priority class from 10% to 50% and measured the effect of it on packet delivery ratio. Simulation result 7.3(a) shows that as the number of nodes increases in the given priority class, the packets delivered in that priority class decreases. Result shows that from given set of nodes when 10% nodes are falling in priority class, it has higher packet delivery than the case in which network has 30% priority nodes. As the number of nodes increases in given priority class the more nodes will contend for priority slot and that decreases the packet delivery of the given priority class. But these priority class nodes get more chances of packet delivery than the normal nodes. This increases overall packet delivery ratio.

For better clarity we have compared the prioritized delivery results with normal nodes. Figure 7.3(b), 7.3(c) and 7.3(d) cover the simulation results with different number of prioritized and normal nodes in 10 one hop contending nodes. As seen in the result as the number of nodes in given priority class increases, the number of packets delivered in that priority class decreases but it still remains more than the normal nodes. Further the difference between the packets delivered in prioritized class and all network nodes decreases. And this pattern repeats for 30% and 50% prioritized nodes.

The result 7.3(b) shows the packet delivery of 10% prioritized nodes with the normal node. With 10% priority nodes, the difference between higher priority nodes and lower priority nodes is less. Here majority of the nodes work as normal nodes and the effect of it is visible in the results. Packet delivery ratio of network having no priority nodes
Figure 7.3: Prioritized Packet Delivery Ratio for 10 one Hop Nodes
7.3 Simulation Results

Figure 7.4: Prioritized Packet Delivery Ratio for 15 one Hop Nodes
and packet delivery ratio of normal nodes for the network having 10% priority nodes are close to each other. Further less number of nodes are in higher class so it has higher packet delivery ratio. But as the number of priority nodes increases in the network, this difference increases as shown in figure 7.3(c) to 7.3(d) and 7.4(b) to 7.4(d).

**Energy in priority class**

Next set of results given in 7.5 shows the per bit energy consumption in given priority class. In this set of results we have compared per bit energy consumption by a node in a given priority class. We have tested our network with 10 and 15 one hop neighbor nodes. In results, X-axis represents the network traffic and Y-axis represents per bit energy consumption in milli Joules. In our simulation, we have increased network traffic from 400 bps to 51.2 Kbps. With this increasing traffic we have measured the per bit energy consumption on Y-axis.

Figure 7.5 and 7.6 show the simulation results for the per bit energy consumption in given priority class for one hop neighbor density of 10 nodes. We have increased the number of nodes in given priority class from 10% to 50% and measured the effect of it on per bit energy consumption. Simulation result 7.5(a) shows that as the number of nodes increases in the given priority class the packet delivered in that priority class decreases. That increases the wait time and number of packet transmission attempts for the nodes, which leads to higher energy consumption for the nodes. Result shows that from given set of nodes when 10% of the nodes are higher priority nodes, network has higher packet delivery and with 30% nodes it has less packet delivery ratio. Because of it 10% nodes have lesser per bit energy consumption than the case in which network has 30% priority nodes.

Further figures 7.5(b) 7.5(c) and 7.5(d) show the simulation results comparing energy consumption between prioritized nodes and normal nodes. Result shows that the prioritized nodes consume less energy compared to normal nodes. It also shows that normal nodes or low priority nodes have higher energy consumption than the overall energy consumption. This difference decreases as the number of priority nodes increases in
7.3 Simulation Results

Figure 7.5: Per bit Energy Consumption by Nodes with 10 Nodes
7.3 Simulation Results

Figure 7.6: Per bit Energy Consumption by Nodes with 15 Nodes
the network because of low energy consumption of the higher priority nodes, the overall average energy consumption decreases.

Result shows that with the increase in traffic, the overall energy consumption also increases. Overall energy consumption and prioritized energy consumption follow the same trend. As the traffic increases the energy consumption increases. As we will see in the throughput result that network throughput increases as the traffic increases. For 10 one hop nodes, throughput increases upto 12.8Kbps and then it starts decreasing. This effect is also visible in energy results. Here, network has capacity upto 12.8Kbps, and it uses it to transmit prioritized data. That increases the energy consumption of prioritized nodes and decreases the energy consumption of normal nodes. After the 12.8Kbps transition point the network has traffic more than its capacity and that increases the energy consumption for all the nodes.

Throughput

Next set of simulation results are of throughput. Figure 7.7 shows the throughput results for the priority class 1 to 5. To analyze the throughput of packet delivery of a given priority class, we have tested our network with varying one hop neighboring nodes and network traffic. Each node in given priority class delivers the same number of packets in the network. We have tested our network with one hop neighbors ranging from 5 nodes to 25 nodes. In each simulation result, X-axis represents the network traffic and Y-axis represents the throughput in bytes. In our simulation, we have increased network traffic from 400 bps to 51.2 Kbps. With this increasing traffic we have measured the throughput in bits/second on Y-axis.

Figure 7.7 shows the simulation results for the throughput in bits/second for 5 to 20 one hop neighbor nodes. Result shows that class one achieves the highest throughput among all the priority classes. As result shows the throughput increases up to traffic 12.8Kbps and then it starts decreasing. Energy result also reflects the same results.

In chapter 6 we have gone through the modeling of IPCAP. We have modeled IPCAP as two dimensional Markov chain and derived equation for various parameters. In Table
Figure 7.7: Throughput for Different Priority Classes
7.3 Simulation Results

7.1 we have compared the throughput results derived analytically with the simulation results. Table shows our simulation result varies by approximately 10% with the numerical results.

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Analytical</th>
<th>Simulation</th>
<th>diff</th>
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<td>8.2%</td>
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<td>7405</td>
<td>7380</td>
<td>11.0%</td>
</tr>
<tr>
<td>10</td>
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<td>7380</td>
<td>9.4%</td>
<td>10</td>
<td>7246</td>
<td>7225</td>
<td>9.1%</td>
</tr>
<tr>
<td>15</td>
<td>7049</td>
<td>7028</td>
<td>9.1%</td>
<td>15</td>
<td>6625</td>
<td>6647</td>
<td>9.7%</td>
</tr>
<tr>
<td>20</td>
<td>3822</td>
<td>3799</td>
<td>10.0%</td>
<td>20</td>
<td>3629</td>
<td>3605</td>
<td>10.3%</td>
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</table>

(a) Class 1

(b) Class 2

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<th>diff</th>
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<th>Analytical</th>
<th>Simulation</th>
<th>diff</th>
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</thead>
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<td>5</td>
<td>6543</td>
<td>6526</td>
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<tr>
<td>10</td>
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<td>6980</td>
<td>7.4%</td>
<td>10</td>
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<td>6078</td>
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</tr>
<tr>
<td>15</td>
<td>5812</td>
<td>5789</td>
<td>10.2%</td>
<td>15</td>
<td>5342</td>
<td>5326</td>
<td>6.8%</td>
</tr>
<tr>
<td>20</td>
<td>2994</td>
<td>2969</td>
<td>10.7%</td>
<td>20</td>
<td>2873</td>
<td>2895</td>
<td>9.5%</td>
</tr>
</tbody>
</table>

(c) Class 3

(d) Class 4

<table>
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<th>Analytical</th>
<th>Simulation</th>
<th>diff</th>
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</thead>
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<td>5</td>
<td>6242</td>
<td>6225</td>
<td>7.3%</td>
</tr>
<tr>
<td>10</td>
<td>5349</td>
<td>5326</td>
<td>9.8%</td>
</tr>
<tr>
<td>15</td>
<td>4896</td>
<td>4881</td>
<td>6.8%</td>
</tr>
<tr>
<td>20</td>
<td>2576</td>
<td>2598</td>
<td>9.5%</td>
</tr>
</tbody>
</table>

(e) Class 5

Table 7.1: Throughput Results Analytical and Simulation for Class-1

In this section we have gone through simulation results of IPCAP. Our study shows that IPCAP derives higher delivery ratio for the prioritized nodes that increases the delivery ratio of critical events. Other supporting results are also shown with the packet delivery ratio results. We have also compared the simulation results with the analytical results. Comparison shows that simulation results varies by approximate 10% with the analytical results.
7.3 Simulation Results

7.3.2 EPCAP

Packet delivery

Figures 7.8 shows the simulation results for packet delivery ratio. In the result, X-axis shows the traffic intensity, and Y-axis shows the packet delivery ratio. We have tested our scheme from very low traffic to high traffic conditions. Here packet delivery ratio gives the fraction of packets delivered to coordinator nodes. Result shows that standard has low packet delivery ratio than the prioritized approach.

We have tested this simulation result for the networks having 10, 15, 20 and 25 one hop neighboring nodes. For each configuration we have tested the network by increasing the number of prioritized nodes in the network. Because prioritized scheme controls the number of nodes contending for the channel. It reduces the number of contenders for each slot which increases the packet delivery in prioritized mechanism.
7.3 Simulation Results

Result shows that as the traffic increases, the delivery ratio decreases for the nodes. The delivery ratio depends on number of nodes. As the number of nodes increases in the prioritized case the delivery ratio decreases. In all the cases simulation result shows that prioritized scheme has high packet delivery count.

Prioritized packet delivery

For EPCAP, second set of results are of prioritized packet delivery in given priority class. Previous result shows the comparison between average common delivery and prioritized delivery. There, comparison was between the network having all nodes of same priority level with network having some nodes as higher priority nodes. With priority scheme, we have two types of nodes in the network one with the higher priority and the other with the normal priority or low priority. Previous result shows that the network with higher priority nodes have higher delivery ratio as the contending nodes are less in given slot. But increased delivery comes at the cost of low packet delivery of normal nodes. Following set of result shows the comparison between average delivery of prioritized nodes and average delivery of normal nodes.

Figure 7.9: Packet Delivery Ratio for 10 one Hop Nodes with 30% and 50% nodes are prioritized nodes

Figure 7.9 shows the result for prioritized packet delivery in given priority class. These results show the comparison between average delivery of prioritized nodes and average delivery of normal nodes. Simulation result 7.9(a) shows that priority scheme (Prioritized
case, All nodes) has higher packet delivery ratio than the network having all the nodes of same priority level, same is discussed in previous subsection 7.3.2. Here, network has 30% prioritized nodes and rest of the nodes are normal nodes. As result shows that increase in delivery ratio of prioritized nodes comes at the cost of normal nodes. Same pattern is there in result 7.9(b) showing 50% prioritized nodes, here the difference between the prioritized and normal nodes is smaller compared to 30% nodes. Increase in average packet delivery of prioritized nodes helps in improving the results of overall packet delivery.

Queue length and delay

Next simulation results show the average queue length and delay experienced by the network. Figure 7.10 shows the average queue length result for the 10 one hop neighboring nodes. Figure 7.10(a) shows the queue length result with 30% prioritized nodes and figure 7.10(b) shows the queue length result for 50% prioritized nodes. The result shows that the prioritized nodes have smaller queue length compared to other scenarios. Here, the prioritized nodes are getting higher chances for their packet delivery that helps in reducing the queue length of prioritized nodes. Prioritized nodes get their chances at the cost of normal nodes. That increases the queue length of the normal nodes and the over all average queue length.

![Graph showing queue length and delay](image)

(a) 30% Prioritized Nodes  
(b) 50% Prioritized Nodes

Figure 7.10: Average Queue Length at Node with 10 one Hop Nodes

Figure 7.11 shows the average waiting time result for the network having 10 one hop neighbor nodes. Figure 7.11(a) shows the waiting time result for 30% prioritized nodes
and figure 7.11(b) shows the waiting time results for the 50% prioritized nodes. The result shows that prioritized nodes have smaller waiting time in the queue than the other cases. Here network achieves the smaller waiting time for the prioritized nodes on the cost of higher waiting time for the normal nodes, that increases the overall waiting time of the network. With prioritized nodes the average waiting time that the network achieves is higher than the waiting time without any prioritized nodes.

![Graph showing waiting time for different prioritization cases](image)

(a) 30% Prioritized Nodes  
(b) 50% Prioritized Nodes

Figure 7.11: Average Waiting Time at Node with 10 one Hop Nodes

In this section we have gone through the simulation results achieved for EPCAP. Next we have compared simulation results with the analytical results. In chapter 6 we have modeled EPCAP as M/G/c model. Model gives system of linear equations. Using IPCAP results and system of linear equation we have derived value of queue length for priority classes. This section shows comparisons between analytical results and the numerical results. It shows that both the results are varying upto 12%. Following table shows our comparison.
7.4 Summary

Table 7.2: Queue Length Results Analytical and Simulation for EPCPA with 50% privatized nodes

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Simulation</th>
<th>Analytical</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Prioritized</td>
<td>Normal</td>
</tr>
<tr>
<td>0.4</td>
<td>33</td>
<td>27</td>
<td>37</td>
</tr>
<tr>
<td>0.8</td>
<td>40</td>
<td>26</td>
<td>42</td>
</tr>
<tr>
<td>1.6</td>
<td>52</td>
<td>24</td>
<td>58</td>
</tr>
<tr>
<td>3.2</td>
<td>154</td>
<td>26</td>
<td>169</td>
</tr>
<tr>
<td>6.4</td>
<td>257</td>
<td>29</td>
<td>280</td>
</tr>
</tbody>
</table>

(a) 15 Nodes

We have simulated IPCAP and EPCAP in Qualnet network simulator provided by Scalable network technology. The chapter covers our major simulation results. Here main emphasis is on critical event delivery. Results show that both the protocols deliver more number of prioritized packets to the base station than the standard. That indicates that IPCAP and EPCAP increase the delivery chances of critical events in event driven wireless sensor networks. Furthermore key performance parameters are discussed both for analytical and numerical results.