CHAPTER 3

PRIORITY BASED ENERGY EFFICIENT HYBRID MAC PROTOCOL FOR EMERGENCY APPLICATION OF WSN

3.1 INTRODUCTION

Wireless Sensor Network (WSN) is an application driven design determined by the requirements of network behavior (Yick et al 2008). Recent developments in MEMS and wireless technology enabled the wireless sensor network for emergency applications, such as building fire monitoring, health care applications and disaster relief applications (Chen et al. 2003). For this type of application, the network must be topology adaptive and the algorithm used for communication should be delay tolerant and energy efficient during normal periodic monitoring (Pan MS et al 2006). In order to transmit data during the emergency conditions in an energy efficient manner and with minimum delay communication protocols play a vital role. Many MAC protocols are designed for wireless sensor network but the performance of these protocols are degraded during the emergency conditions (Yigitel MA et al. 2011).

Hence, to handle the emergency situation of wireless sensor network, the energy efficient hybrid MAC protocol (EE-MAC) is proposed in this chapter. The proposed protocol uses the priority scheme for the messages in order to reduce the delay of packet transmission during the emergency situations. The combination of schedule based protocols TDMA and FDMA
are used for channel allocation and for improved channel utilization. Moreover, this protocol takes advantage of multiple frequencies provided in recent WSN hardware platforms and it gives high packet delivery ratio and good energy efficiency. This protocol is highly emphasized due to its qualities like high packet delivery ratio, bounded end-to-end delay across multiple hops, collision free operation and increased lifetime. The next section provides a brief review of literature of MAC protocols for wireless sensor network during emergency conditions.

3.1.1 Related Work

Normally, the applications like real-time streaming of voice and video requires comparatively maximum throughput, high bandwidth utilization and bounded end-to-end delay of few milliseconds. Emergency applications such as building fire monitoring, disaster relief applications require minimum delay, less energy consumption and maximum packet delivery ratio. All these design constraints should be achieved with available sensor node limited resources. Thus, the design of energy efficient Medium Access Control (MAC) protocols for wireless sensor network has become a more challenging task and results in a very different design trade-off than other wireless network. In order to reduce the collision in channel access and to enable simultaneous data transmission, multiple channels are used (Kim Shin & Cha 2008).

By combining the advantages of TDMA and FDMA the hybrid MAC (HyMAC) protocol (Salajegheh et al. 2007) achieves better channel utilization, maximum throughput and minimum end-to-end delay. With the help of HELLO messages, the base station collects the details of all nodes and then assigns time slot and frequency slot using BFS scheduling algorithm. However, this protocol does not support the emergency situations since it gives equal priority to all nodes.
The priority concept is used in the I-MAC (Intelligent hybrid MAC) protocol (Ines Slama et al. 2010) for better channel utilization and energy efficiency. In this protocol, the advantages of CSMA and TDMA channel accessing schemes are combined with priority scheme. Like Z-MAC (Rhee et al. 2008) protocol, it discovers the neighbor and uses DNIB (Distributed Neighborhood Information Based algorithm) algorithm for slot allocation (Slama et al 2008). With known AIFS (Arbitrary Inter Frame Space) value and CW (Contention Window) size, priorities are assigned to the nodes during transmission phase in proportion to the topological changes. During emergency conditions, more number of users will try to transmit data and in this case the TDMA used in I-MAC do not yield better channel utilization.

In EP-MAC (Arifuzzaman & Matsumoto 2012) parallel transmission is combined with TDMA link scheduling. To enable the multiple transmissions simultaneously the parallel transmission concept that utilizes RTS and CTS are used (Ammar et al. 2010). To enhance the energy efficiency further, adaptive transmission power control concept (Gomez et al. 2001) is utilized. To handle the problems of clock drift and error due to synchronization, data slot length is selected as greater than the required period. The nodes having more messages in the queue are given higher priority than the nodes with minimum messages and according to priority the contention window size is adjusted. But the parallel transmission will yield poor results during emergency conditions due to heavy traffic.

3.2 PROPOSED EE – MAC PROTOCOL DESIGN

For channel accessing, the proposed EE-MAC protocol combines the merits of TDMA and FDMA. This allows the nodes to transmit data simultaneously in a collision free manner. The concept of priority mechanism is used to handle emergency conditions. This feature enables the fast data
transmission of nodes that are involved in emergency scenario. All these features allow the network to operate in an energy efficient manner.

The performance of EE-MAC is independent of underlying synchronization protocol, however we believe that the proposed protocol performs well in WSN platforms such as FireFly (Rowe A et al. 2006) in which out of band hardware synchronization is used. In FireFly, the nodes use 2 different time synchronizing modules: AM/FM time sync module for indoor environment and WWVB receiver for outdoor environment. The time synchronizing module detects the periodic sync pulse and triggers an input pin in the microcontroller which updates the local time. The WWVB receiver module consumes 0.6mA while active and 5µA when powered off. The synchronization energy cost of single chip AM receiver is one tenth the energy of sending/receiving in band packet. The software based synchronization protocols such as RBS (Elson et al. 2002), TPSN (Ganeriwal et al. 2003) and FTSP (Marótí et al. 2004) are not used here because of degraded network performance due to their high link error rate, even when the received signal strength is above threshold.

EE-MAC operates in two phases: a setup phase and a transmission phase. During the set-up phase the following operations take place.

- Neighbor discovery
- Local framing
- TDMA and FDMA slot assignment
- Global synchronization

These operations run during the set-up phase and for topological changes like new node joining, old node leaving and node position change. Each node runs the neighbor discovery operation in order to find out its one-
hop and two-hop neighbors in the network. After collecting neighbor information, the number of time slots used is calculated. Periodically these slots are reused by nodes in a predetermined period called Local frame. The collected neighbor information is very much useful for time slot and frequency slot assignment. The time slot is allocated for each node such that no two nodes are assigned with same time slot within two hop distance. The frequency slot is assigned to each node such that the siblings should have same frequency slot. For slot assignment, NSAA (Node Slot Assignment Algorithm) scheduling algorithm is used. After the local frame and scheduling, the Global synchronization is done.

3.2.1 Neighbor Discovery

During the neighbor discovery phase all nodes collect the details of their one-hop and two-hop neighbor list. For this the protocol uses HELLO message. All nodes will broadcast one HELLO message. If any node hears a HELLO message from any other node in its one hop distance, it adds that node to its neighbor list. The updated neighbor list is included in the next HELLO message sent by that node. Based on the HELLO messages received from all nodes, the base station creates the schedule. The structure of the HELLO message is shown in Figure 3.1. Here, the type field specifies the type of the node and priority field is used to indicate the priority requested by the node. The third and fourth fields are used to specify the source and destination addresses. Length of the packet is specified by the Length field and the number of hops required to reach the base station is given by hop field. The list of one-hop and two-hop neighbors is included in the neighbor list field.
3.2.2 Local Framing

The TDMA slot size is fixed for given application. The maximum size of the time slot is calculated based on one packet propagation time, the time taken to receive the acknowledgement if the transmission is success, the sum of minimum and maximum contention window size. After the scheduling of time and frequency slot, the size of TDMA frame is to be selected. The TDMA frame size is selected in order to enable the time slot reuse in a collision free manner. The maximum number of time slots can be calculated by using the following formula.

\[ N_t = \text{ceiling} \left( \frac{T}{P_t + G_t} \right) \]  

(3.1)

where \( N_t \) is the number of time slots, \( T \) is the total time period of the TDMA frame and \( P_t, G_t \) represents packet transmission time and guard time respectively. This time frame size only decides the number of time slots to be used. The local frame of the node is equal to \( 2^n \). Let \( TS_{\text{ass}} \) be the assigned slot for a node within two-hop neighborhood of a node. This assigned slot should satisfy the Equation (3.2).

\[ 2^{n-1} \leq TS_{\text{ass}} \leq 2^n \]  

(3.2)

This enables the nodes to reuse the assigned time slot for each \( 2^n \) slots without collision between two-hop neighbors. This local frame approach...
allows the scheduling scheme adaptive to topological changes and thus increases the channel utilization of proposed protocol.

3.2.3 Node Slot Assignment Algorithm: NSAA

The time slot and frequency slots are assigned to the nodes using the scheduling algorithm NSAA. This scheduling algorithm will provide higher throughput, low end to end delay and lower energy consumption. Based on the neighbor list sent by the nodes, the base station will construct the network connectivity graph. The operation of scheduling algorithm is described below. During slot assignment, two types of collisions are possible and are referred as primary and secondary conflicts. When a node performs more than one function at a time then the primary conflict will occur. For example, if a node is performing transmission and reception simultaneously then it leads to primary conflict.

When one node interferes with the transmission of another node, a secondary conflict will occur. Based on these 2 definitions, two nodes are said to be in conflict if and only if they transmit simultaneously. Conflict will occur more in link scheduling and demands attention in broadcast scheduling. The slot assignment problem is assigning slot to all nodes in such a way that no two nodes within two-hop distance should have same time slot. The operation of NSAA scheduling algorithm is described by the flowchart and is given in Figure 3.2. First the algorithm performs the Depth First Search (DFS) by considering the base station as root and constructs a tree. Here, DFS is preferred because it requires less memory space. Then each node is assigned with a time slot and frequency slot in random manner. Then the possibility of interference in one hop and two hop neighbors is checked. If two nodes ‘x’ and ‘y’ are having interference, then the algorithm checks whether they are siblings or not. In tree architecture, two nodes are said to be siblings if they belong to same parent. If the interfering nodes are siblings, then different time
slots are allotted for them because siblings can’t perform transmission to same parent in the same time slot. If the condition is not satisfied (i.e.) for non-siblings, different frequency slots are assigned. Thus, sibling concept is used to overcome the possibility of interference in EE-MAC protocol.

![Flow diagram of NSAA scheduling algorithm](image)

**Figure 3.2 Flow diagram of NSAA scheduling algorithm**

Once the algorithm completes this scheduling for all nodes the time slots allotted to them will be inverted using the Equation (3.3).

\[ t_{\text{new}} = t_{\text{max}} - t_{\text{current}} + 1 \]  

(3.3)
Time slot inversion is done such that parent will have the higher time slot number than the child. This allows the parent to collect the data from child and undergo data transmission. The pseudo code of the scheduling algorithm is given in Figure 3.3.

Figure 3.4 shows the example of scheduling algorithm used in EE-MAC. Here three frequencies and seven time slots are used. During the slot assignment phase itself, the priority is also assigned based on the request given by the nodes in HELLO message. Here, a network of ten nodes is constructed and one node is considered as base station. After tree topology creation, the time and frequency slots are assigned from root to leaf node. After completing first leaf, second one is considered and this step is continued, until all nodes are assigned with schedule. Here the schedules (2, 2), (3, 2) are siblings and are having different time slots.

```
NSAA (G)
graph G=(V,E)
unmark all nodes
list L=empty
tree T= empty
for each (v,w) ϵ E do
while (L non empty)
take first node of L
if w not yet visited
   add (v,w) to T
   assign time slot and frequency slot
   remove edge (v,w) from end of L
else
   traverse Non Tree Edge (v, w)
end if
end while
for all visited nodes of network do
if time slot(v)=time slot(n) and frequency slot(v)=frequency slot(n) then
   if parent(v)=parent(n)
      time slot(v) = time slot(n) + 1
```
else
    frequency slot(v) = frequency slot(n) + 1
end if
end if
do time slot inversion
end for
end for

Figure 3.3 Pseudo code of NSAA algorithm

Figure 3.4 Example of NSAA scheduling algorithm

3.2.4 Global Synchronization

Once local framing is completed, global synchronization is set-up. For doing this each node starts its time slot 0 at the same time. This is achieved by setting the starting period of slot 0 to the starting of real time. This global synchronization is done once at the set-up phase only. After completing the set-up phase, the assigned time slot and frequency slots are broadcasted to all nodes using schedule packet. Thus, each node knows their two-hop neighbor schedule. All nodes will run the local synchronization during the transmission phase. The format of schedule packet is shown in Figure 3.5. The Priority field specifies assigned priority to node and schedule field carries the time and frequency slots assigned to nodes.
3.2.5 Priority scheme

Based on the assigned priority, the contention window (CW) size and AIFS (Arbitration Inter Frame Space) value are adjusted. The node having higher priority is given with smaller values of AIFS and CW. During the emergency condition, the nodes having lower priority can contend for channel and get maximum priority. At this time, the free slots are assigned to the requesting nodes with higher priority. Suppose the slots are not free, then nodes will select the random back off timer and contend after the expiration of timer. Randomly back off timer value is selected between 0 and CW (contention window). The CW value is assigned to a minimum at first transmission and is gradually increased to maximum value in the successive transmissions. The maximum value of CW is given by the Equation (3.4).

$$CW_{\text{max}} = 2^n CW_{\text{min}}$$ (3.4)

**Table 3.1 Different Priority levels**

<table>
<thead>
<tr>
<th>AIFS value</th>
<th>CW_{\text{min}}</th>
<th>Priority level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CW_0</td>
<td>3</td>
</tr>
<tr>
<td>CW_0</td>
<td>(CW_x + 1) / 3</td>
<td>2</td>
</tr>
<tr>
<td>CW_0</td>
<td>(CW_x + 1) / 2</td>
<td>1</td>
</tr>
<tr>
<td>CW_0</td>
<td>(CW_x + 1)</td>
<td>0</td>
</tr>
</tbody>
</table>
If the channel is free after the expiration of back off timer, then the node will start transmission using the data packet. Different levels priority and the corresponding AIFS, CW values are given in the Table 3.1.

Priority level 3 (higher priority) is given to the owner node of the slot and the remaining priority levels are given to the non-owner nodes of the slot. According to the requirements and constraints faced by the nodes, the priority is assigned to them and is shown in Figure 3.6. This shows that the nodes having higher priority are assigned with shorter contention window size compared with low priority nodes. Due to the changes in the network, the responsibility of the node may vary. Therefore, the priority scheme must be able to dynamically adapt to the network changes.

An optimal solution is to make nodes auto attribute its own priority level. This priority can be fixed based on some statistics collected by nodes during their lifetime which includes forwarding load, the distance to the base station, the remaining battery charge etc.

Figure 3.6 Priority based channel access in EE-MAC
The format of data packet used in EE-MAC is shown in Figure 3.7. Here, all the fields are same as hello and schedule packet except data field that carries the information.

![Figure 3.7 Data packet format of EE-MAC](image)

### 3.3 PERFORMANCE EVALUATION

Simulation is one of the important technologies in modern time. The simulation in computer can model hypothetical and real-life objects on a computer so that it can be studied. The network is also simulated on the computer. A network simulator is a technique of implementing the network on the computer. Through this the behavior of the network is calculated either by network entities interconnection using mathematical formulas, or by capturing and playing back observations from a production network.

The Network Simulator provides an integrated, versatile, easy-to-use GUI-based network designer tool to design and simulate a network. Network simulator allows the researchers to test the scenarios that are difficult or expensive to simulate in real world. It is particularly useful to test new networking protocols or to changes the existing protocols in a controlled and reproducible environment. One can design different network topologies using various types of nodes (hosts, hubs, bridges, routers and mobile units etc.). In this work NS-2 simulator is used for simulation.
3.3.1 NS-2 (Network Simulator version 2)

NS-2 is a discrete event simulator targeted at networking research (Fall 2001). It provides support for simulation of TCP, routing, and multicast protocols over all network (wired and wireless). The NS-2 simulation environment offers great flexibility in investigating the characteristics of sensor network because it already contains flexible models for energy-constrained wireless ad hoc network. In this environment a sensor network can be built with many of the same set of protocols and characteristics as those available in the real world. The mobile networking environment in NS-2 includes support for each of the paradigms and protocols. The wireless model also includes support for node movement and energy constraints.

NS-2 has many and expanding uses including:

- To evaluate the performance of existing network protocols.
- To evaluate new network protocols before use.
- To run large scale experiments not possible in real experiments.
- To simulate a variety of IP network.

Due to salient features of NS-2, it is used for simulation of EE-MAC. The simplified user’s view of NS-2 is shown in Figure 3.8. The data link layer of existing NS-2 package is modified to incorporate proposed MAC protocol. The overall performance of EE-MAC is evaluated in terms of energy consumption, delay and packet delivery ratio. For analysis purpose, the simulation results of EE-MAC are compared with performances of existing conventional MAC protocols EP-MAC and I-MAC. The scenario is
created for 100 nodes using random deployment. Parameters used in the simulation of EE-MAC are summarized and is given in the Table 3.2.

(Source: Pan & Jain 2008)  
Figure 3.8 Simplified user's view of NS-2

The simulation is carried out by varying number of packets generated, number of nodes in the network and by changing the packet size. All these scenarios are described in three different cases.

Table 3.2 Simulation parameters of EE-MAC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio propagation model</td>
<td>Ground wave propagation</td>
</tr>
<tr>
<td>Radio propagation range (m)</td>
<td>25-30</td>
</tr>
<tr>
<td>Transmit power</td>
<td>36 mW</td>
</tr>
<tr>
<td>Receive power</td>
<td>14.4 mW</td>
</tr>
<tr>
<td>Traffic type</td>
<td>CBR</td>
</tr>
<tr>
<td>Topology</td>
<td>Random</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>100 X 100</td>
</tr>
<tr>
<td>Packet Size (bits)</td>
<td>200 – 800</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>25 – 100</td>
</tr>
<tr>
<td>Routing Protocol</td>
<td>AODV</td>
</tr>
</tbody>
</table>
3.3.2 Performance of EE-MAC under various number of packets generated

Number of nodes in network and packet size is kept constant in this case and by varying number of packets generated from 100 to 400, the simulation is carried out. The energy consumed by the nodes, average delay for packet transmission and packet delivery ratio are calculated. For analysis purpose the results of proposed EE-MAC protocol is compared with existing protocols I-MAC and EP-MAC both numerically and graphically. The numerical results are given in the Table 3.3. In this case numbers of nodes are set to 60 and packet size is kept as 400 bits. The obtained results show that the proposed EE-MAC protocol performs better than existing EP-MAC and I-MAC for various number of packets generated.

Table 3.3 Results of EE-MAC in case 1

<table>
<thead>
<tr>
<th>Para Meters</th>
<th>Data Packets Sent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Received Packets</td>
<td>82</td>
</tr>
<tr>
<td>Packet delivery ratio (%)</td>
<td>82</td>
</tr>
<tr>
<td>Average delay(s)</td>
<td>0.22</td>
</tr>
<tr>
<td>Energy (µJ/bit)</td>
<td>212</td>
</tr>
</tbody>
</table>

3.3.3 Performance of EE-MAC under variable packet size

In this case, the number of nodes in network and number of packets are kept constant. By varying the packet size from 200 bits to 800 bits the simulation is carried out. The average delay taken by each node to deliver the data packet, energy consumed and the packet delivery ratio of EE-MAC are calculated and compared with I-MAC and EP-MAC. The numerical
comparison is shown in Table 3.4. Here number nodes are set to 60 and the number of packets sent is set aside as 300. For all packet size, the performance of EE-MAC is better than other protocol I-MAC and EP-MAC.

**Table 3.4 Results of EE-MAC in case 2**

<table>
<thead>
<tr>
<th>Para Meters</th>
<th>Packet Size (Bits)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200</td>
<td>400</td>
<td>600</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Packet delivery ratio(%)</td>
<td>81.33</td>
<td>90.67</td>
<td>92.67</td>
<td>77.3</td>
<td>87.67</td>
</tr>
<tr>
<td>Average delay(s)</td>
<td>0.26</td>
<td>0.20</td>
<td>0.155</td>
<td>0.416</td>
<td>0.328</td>
</tr>
<tr>
<td>Energy (µJ/bit)</td>
<td>221</td>
<td>191</td>
<td>157</td>
<td>263</td>
<td>231</td>
</tr>
</tbody>
</table>

**Table 3.5 Results of EE-MAC in case 3**

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>Packet delivery ratio (%)</th>
<th>Average delay (s)</th>
<th>Energy (µJ/bit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>90.33</td>
<td>94.33</td>
<td>95.67</td>
</tr>
<tr>
<td>20</td>
<td>88.33</td>
<td>93.33</td>
<td>94.67</td>
</tr>
<tr>
<td>30</td>
<td>84.33</td>
<td>91.67</td>
<td>93.67</td>
</tr>
<tr>
<td>40</td>
<td>82</td>
<td>90.33</td>
<td>92.33</td>
</tr>
<tr>
<td>50</td>
<td>79.67</td>
<td>89</td>
<td>91</td>
</tr>
<tr>
<td>60</td>
<td>77.3</td>
<td>87.67</td>
<td>90.3</td>
</tr>
<tr>
<td>70</td>
<td>75.67</td>
<td>86</td>
<td>89.3</td>
</tr>
<tr>
<td>80</td>
<td>73.33</td>
<td>83.67</td>
<td>87.67</td>
</tr>
<tr>
<td>90</td>
<td>72</td>
<td>82.67</td>
<td>86.33</td>
</tr>
<tr>
<td>100</td>
<td>71.33</td>
<td>80.33</td>
<td>84.33</td>
</tr>
</tbody>
</table>

**3.3.4 Performance of EE-MAC under various number of packets**

Number of packets sent by the node and packet size is kept constant in this case. By varying the number of nodes in the topology from 10 to 100,
the simulation is carried out and the compared results of EE-MAC with I-MAC and EP-MAC are given in Table 3.5. In this case packet size is kept as 400 bits and number of packets sent by the node is fixed to 300. From the results obtained, it is evident that the performance of the EE-MAC is better than I-MAC and EP-MAC in terms of energy consumption, average delay for a node to deliver the packet and packet delivery ratio.

3.3.5 Energy calculation

Energy consumption of nodes in I-MAC, EP-MAC and EE-MAC for all three cases are measured and compared for analysis purpose. This measured energy includes, the energy consumed to transmit data, to receive the data/acknowledgement, to retransmit the packet in case of a collision and for idle listening. Energy spent on different state of sensor node is calculated by using following formulae. The energy consumed to transmit the data is given by Equation (3.5).

\[
E_{txn} = \begin{cases} 
E_{bt} * n + E_{ps} * n * d^2 & \text{if } d \leq d_0 \\
E_{bt} * n + E_{pl} * n * d^4 & \text{if } d > d_0 
\end{cases} 
\]  

(3.5)

where, \( E_{txn} \) is the energy consumed by the radio electronics for transmitting ‘n’ bits of information, \( E_{bt} \) is the energy dissipated by the transmitter electronics, \( E_{ps}, E_{pl} \) are the energy consumed by power amplifier for small distance and large distance respectively. If the distance is small (i.e.) less than cross-over distance, then the energy dissipation follows Friss free space model (i.e.) \( d^2 \) power loss otherwise follows the two-ray ground model (Cheng et al. 2006). The energy consumption of receiver is given by Equation (3.6).

\[
E_{rxn} = E_{br} * n
\]  

(3.6)
where, $E_{rxn}$ is the energy consumed by the radio to receive the data, $E_{br}$ is the energy dissipated by the receiver electronics for n-bit data reception. The total energy consumed for both data transmission and reception is given by Equation (3.7) and (3.8).

$$E_t = \sum_{i=1}^{N} E_{txn}(i) \tag{3.7}$$

$$E_r = \sum_{i=1}^{N} E_{rxn}(i) \tag{3.8}$$

where $N$ represents maximum number of nodes and ‘i’ value varies from 1 to $N$. The total energy consumption is calculated by combining the energy consumed for transmission and reception. This protocol is developed for emergency applications only. Here, traffic will be more and all nodes are in active state to transmit/forward data packets to central/sink node where the decision is made. Thus idle and sleep periods are very less compared to active period and not included in energy calculation.

The calculated energy values for all three cases are compared in the graph and are shown in Figures 3.9, 3.10 and 3.11. It can be observed from the figures that the energy consumed by EE-MAC is lesser than I-MAC and EP-MAC in all scenarios. When the numbers of nodes increase, the energy consumption increases in all algorithms due to heavy traffic, whereas it is minimum in EE-MAC compared to other protocols. When the number of nodes is 60, the proposed EE-MAC protocol achieved energy saving of 20.5% compared to I-MAC and 9.5% in comparison with EP-MAC. I-MAC protocol allows contention in TDMA slots during more traffic when the numbers of nodes are increased. During contention if the nodes fail to access the channel then they have to wait for next contention. This increases the idle listening of nodes and thus energy consumption is increased in I-MAC. In EP-MAC, the usage of parallel transmission reduces the energy consumption. However, the transmission of RTS and CTS packets increases overhead to the protocol and
thus energy consumption is increased. The proposed EE-MAC protocol does not use RTS, CTS packets and contention is not used during maximum network density. This leads to reduced energy consumption.

When the numbers of packets sent by the nodes are increased, the energy spent to deliver the packets also increased for both protocols but it is reasonably less in EE-MAC. When the number of packets transmitted is 200, EE-MAC achieved energy saving of 26.1% in comparison with I-MAC and 15.2% with EP-MAC. This reveals that the proposed EE-MAC performs better than other conventional MAC protocols. When the packet size is 600 bytes, EE-MAC achieved the energy efficiency of 18.2% and 8.5% in comparison with I-MAC and EP-MAC protocols respectively.

![Figure 3.9 Energy consumption for different number of nodes](image-url)
3.3.6 Average Delay

Average delay taken by the node to deliver the data packet is calculated for EE-MAC, I-MAC and EP-MAC protocols in all 3 cases. The
results are plotted in the graph and are shown in Figure. 3.12, 3.13 and 3.14. From these figures we observe that EE-MAC performs better than I-MAC and EP-MAC in all conditions. When the packet size is less both protocols are having less delay. When the number of nodes are 60, the average delay is reduced in EE-MAC about 41.4% and 11.5% in comparison with I-MAC and EP-MAC respectively. When the packet size is 600 bits, the EE-MAC achieved the delay reduction by 34.3% and 20.3% with respect to I-MAC and EP-MAC.

![Graph showing average delay vs packet size]

**Figure 3.12 Average delay of a node for various packet size**

During the transmission of 200 packets, I-MAC introduced the delay of 0.29 seconds. This is due to the waiting time of nodes for channel access. However, the idle listening problem is overcome by the usage of simultaneous data transmission with multiple frequency slots. Thus, EE-MAC reduced the delay by 41.4% in comparison with I-MAC. In EP-MAC, parallel transmission is enabled only after the successful transmission of RTS and CTS packets. To handle emergency no priority mechanism is used in EP-MAC. This leads to increased average delay of network. However, the usage
of priority mechanism and parallel transmission without condition improved the delay efficiency of EE-MAC protocol.

![Figure 3.13 Average delay of a node for various numbers of nodes](image1)

![Figure 3.14 Average delay of node with different number of packets transmitted](image2)
3.3.7 Packet Delivery Ratio

In wireless network, packets may be dropped during the route reconstruction and congestion period. This packet loss will degrade the throughput performance in significant manner. To solve this issue and to improve the network performance, the packet delivery ratio (PDR) is to be increased and loss ratio is to be reduced. Packet delivery ratio is calculated by measuring total number of packets transmitted and total number of packets received. The formula to measure delivery ratio and loss ratio are given by Equation (3.8) and (3.9). In all three cases, the simulation is run for 200 seconds and the packet delivery ratio is calculated and compared with existing MAC protocols I-MAC and EP-MAC. These results are shown in Figures 3.15, 3.16 and 3.17.

\[
PDR = \frac{\text{No. of packets delivered}}{\text{No. of packets transmitted}}
\] (3.8)

\[
\text{Loss ratio} = 1 - PDR
\] (3.9)

![Figure 3.15 Packet delivery ratio for different packet size](image)
When the number of nodes and number of packets are increased due to heavy traffic congestion problem is introduced. This leads to reduction.
in delivery ratio of all protocols. However, it is better in EE-MAC compared to I-MAC and EP-MAC. For 60 nodes, the delivery ratio is improved by 16.8% and 3% with respect to I-MAC and EP-MAC. When 200 packets of data are transmitted EE-MAC achieved 14.3% of improvement in delivery ratio compared to I-MAC. However, compared to EP-MAC, the proposed EE-MAC achieved delivery ratio of 2.8% only. While running the simulation by varying packet size, 17.6% and 2.7% of delivery ratio is improved by EE-MAC in comparison with I-MAC and EP-MAC.

![Figure 3.18 Packet loss ratio comparison](image)

**Figure 3.18 Packet loss ratio comparison**

Usage of parallel transmission with multiple frequency slots improved the delivery ratio in EE-MAC. Conversely, in EP-MAC to implement parallel transmission the RTS and CTS packets are to be transmitted. During this time, some packets may be dropped which leads to reduction of delivery ratio. Whereas, parallel transmission concept is not used in I-MAC and it is affected by congestion during heavy traffic. This affects the packet delivery ratio in significant manner. The loss ratios of all three
protocols are compared and are shown in Figure 3.18. This figure reveals that the proposed EE-MAC reduced the loss ratio to a greater extend.

3.4 CONCLUSION

Hybrid MAC protocols I-MAC, EP-MAC and proposed EE-MAC protocol, a hybrid medium access protocol with priority technique are implemented using simulation and their performances are compared. EE-MAC protocol is found to be efficient than I-MAC and EP-MAC since this protocol allows all nodes to access the media in an efficient, collision free and quick manner. This is achieved through an adaptive prioritization mechanism embedded with the hybrid of TDMA and FDMA techniques. In addition to this, life time of node is extended because prioritization mechanism not only reduces the back-off period and also reduces the collision between the nodes.

Therefore by combining the TDMA and FDMA techniques and introducing prioritization to access the channel, EE-MAC becomes more energy efficient, more robust to topological changes and very good in channel allocation. According to the topology changes, EE-MAC adapts itself and improves the delay performance, packet delivery ratio and reduces energy consumption. The overall performance of the EE-MAC is evaluated through simulation using NS-2 and the given results show significant improvement compared to I-MAC and EP-MAC, in terms of energy efficiency, packet delivery ratio and delay.

However, the proposed EE-MAC protocol is designed based on emergency situation only and if there is no emergency that is under normal scenario there is no transmission or minimum transmission. Therefore nodes of EE-MAC protocol are either in listen or sleep period. Figure 3.19 shows the performance of EE-MAC under various traffic conditions.
Figure 3.19 Performance of EE-MAC under varying traffic conditions

This figure reveals that EE-MAC performance is degraded under low traffic conditions. This is because of node in idle state consumes energy equivalent to energy required for data reception. This increases total energy consumption of EE-MAC protocol compared to existing protocols and hence EE-MAC is not suitable varying traffic conditions. Hence, a protocol to consider the various traffic conditions of sensor network is discussed in chapter 4.