Balancing Energy Consumption in Intra-Vehicular Wireless Network (IVWN) of Automated Cars

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
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By

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DECLARATION OF AUTHORSHIP

I declare that the work presented in this dissertation with title "**Balancing energy consumption in Intra-Vehicular Wireless Network(IVWN) of automated cars**" towards the fulfillment of the requirement for the award of the degree of Master of Technology in Computer Science & Engineering submitted in the Dept. of Computer Science & Engineering, Indian Institute of Technology, Roorkee, India is authentic record of my own work carried out during the period from July 2015 to May 2016 under the supervision of Dr. Sudip Roy, Assistant Professor, Dept. of CSE, IIT ROORKEE.

The content of this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

DATE: ……………….. SIGNED: …………………….

PLACE: ………………. (SURENDRA MEENA)

CERTIFICATE

This is to certify that the statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

As the demand of comfort and automation in vehicular systems increases, several hundreds of devices (sensors, actuators, etc.) are being placed in newer automotive systems. With the increase in wiring cables connections between these devices, the weight of a vehicle increases significantly, which degrades the fuel efficiency of vehicle. In order to reduce the weight of a car, wireless communication has been introduced to replace wiring cables between some devices. However, the extra energy consumption for packet transmissions by wireless devices requires frequent maintenance, e.g., recharging of batteries and also there is a risk of packet unwanted packet losses. Here we are trying to balance the energy dissipation among devices while maintaining the delay constraint for safety critical issues in vehicular wireless Sensor Network (VSN). So, that the overall battery lifetime or network lifetime can be increased and the frequent recharging of batteries can be avoided and hence reduce the maintenance overhead.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In recent years, the need of automated vehicles is increased significantly. With increasing this demand the manufacturers are trying to increase automation by increasing in the number of devices. In an vehicular automotive systems, there lot number of devices are used, for example electronic control units (ECUs), actuators, and sensors, For constructing an intra-vehicular network (IVN) those all devices are need to be connected. Nowadays in automotive systems, several functions can be embedded in the IVN such as brake systems, fuel systems, shock absorbers etc[4]. The functions which are executed by either wired or wireless devices and they need to be connected with an ECU to do computations. Thus it is needed to interconnect all device and ECU to each other depending on functions. As the automation and comfort increases the need of electronics device is also increasing and results more complex interconnections. If the number of interconnections increases between devices, then it results in increasing of total wiring weight and need more power to supply for wireless devices. Therefore, minimization of the total weight and transmit power is now becoming an important issue. The total wiring weight of an general automotive system can be more than 30 kilograms [2], and it is the third heaviest and costliest component in the IVN. It is estimated that a in a recent sedan there is total more than 3Km of wires [4,5]. Due to this, the idea of using wireless devices in Intra-vehicular network (IVN) comes into picture .Now the manufacturers having a big challenge of increasing the total Network lifetime of vehicular wireless Sensor Network, so that the overhead of frequent recharging of batteries can be avoided.

In this report we implemented an algorithm for balancing the energy consumption in IVWN. This algorithm is based on dijkstra's algorithm approach. We have several wireless functions and set of ECUs as test cases. Fig1. showing an example of the whole setup of routing graph, In which there are two ECUs(labelled as ECU1 and ECU2) and three functions(F1,F2, and F3) which have 3,3 and 2 wireless nodes respectively and executed by ECUs according to the less total transmit power.

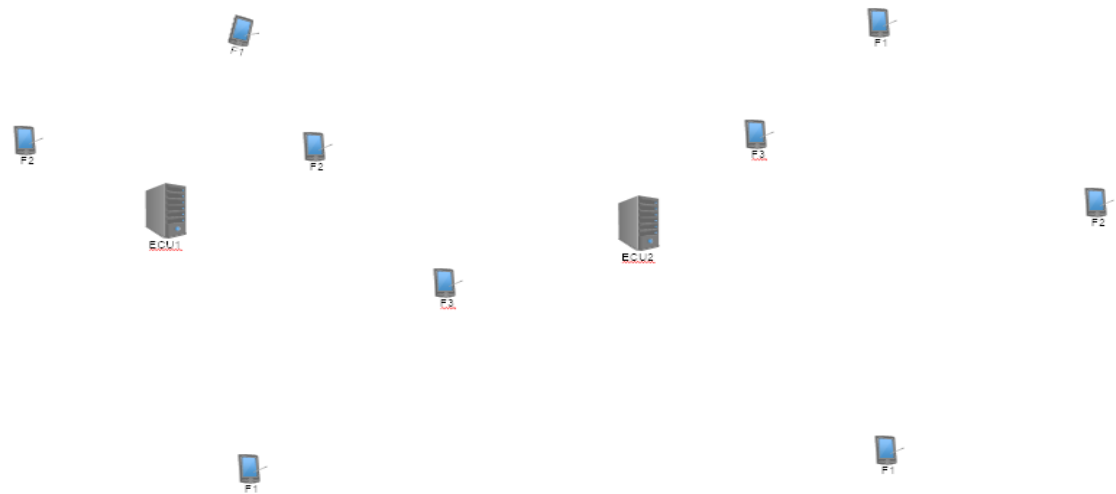


Figure 1-1. Two ECUs and Three Functions' nodes

As shown in the figure2, We have the location of the sensor nodes and ECUs. According to the transmit power we will connect each node of same function to any of the ECUs. Suppose on connecting Function1 with ECU2 consuming least transmit power among two of them, then we will assign that particular ECU to the respective function.

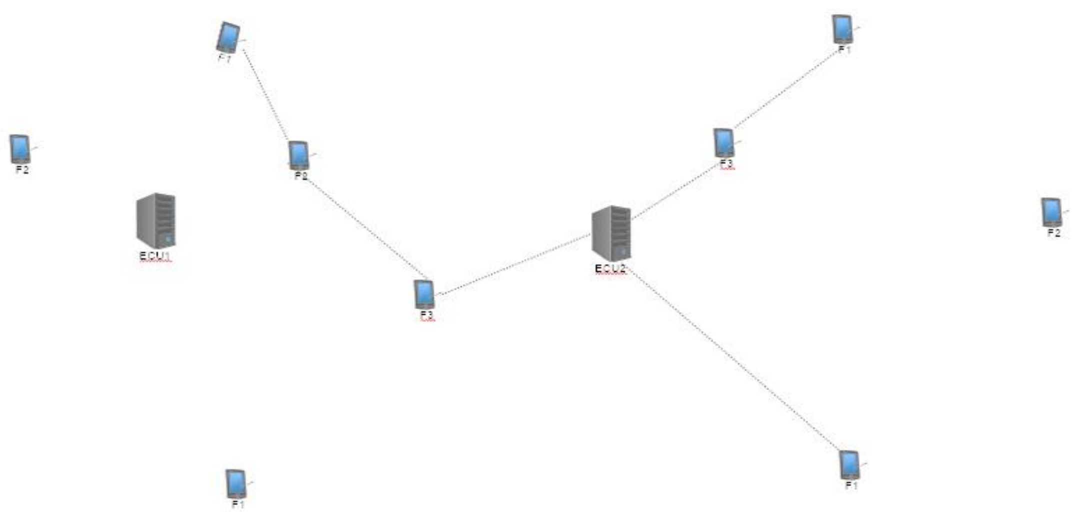


Figure 1-2. ECU2 is executing the Function1, Function2 nodes are used as a relay to decrease the tranmit power

Similarly, we will calculate the total transmit power for each of the function with each ECU and assign them ECU which led to least transmit power. For further reducing the the transmit power will use the nodes of other functions as relay in the path from source node to ECUs.

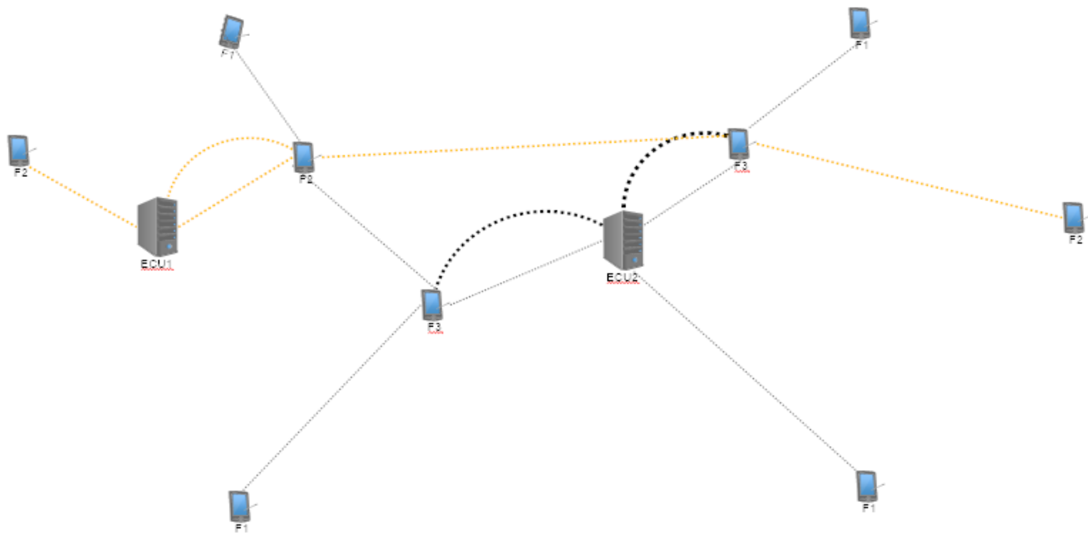


Figure 1-3 In this figure two ECUs are executing Three functions

In above the wireless nodes are using other functions nodes to decrease the total transmit power. Here we are not dealing with the delay but in actual scenario there is a need of transmitting the signals in particular time due to security issues. So afterwards we will deal with delay also. As my basic idea of this algorithm is based on the work has already done in Wireless Sensor Network. Here, in this report we will present the comparison of the lifetime of the IVWN network by using transmit as a link cost with IWVN lifetime using energy as a link cost between two nodes. There are some issues with the algorithm I presented but they can be resolved further, for example I have not considered the capacity of the nodes and ECUs.

1.1. Motivation and Background

In order to fulfill the need of the fully-automated and comfortable vehicles, vehicle designers used lots of electronic devices in a vehicle. For good functionality the electronic devices need to be connected in a network that is called Intra Vehicle Network (IVN). As the desire of comfort and automation increases, the number of electronics devices are also need to be increased for more functions such that Engine Control Module (ECM), Electronic Stability Control (ESC), Anti-Lock Braking System (ABS, etc. So, IVN became very complex mesh of interconnections these days and degrades the performance of vehicle due to its weight and power needed to operate different functions. As shown in figure below:-

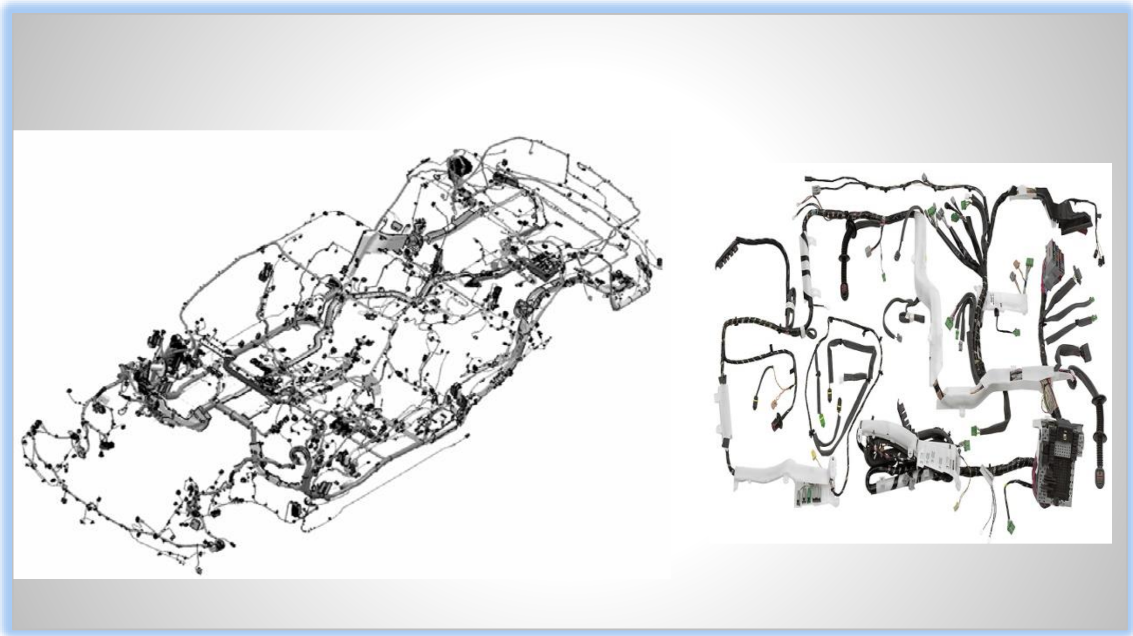


Figure 1-4 IVN in a vehicle [6]

As we can see, here, some modification can be done by routing the devices to ECU in a more better way by using algorithms which are already existing such as Floyd Warshal algorithm, Dijkstra's algorithm, Prim's and Kruskal algorithm etc, to find the shorter connection length between given devices and ECU to minimize the total wiring weight and total transmit power and hence increasing the overall performance of vehicle. So, it is a very good field to do research in future and wire routing can be further improved by having knowledge of more better existing algorithms or by using some heuristic algorithms. In our studies it is assumed that the actual IVN can be represented on 2-d plane as shown in figure below:-

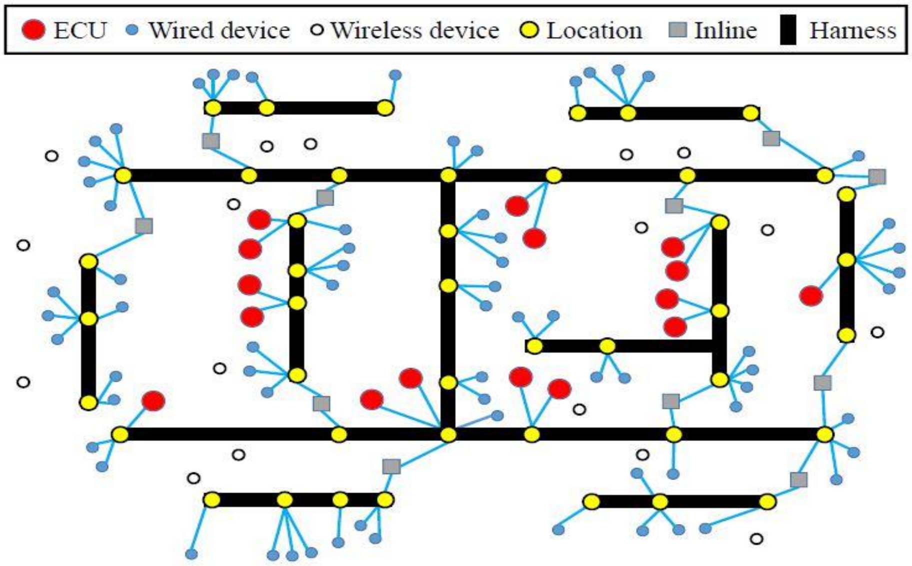


Figure 1-5 An example IVN.[2]

1.2. Definitions:

Routing Graph: It includes a set of vertices V and a set of edges E and function. Where vertices are devices and ECUs, Edges is the connection between these devise and ECUs.

Electronic Control UNIT (ECU):- An ECU is an embedded system that controls/monitors systems in a car. For each ECU there is a set of devices which demands resources.

Devices:- These are the sensors and actuators in network

Function:- It is function of the automative system which need to be executed with the help of wired or wireless nodes. There can be several number of functions in a single automative system, such that (Anti-Lock Braking system)ABS, functions for safety measures. The devices which are used to operate the function is need to be connected with an ECU. ECU is a kind of microprocessor which is used to collect the information from nodes which are connected to it and after that it will process them to convert the signals in a function. Each ECU has limited amount of memory to be used, so that we can connect a limited number of functions to it because each function need some memory also. On the basis of that we will assign the particular functions to a particular ECU.

Capacity: Capacity of a device is defined as the number of devices it can relay as a hop.

Link cost: This is cost transferring the data between any two devices or between ECU and device. Denoted as Cij(cost between i and j).

Network Lifetime: It is the time which is taken by any one of the component in the whole network to deplete its power to zero which led network disconnected and hence ends network life.

Accumulated Energy: The energy used to transmit data packets from one device to other. It is added with the previous accumulated energy every time when that device is in use to transmit packets. It is used in calculating the link cost.

Channel Attenuation:- It is the ratio of received power to transmit power between any two devices. It is denoted as $\alpha_{j,k}$ channel attenuation between device j and k.

$$\alpha_{j,k} = \frac{RSSI}{Ptx}$$

1.3. Problem Statement

Here we are assuming that we have given a number of functions and some ECUs which are used to execute them. We have to connect the nodes of the each function to any of the one ECU such that the total transmit power is minimized and then balance the energy among the nodes for further transmissions of data such that the total network lifetime can be increased.

2. Literature Survey

Several wireless technologies has been proposed regarding energy and power balancing in the wireless sensor Network (WSN).In [3] they proposed algorithm which minimizes the total transmit power in the vehicular wireless sensor network. They used minimum cost maximum flow graph (MCMF) for satisfying the delay constraints in the VSN. Here they consider queuing delay and transmission delay as total delay and assuming the propagation delay to be negligible. So delay can be represented as the number of hops coming in the path from source to destination in VSN. So the number of stages of MCMF depends on the given maximum delay for respective functions. And In [6,7] there is modified Dijkstra's algorithm is used in which they used a function of accumulated energy as linking cost and finds the paths. Here they are trying to balance the energy depletion in all the devices, by doing that they are increasing the network life time. Both the methods are briefly explained below.

2.1. Minimization of total transmit power while maintaining the end to end delay [3].

This algorithm has following four steps:

1. Delay bounded routing tree construction
2. Find congestion paths
3. Function re-routing
4. Function mapping

The set of wireless devices for each function needs an ECU for processing the information gathered by them. Hence they need to be connected to ECUs. So here they all routing trees which can be possibly constructed are constructed by mapping each function to all ECUs. After mapping of functions is done perform the delay bounded routing tree construction.

1.) **Delay bounded routing tree construction**:

For constructing delay bounded routing tree they used MCMF, in which transmit power is used as a linking cost between every pair of devices of same function is given by:

$$\mathbf{RSSI = P_{ij} / (4*\Pi) d_{ij}}$$

Where RSSI is received signal strength indicator, which is to be maintained in order to receive the data successfully, here they took it -60dbm. So from given equation transmit power for each link can be calculated and used as a link cost in MCMF graph. The MCMF graph for routing tree construction of wireless IVN is denoted by G=(V,E), where V be the set of nodes and E set of be the directed edges in the graph as shown in graph below:

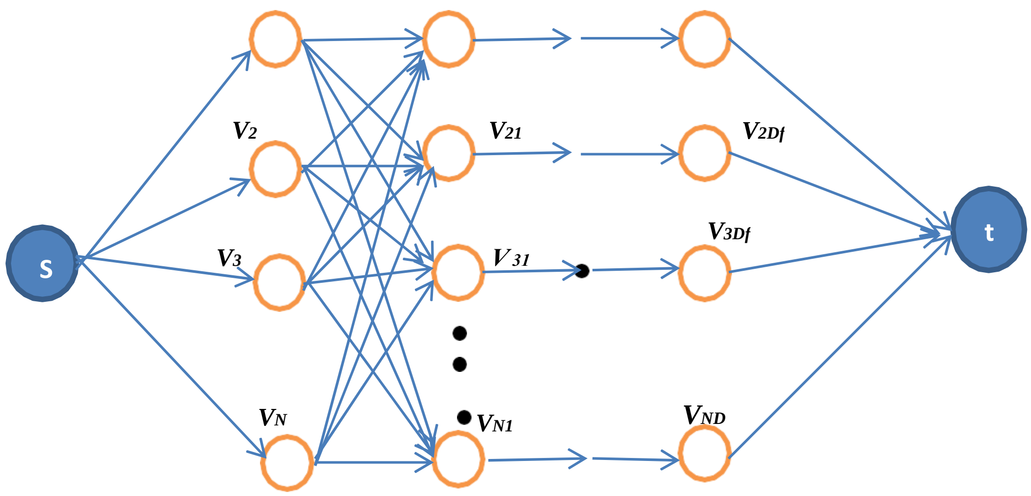


Figure 2-1 Minimum-cost maximum flow (MCMF) network model for constructing wireless IVN routing trees[3].

For every ECU and every function, they constructed a MCMF graph in which evry node of the same function is connected to an single ECU, then they used a MCMF algorithm which will satisfy the transmission delay and minimize the transmit power. Here f is denoting the function and N is the wireless devices which function f is having. Df is the maximum hop delay, that need to be meet for end to end delay time constraint. For each pair of devices in a same function connected and the number of layers of MCMF is depends on the corresponding maximum delay hop number Df. The proposed MCMF graph is taking care of that each and every device is connected to the ECU without any violation of the transmission delay constraint. On the basis of above network, the routing paths for wireless devices can be calculated by the algorithm given in [10] to connect them to the ECU by taking care of delay.

2.) Find congestion paths:

After MCMF graph and finding paths, there can be some nodes in it which may be used as relay in paths more than their capacity. Find them by calculating their usage rate and pointed as congestion points in the network and these paths are represented as congestion paths. After finding congestion paths, find the cost of each path by calculating the transmit power between every pair of nodes. After that sort the congestion paths on the basis of their transmit powers and select M congestion paths which have maximum transmit power, for every device d which is becoming congestion point, re-route the M selected congestion paths in which the device d is coming after updating the capacity of each and every edge of the MCMF graph which is remaining and then call the MCMF algorithm again.

3.) Function re-routing

Improvisation in the transmit power can be done further by sharing one ECU among different functions. This method will improve the transmit power because it will let all the wireless devices which are connecting to same ECU allow to be used as relay nodes in between of other function's nodes, and this changes the original routing trees and decrease the total transmit power. For re-routing there will come some changes in MCMF graph in which the number of nodes in each column increases and the capacity of link will be set according to capacity of corresponding function. By applying same algorithm as above the routing paths are calculated and the congestion paths calculations are done. Here, is the given example figure 2-2 for function re-routing.

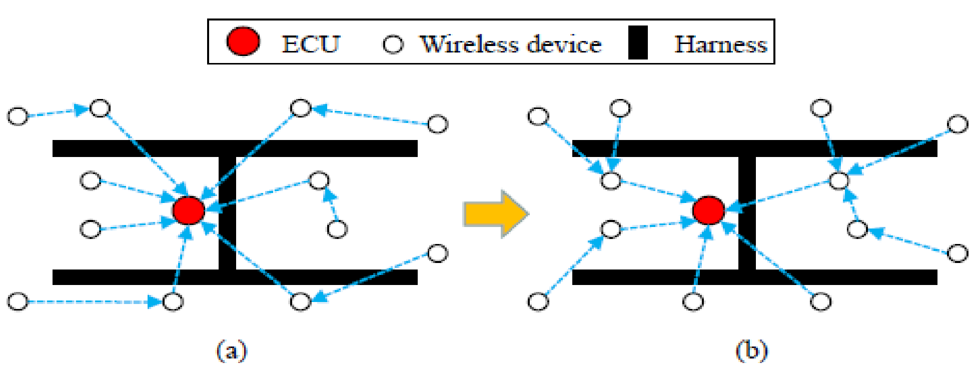


Figure 2-2 (a) Wireless function nodes are connected to an ECU, and (b) wireless function is re-routedin order to decrease the transmit power[3].

4.) Function mapping:

After the construction of routing trees, mapping of each function to an ECU while minimizing the total transmit power can be done by using ILP formulation below:

$$\min\left(\alpha\sum_{i\in W}\sum_{k\in E}C_{ik}x_{ik}+\beta\sum_{j\in W'}\sum_{k\in E}C'_{jk}x'_{jk}\right)$$

$$\sum_{i\in W}M_i x_{ik}+\sum_{j\in W'}M'_j x'_{jk}\le R_k \qquad \forall k\in E$$

$$\sum_{k\in E}x_{ik}=1, \qquad \forall i\in W,$$

$$\sum_{k\in E}x'_{jk}=1, \qquad \forall j\in W',$$

In the algorithm above [3], link cost between two nodes is the transmit power, which is used to send data among those two devices. Due to this, the path from each node to ECU is the one which needs the minimum amount of accumulated energy among all the nodes in that path. This might result that only any of the single node will reduce its power to zero before all others wireless nodes, and this led to ends Network Lifetime while other wireless nodes still having energy remaining to use. So, the solution for this is instead of minimizing the total power, we should balance the energy which is consuming by all wireless nodes in VSN so that the total network life time can be increased because all of its nodes will deplete all together and no single node will deplete fast and hence increases the life time of network.

2.2. Balancing the energy among devices in VSN [7]

In [7] they proposed global routing protocol which is based on Dijkstra's algorithm applied on Wireless Body Area Network (WBAN). In this protocol link cost function is designed such that, it balances the energy consumption throughout the network. Here the link cost function is designed such that all the nodes deplete its' power sources all together and hence increases the network lifetime. Here due to variable link cost between the nodes, they used modified Dijkstra's algorithm [7], which is able to make use of the variable link cost. This link cost is designed such that it avoids the use of nodes in the relays or paths, which are having less energy remaining or high accumulated energy (sum of used energy).

2.2.1. Balancing Energy Consumption:

In any routing algorithm, the cost of link is collected periodically at ECUs in the form of channel attenuation (in equation 2nd) for each and every links in that network, and all the calculations are to be done at the ECUs. After calculating the channel attenuation (eq. 2nd) the energy used by each node can be calculated by following given equation 3. After calculating the accumulated energy of node j, the link cost between j and k can be calculated by using following equation1st.

$$C_{j,k}^{i} = \frac{RSSI_T}{\alpha_{j,k}} \times \left(\frac{1 + \left(\frac{E_i^k}{E_i^{min}} \right)^M}{2} \right)$$

$$\alpha_{j,k} = \frac{RSSI}{P_{tx}}$$

$$E_i^j = E_{i-1}^j + \frac{RSSI_T}{\alpha_{j,k}}$$

The link-cost can be calculated by by above above depicted equation in which the accumulated energy of the next node, E_k is divided by E_i^{min}, where E_i^{min} is the minimum accumulated energy among all nodes. Then the ratio of E_k to E_i^{min} is raised to the power of M, where M is a constant and its' value will always be greater than or equal to zero, it is used to determine the energy imbalance in the whole network. If the energy depleted by any of the node which is much greater than the E_i^{min}, then that particular node will not be used as a relay or hop for other nodes routing paths, because its' link cost will become very high.

In the following section we are going to present our method in which we are using the above formula for updating the link costs between wireless nodes by keeping a track on their respective accumulated energies. In our approach we are using three values for ‘M’ (0,5 and 10). For different values of M we are running our program and showing the simulation results in the form of graphs and table.

3. PROPOSED FRAMEWORK

3.1. OBJECTIVES

- Balancing the energy in wireless network to increase the network life time.
- Reducing the total transmit power

3.2. Proposed Method

In this method we are using dijkstra’s algorithm as mentioned in the[7].For delay constraint we will restrict the number of nodes coming into shortest paths calculated by modified Dijkstra’s algorithm proposed in[7]. Since here we are putting a constraint of time delay so we have to change the proposed modified Dijkstra’s algorithm. Dijkstra’s algorithm will find out the shortest path from wireless devices to ECUs in given routing tree. But here we have given the maximum delay hop number constraint. If the number of hops in that path are more than given Df (maximum delay hop number) then we cannot choose that particular path and we have to drop that from our calculations. And will calculate other paths which satisfy the delay constraint.

Modified Dijkstra’s Algorithm[7]

1. For i=0 to total number of Nodes
2. Visited[i] = 0
3. Distance[i] = 0
4. Previous_node[i]=node[i]
5. end of for loop
6. Distance[target] = 0
7. min_energy=minimum(node.energy)
8. while (visited[k])
9. src= node with smallest distance
10. for i = 1 to number of Links do

```
        if link[i].source = source_node
           Node_dest = link[i] .destination
             if Visited[Node_dest] = 0 then
               Cost = linki.power * (1 + (Node_dest.energy/min_energy)M)/2
               Newdistance = Distance[source_node] + cost
                   if Newdistance <Distance[Node_dest]
                      Distance[Node_dest]  = Newdistance
                      Previous_node[Node_dest] = source_node
                    End of  if
             End  of if
        End of if
   End of for loop
 Visited[Source_node] =1
end of while loop
```

Algorithm 2. Accumulated Energy Function

```
for i = 1 to total number of Nodes do
   Node_ptr = Node[i]
     if Previous[Node_ptr] = Node_ptr then
        There are zero paths to Node[i]
     Else
       While Previous[Node_ptr]  = Node_ptr
           link_ptr ← link between Node_ptr  and Previous[Node_ptr]
           Node_ptr.energy+ = link_ptr.power
           Node_ptr ←Previous[Node_ptr]
       End of  while loop
     end of  if
end of for loop
```

3.2.1. Steps of proposed method

Given a set of wireless functions (since here we are dealing with wireless devices only) , and set of ECUs are given As shown in the figure below.

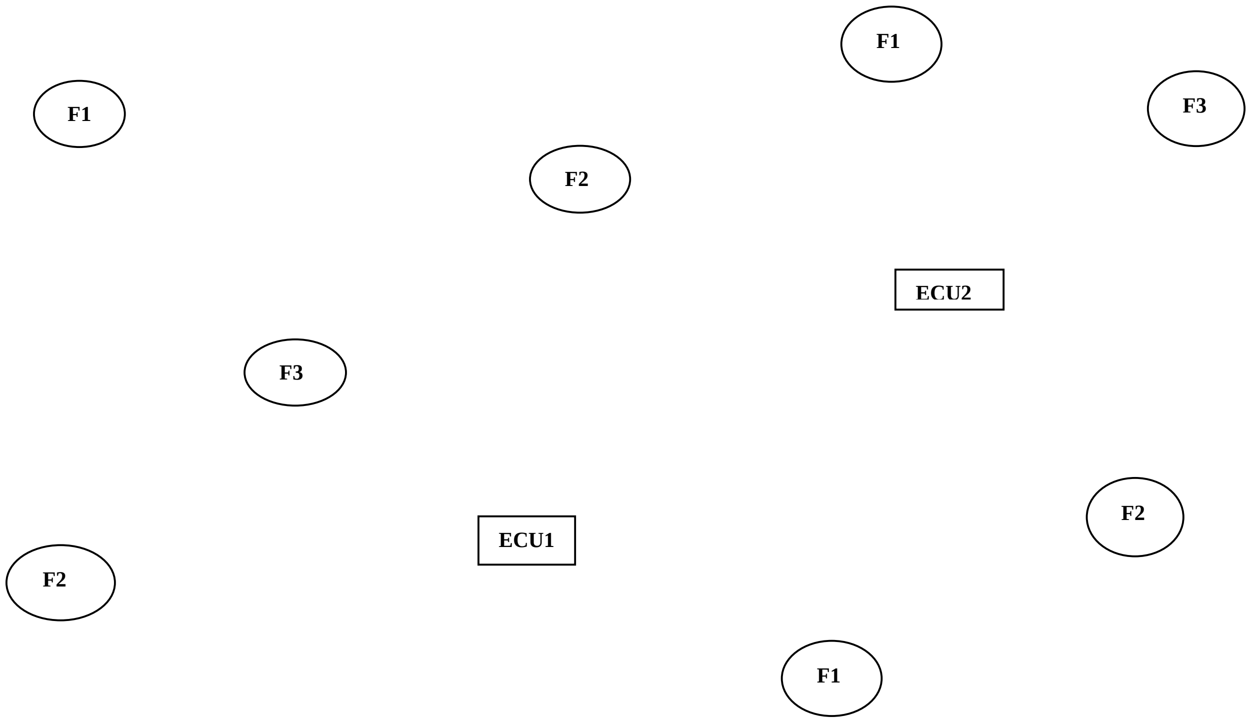


Figure 3-1 In this figure there are two ECUs(ECU1 and ECU2) and three functions F1,F2 and F3 each have 3,3 and 2 nodes respectively

Step1:-Routing graph implementation:

In this step we are connecting all the nodes of functions to each ECU. In short we have made complete graph between all the wireless nodes and connect them to each ECU. We calculated the transmit power of each edge established in our routing graph as assign as a link cost among wireless nodes initially As shown in the figure 9. The formula for finding the link cost between two nodes (i and j) in terms of transmit power is as follows.

$$P_{i,j} = RSSI * (4 * \pi)^2 * d_{ij}^2$$

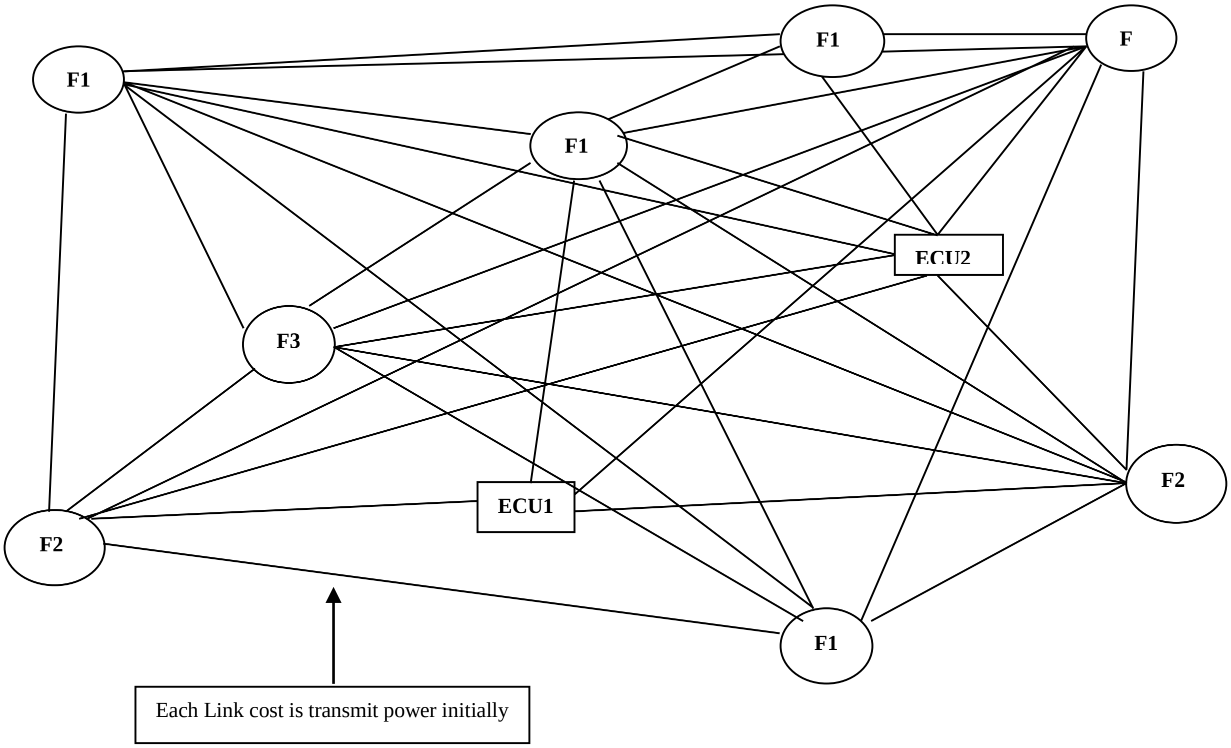


Figure 3-2 Complete graph is made among nodes and afterwards a connection is established between each node and and ECU.

Step2:-Assigning ECUs to each function

After obtaining the routing graph we are applying Floyd Warshal algorithm on the given routing graph and store the each pair shortest path cost in a matrix. After that we can have the transmit power with each ECUs for a particular function. For doing this step we are using the function on the basis of number of nodes in it. If the number of nodes are more for a particular function then we are assigning ECU to that function first, then we subtract the ECUs' memory by the memory used by that function (Here we are assuming that an ECU can be assigned at most two of the functions). After which we are doing same for next function. If any of the function needs more memory than ECUs' remaining memory then we reject that ECU and search for next optimal ECU such that the transmit power is least. Algorithm is follows.

<u>Floyd Warshal Algorithm</u>

1. for i = 0 to # total_nodes

2. for j = 0 to #total_nodes

```
      If   i=j   then
         distanc[i][j] = 0
      Else
         distanc[i][j] = cost[i][j]
     End if
  End for
End for
for  k = 0 to #total_nodes
  for   i = 0 to #total_nodes
     for   j = 0 to #total_nodes
         if    distanc[i][k] + distanc[k][j] < distanc[i][j]
         Then
         distanc[i][j] = distanc[i][k] + distanc[k][j];
       End if
  End for
End for
```

After applying Floyd Warshal algorithm we can have the shortest distance matrix (distanc[][]). Therefore we will apply following algorithm to assign the ECUs to each function by checking ECU memory restriction. We will call following algorithm for every function.

Algorithm For assigning ECUs

```
For j=0 to #ECUs
     If  Elist[j].ecu_memory  > 0  then
         For  k=0 to Flist[i].no_of_nodes
               function_cost+=distanc[k][j+tot_nodes]
         End for
         If function_cost < mini
                   mini=function_cost
                   Flist[i].Fcost=mini
                  Flist[i].ecu_assigned=j
```

10. tot_cost=0

11. End if

12. End if

13. End for

Step 3:- Apply Modified Dijkstra's algorithm

After assigning the ECUs to each function we are applying modifying Dijkstra's algorithm which is quite similar to algorithm in[7] on the routing graph we made before. Now in this algorithm we need to keeping track of the shortest paths which we will get. After getting each path for each node to its' respective ECU, we have to update the accumulated energy of all the nodes associated with it. And after that the link cost will be modified accordingly. Similarly this procedure will be followed by other nodes of a function.

Modified Dijkstra's Algorithm

```
 Modified Dijkstra(Flist, Elist)
1.  Src=ecu
2.  dist[tot_nodes  + tot_ecus+1]
3.  Set_visited[tot_nodes  + tot_ecus+1]
4.  Parent[tot_nodes  + tot_ecus+1]
5.  dist[src]=0
6.  for i=0 to Flist.Nodelist.size()
7.      dist[i]=INT_MAX
8.      Set_visited[i]=false
9.      Parent[i]= -1
10.  end for
11. for i=0 to all nodes
12.    u=min_index(dist,tot_nodes,Set_visited)
13.    for v=0 to all nodes
14.        if  !sptSet[v] && dist[u] + cost_matrix[u][v] < dist[v]
15.            Parent[v]  = u
16.            dist[v] = dist[u] + cost_matrix[u][v]
```

```
                  if   array_node[v].func_no= =f_no
                      Update_Accumulated_energy(f_no, v, parent)
                      break;
                   end if
           end if
    end for
end for
```

Update_Accumulated_energy(f_no , v , parent[ ])

```
Do
Accumulated_energy[v]=prev_accumulated_energy[v] + (RSSI / α)
While(parent[v]!= -1)
Update_link_cost(tot_nodes,tot_ecu,E_min )
```

Update_link_cost(tot_nodes , tot_ecu , E_min)

```
for i=0 to tot_nodes
     for j=0 to tot_nodes
          if i==j
              Cost_matrix[i][j]=0;
           end if
          else
         Cost_matrix[i][j]=(1+(Flist[f_no].Nodelist[j].acc_energy/E_min)^M)/2 *(RSSI / α)
           end else
     end for
end for
```

After applying above algorithms we are finding the maximum accumulated energy among all the nodes and checking, In how many transmissions it will be equalized by the initial power of the node. As we took 5 volt batteries for each of the wireless node So, it will produce a finite value of power. When the maximum accumulated energy of any of the node becomes more than initial power then that particular node will be dead. And hence the network will be ended.

4. Simulation Results

In the result Section we compared the total number of transmissions can be possible by using power as a link cost as mentioned in[3] and by balancing the energy as mentioned in our approach. There are total 10 test cases for which we are going to run our algorithm and the algorithm mentioned in [3]. Initially Assumptions are as follows

1. RSSI=-60 dBM.
2. Packet generation rate= 10 packets/second.
3. 5 volt of battery for each sensor node.
4. 5 mA current is required for transmission.

We know that,

Power = Volt * Current = V*I

Therefore, initially each wireless node will have following power:

Power = $5*5*10^{-3}$

⇨ $25*10^{-3}$ Watt

⇨ 25000 micro Watt

For comparing with the results comes from algorithm mentioned in[3], we modified that algorithm so that we can get the total number of transmissions. We are calculating the maximum transmit power among the wireless nodes. Once we get the particular node's transmit power which is maximum, then we are dividing that value with the initial power of node (25000 micro Watt). It will results the total number of transmissions can be possible by that approach.

4.1. Result Table:

Table 1 Comparision of transmissions between Algorithm[3] and proposed algorithm.

Test cases	Number of Transmissions by algorithm[3]	Number of Transmissions by our algorithm(M=0)	Number of Transmissions by our algorithm(M=5)	Number of Transmissions by our algorithm(M=10)
1st test case	1971	1108	1872	2170
2nd test case	1740	537	1060	1423
3rd test case	1415	908	1046	1840
4th test case	2195	2448	2643	2567

4.2. Result Graphs

Here we are showing results which are tested on test case 1, which have 9 wireless functions and 18 ECUs. Following are the graphs showing accumulated energy dissipation of every node for different values of M, 0,5 and 10 respectively. Here we are taking initial ten nodes for drawing our graph **y-axis showing accumulated energy and x-axis showing transmission rounds**.

Test Case1:-

Figure 4-1 Dissipation of accumulated energy in wireless nodes for M=0

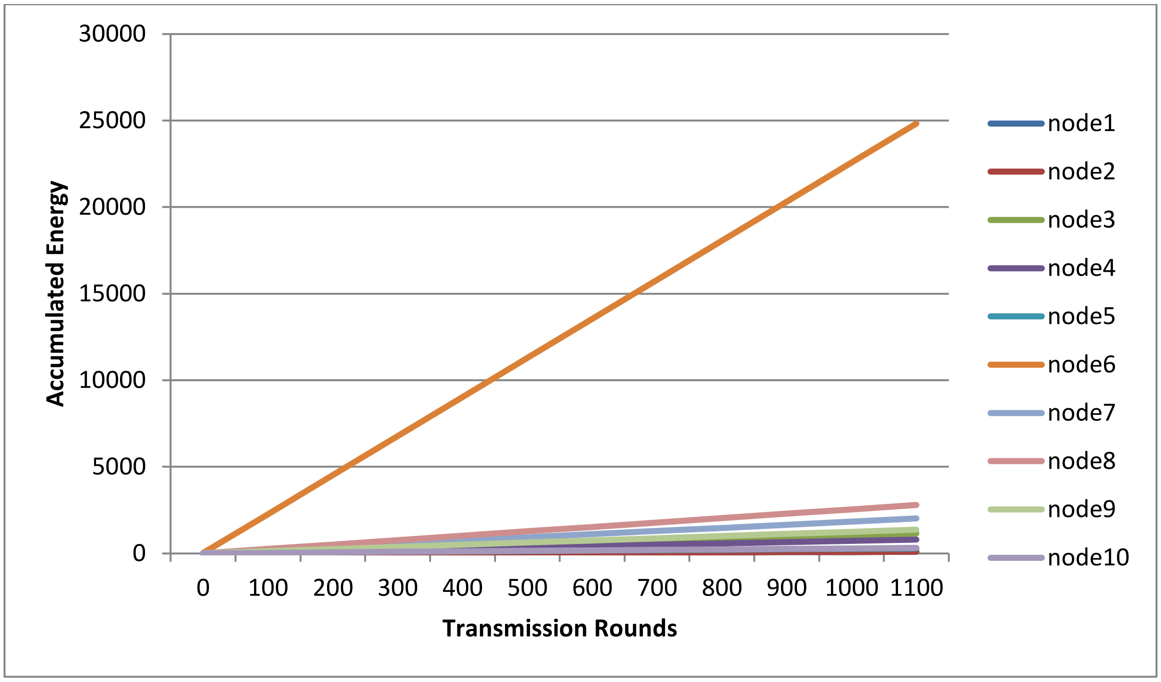


Figure 4-2 Dissipation of accumulated energy in wireless nodes for M=5.

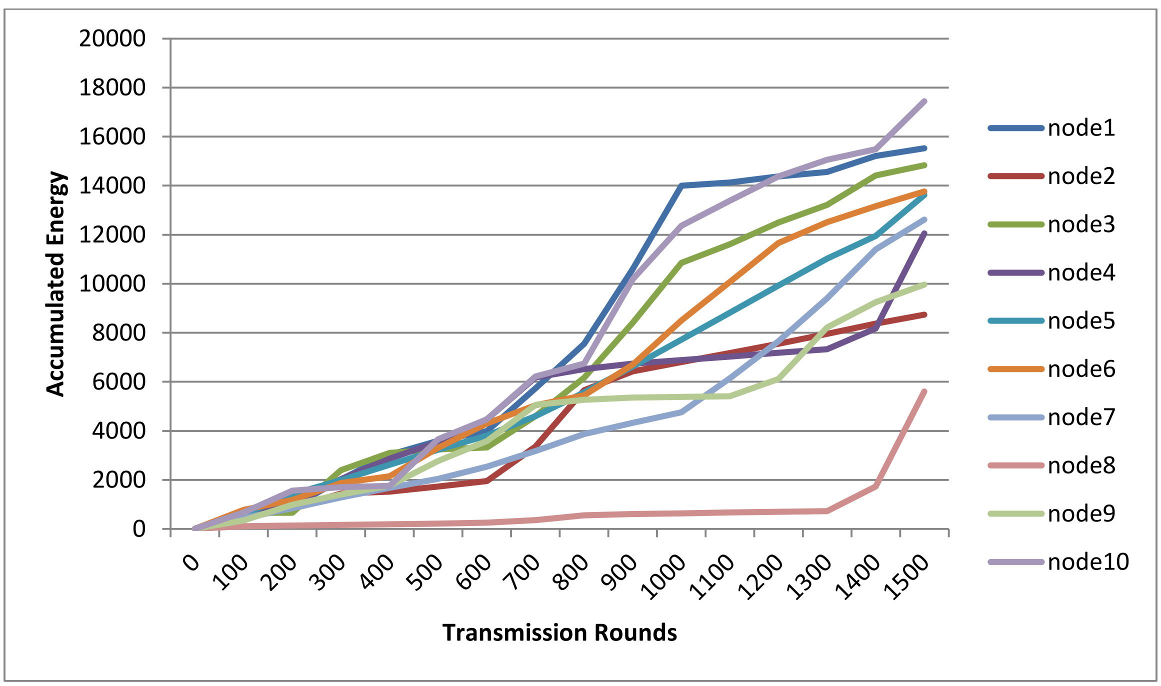
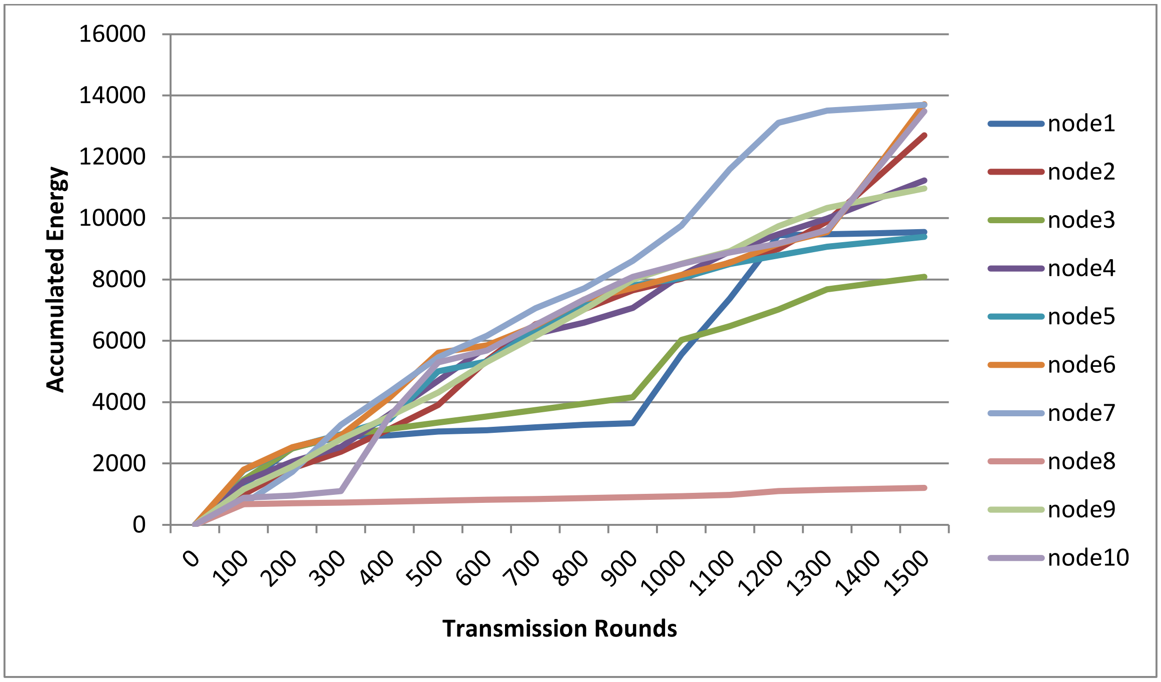


Figure 4-3 Dissipation of accumulated energy in wireless nodes for M=10.



<u>Test Case2:-</u>

Figure 4-4 Dissipation of accumulated energy in wireless nodes for M=0.

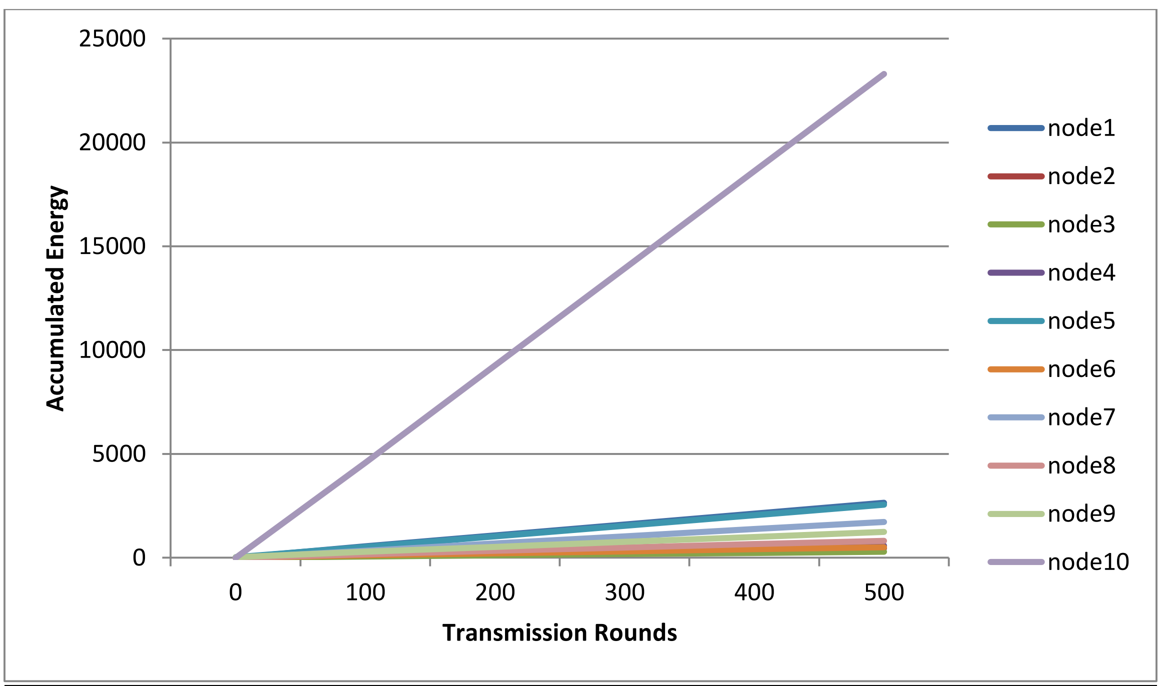


Figure 4-5 Dissipation of accumulated energy in wireless nodes for M=5.

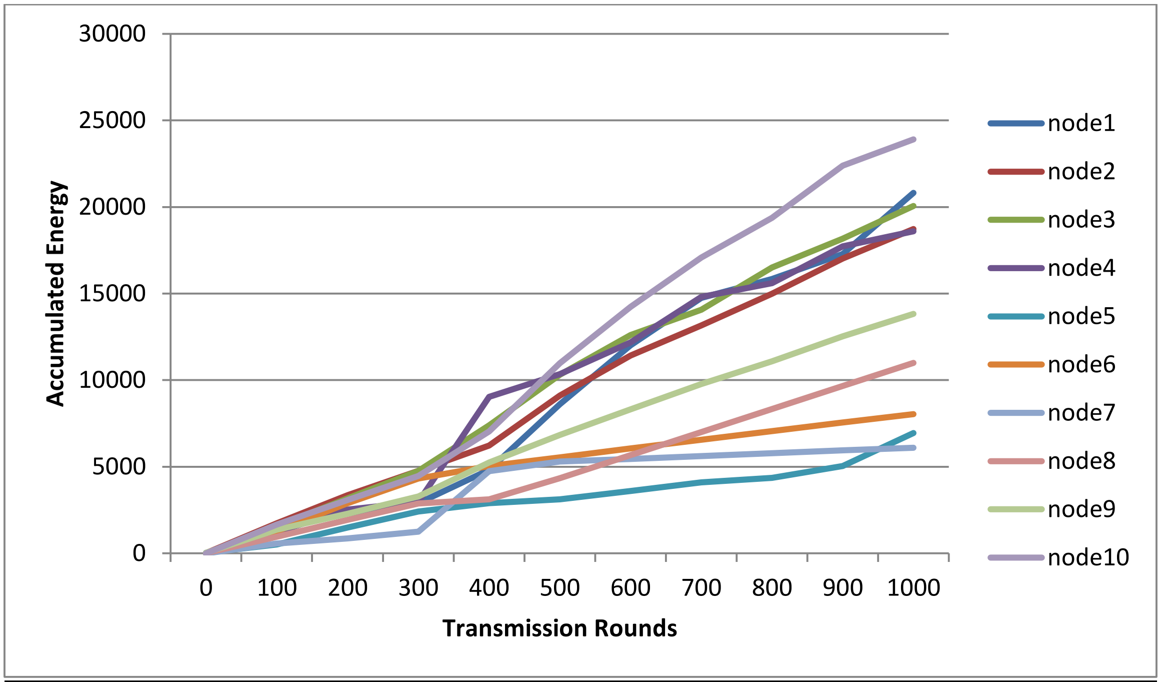
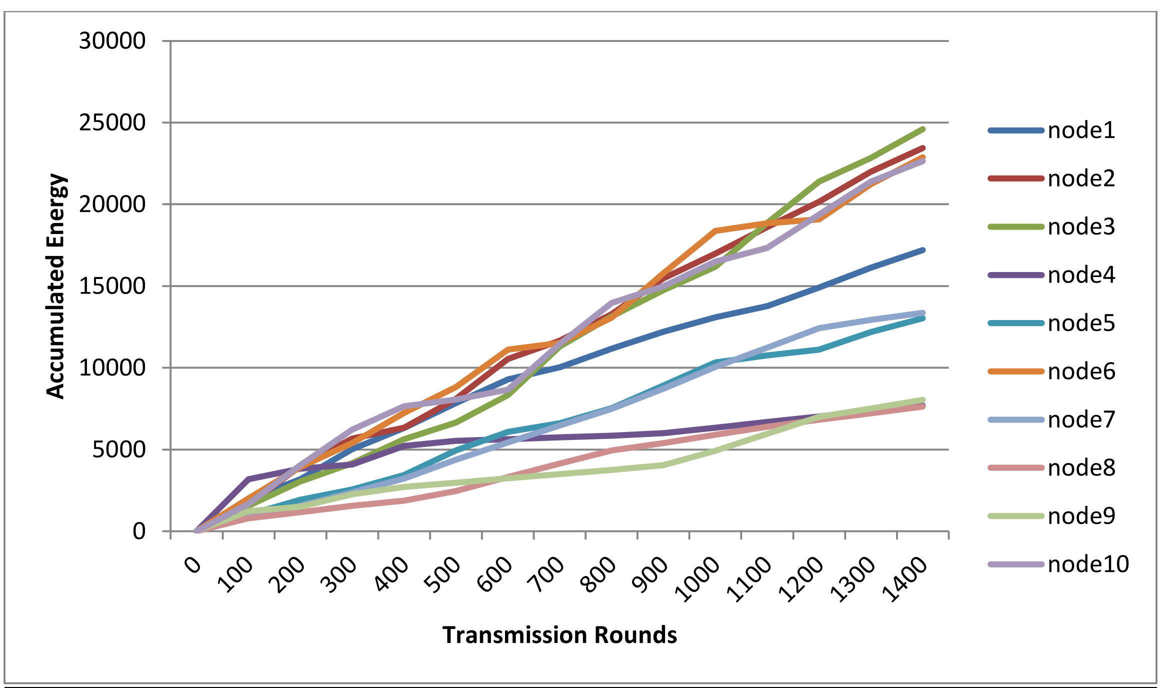


Figure 4-6 Dissipation of accumulated energy in wireless nodes for M=10.



Test Case3:-

Figure 4-7 Dissipation of accumulated energy in wireless nodes for M=0.

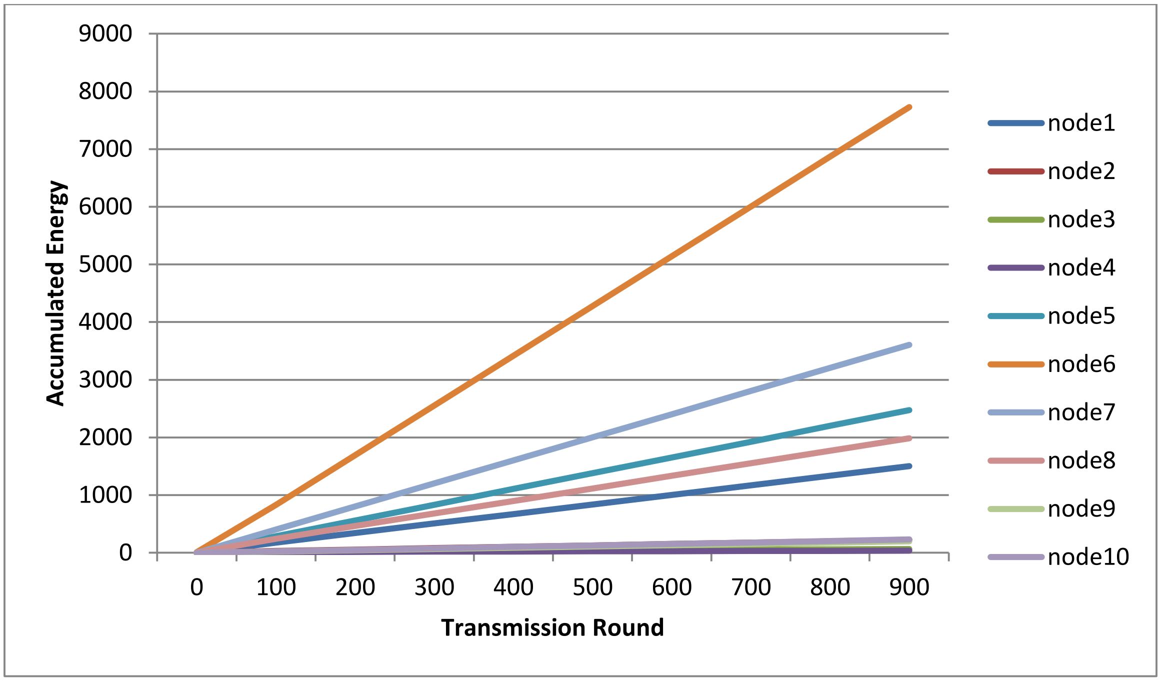


Figure 4-8 Dissipation of accumulated energy in wireless nodes for M=5.

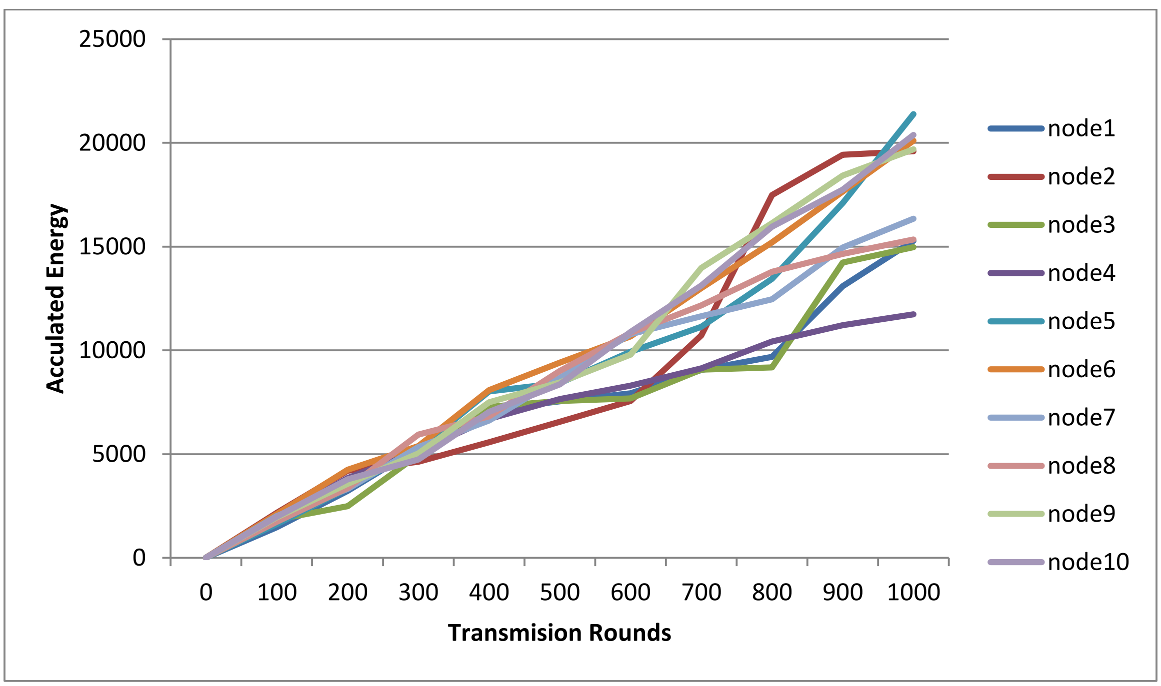
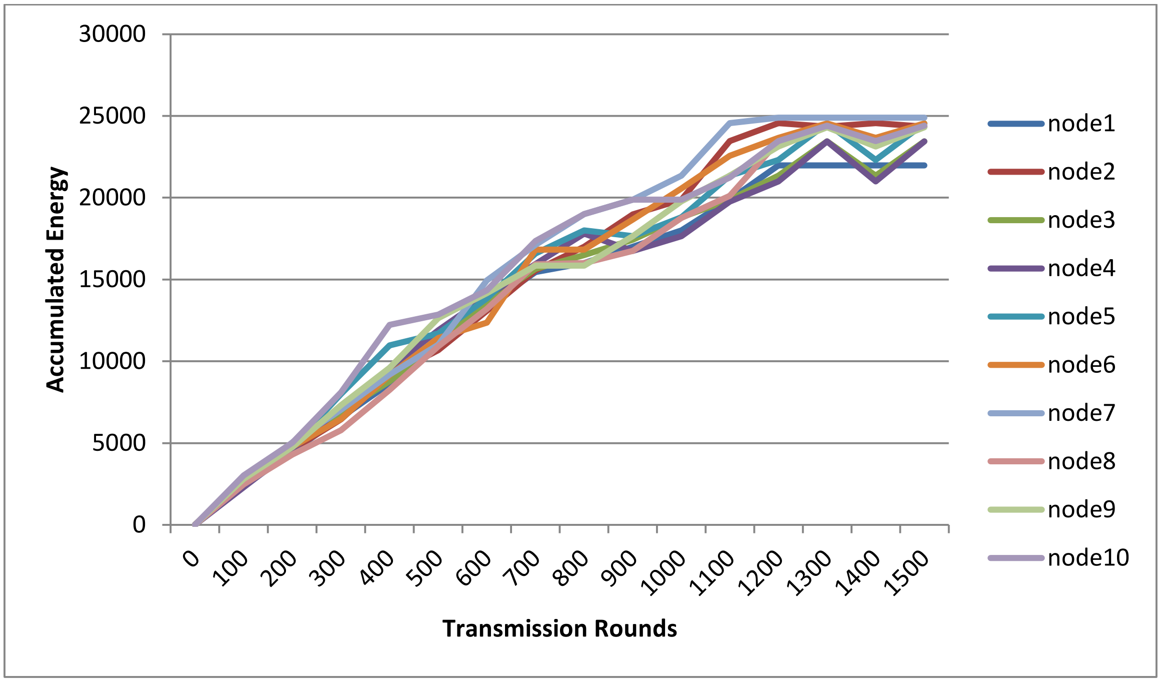


Figure 4-9 Dissipation of accumulated energy in wireless nodes for M=10.



Test Case 4:-

Figure 4-10 Dissipation of accumulated energy in wireless nodes for M=0.

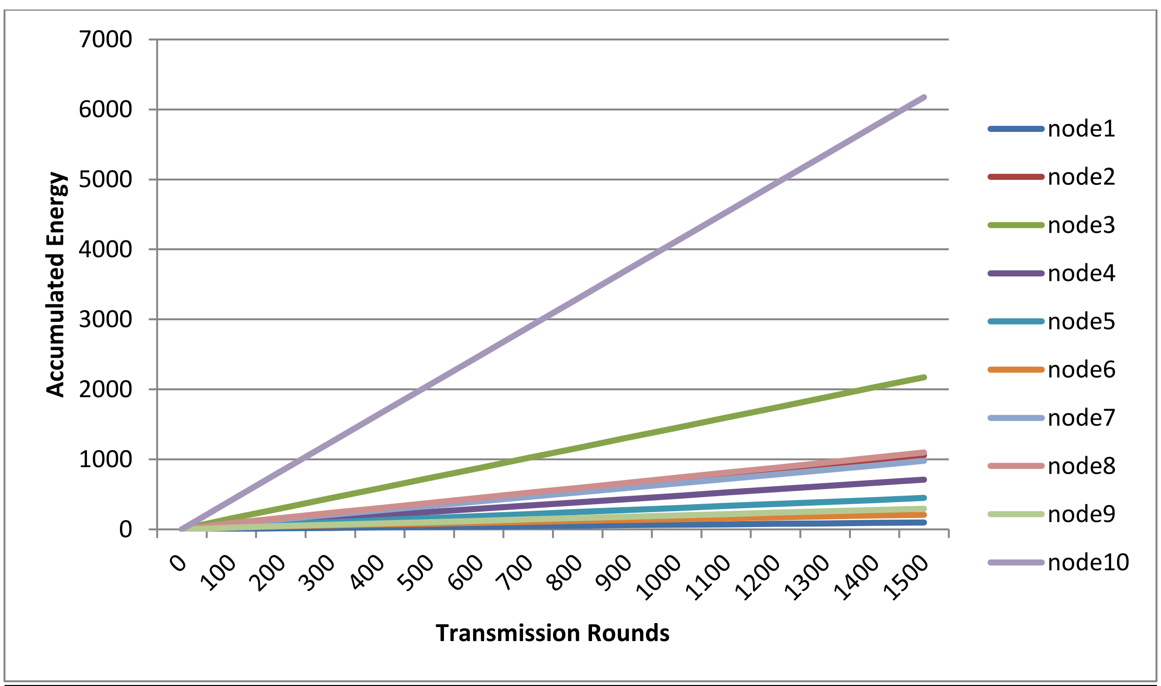


Figure 4-11 Dissipation of accumulated energy in wireless nodes for M=5.

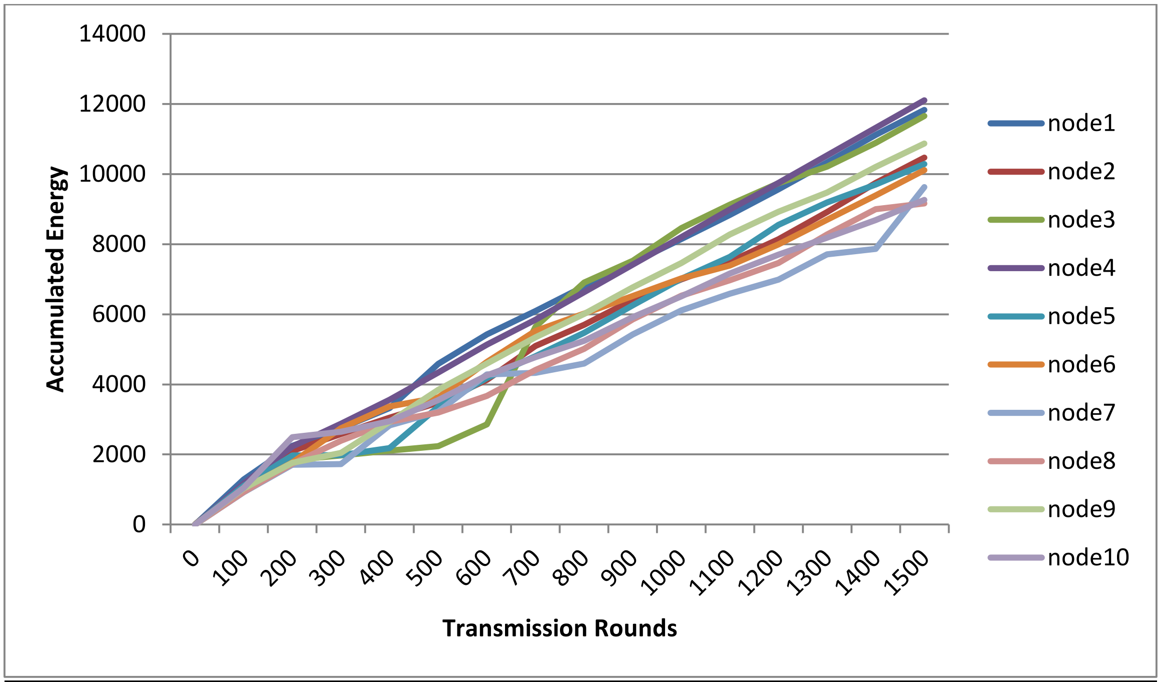
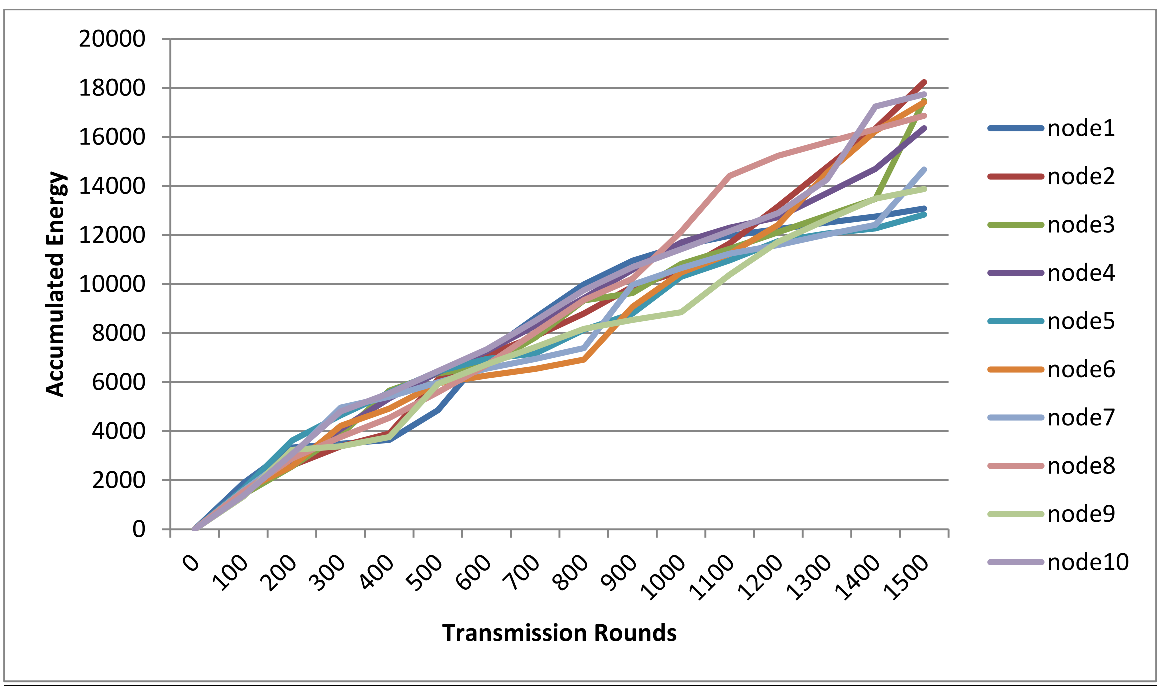


Figure 4-12 Dissipation of accumulated energy in wireless nodes for M=10.



As the results shows that more the value of M we take, more it will balance the energy among the wireless nodes and hence increases the total number of transmissions (as shown in table) and the overall network lifetime.

5. Conclusion

In this report we presented a method which can be used to increase the lifetime of VWSN. In this report we shown some simulation results of already proposed methods for energy balancing, which clearly shows that using transmit power will results lesser battery life. By balancing energy we can increase the total battery maintenance period. With our method there are some issues but they can be solved further. Following are the issues and approach for solutions.

5.1. Issues:

1. In our approach we did not considered the end to end delay.
2. This approach is based on heuristic so it is not optimized.

5.2. Solutions:

1. End to End delay can be achieved by some further changes in the Dijkstra's algorithm which we used. By restricting the length of the paths to D_f at time of calculating the paths.
2. The approach of assigning the ECUs to function is not a good idea instead of that there can be linear programming applied to assign the ECUs.

6. References

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