Sink Placement for multihop Wireless Sensor Networks using Energy Efficient mechanism

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Abstract: MAC protocols are faced with energy consumption challenges largely due to idle listening and node activity scheduling; media access is utilized to mitigate the problems. This work presents a combined energy-efficient medium access control (MAC) and routing protocol for large-scale wireless sensor networks that aims to minimise energy consumption and prolong the network lifetime. The energy consumption may high if the SINK is located too far from the CHs. So instead of having a common SINK for the entire network, multiple SINKs can be shared between them. This will reduce the energy consumption of CHs due to the long distance between the CH and SINK. The performance measures used for evaluation are energy consumption, delay, and network lifetime. The results indicate that combining routing and MAC schemes conserves energy better than utilizing MAC scheme alone.

Keywords: MAC, Cluster Head (CH), SINK node, Clustering, Energy Consumption.

1 Introduction

Wireless sensor network (WSN) consists generally of a large number of sensor nodes randomly deployed in a geographical area, self-organising into a network to monitor the physical environment [1]. The wireless sensor nodes operate in an unattended mode over time without means of renewing their energy resource supplied by the batteries. Energy efficiency is the main design challenge in these networks as it determines their lifetime. The major source of energy consumption in the sensor nodes is their radio communication employed by their transmitter [2]. Medium access control (MAC) protocols arbitrate sensor nodes' access to the channel. MAC protocols are faced with energy consumption challenges largely due to idle listening and node activity scheduling; media access is utilised to mitigate the problems. Routing protocols help select communication routes between communicating node pairs. The use of wireless communication by sensor nodes as a medium of transmission also presents a challenge for routing protocols. Owing to the fading characteristic of the wireless channel, reliability remains a concern for the selected communication routes. The use of channel quality indicator (CQI)- based routing metrics alleviates this problem. Most research efforts investigate the performance of MAC protocols independently; however, combining the efficiency of both MAC and routing protocols could further enhance the energy performance. Large- scale WSNs are faced with communication overhead of individual nodes transmissions to the base station (BS) leading to excessive energy consumption. Clustering techniques [3] have been adopted to overcome these constraints. Clustering is faced with the challenge of unbalanced energy consumption problem. To overcome this challenge, variable cluster size technique is used in this work.

2 Related work

A variety of energy-efficient code division multiple access (CDMA)-based, time division multiple access (TDMA), and hybrid MAC protocols have been proposed for WSNs. Clustered wireless protocols have adopted the TDMA access schemes for their intra-cluster communication [1, 2, 4–7]. They include TDMA MAC [5], bit map-assisted (BMA) MAC [6], and bit map-assisted–round robin (BMA-RR) MAC [7]. TDMA MAC allocates collision-free time slot for each node within a cluster. The drawback of this protocol is that the nodes stay active during their allotted slots leading to idle listening when nodes have no data to transmit. BMA MAC enhances the performance by switching off the radio modules on nodes without data to send to conserve energy. Its policy of one node per slot leads to the inability to adapt to the variable traffic loads. BMA-RR MAC is an improvement of the TDMA and BMA MAC protocols. It uses an adaptive round robin TDMA scheduling scheme that adapts to the nodes data traffic. The protocol suffers from the following; it does not take into consideration the remaining energy levels of the nodes and nodes may die out while they have outstanding data in their buffers; it does not address the energy concerns beyond the cluster communication; it has the common problem of idle listening; lastly, it does not consider the channel characteristics for node- based activity scheduling. For these reasons, this work proposes a unique protocol that combines a cross-layer-based scheduling MAC for intra-cluster communication with a CQI-based routing protocol to achieve the best energy savings.

Multihop communication has been used in WSNs to minimize the energy consumption based on the first-order radio communication model [2]. The selection of routes to the destination has been achieved through hop-by-hop or source routing protocols. For wirelesses sensor communication, source routing protocols are preferred due to their low overhead. Some of the protocols include, dynamic source routing (DSR) [8], *ad hoc* on-demand distance vector (AODV) [9], energy-efficient unequal clustering (EECU) [10], and multihop routing protocol with unequal clustering (MRPUC) [11]. In DSR protocol, the packets sent have an ordered list of all the intermediate nodes on the routing path in their header. The frequency of route requests is reduced as the nodes keep a cache for the learnt routes. AODV

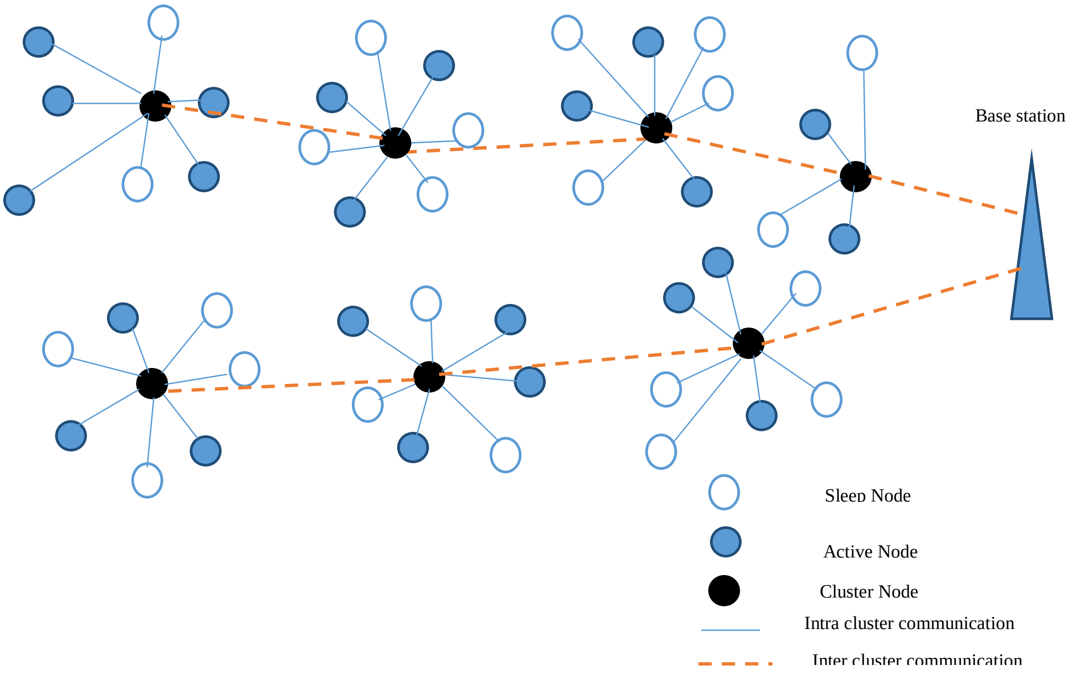


Fig. 1 *WSN network model*

To ensure that routes are valid by sending the hello messages periodically for link breakage detection; however, this creates communication overhead by the frequent hello messages. These protocols do not take the link quality to the next hop node into consideration for the choice of routes. They also do not consider the energy level of the nodes on the route to the destination leading to their poor performance. The EECU utilises an energy-aware multihop routing protocol for its inter-cluster communication over an unequal cluster topology. However, it does not utilize an energy- efficient MAC protocol for its communication and does not consider the channel quality of the selected route leading to excessive energy consumption as the success probability of transmission is not guaranteed. MRPUC is a multihop routing protocol based on unequal clustering. It selects routes based on the distance and energy level of the cluster head (CH). The protocol does not consider the channel reliability resulting into energy losses due to retransmissions. Furthermore, it uses an ideal TDMA MAC for its communication, which limits further performance improvement as this scheme is prone to idle listening. Ring routing [12] is another protocol proposed to resolve the issue of early energy depletion on nodes closest to the sink in multihop networks. This protocol proposes establishment of rings structures upon movement of the sinks, and new positions of the sinks are delivered with less overhead. The ring routing protocol efficiency is however limited to mobiles sinks alone, where the sink is stationary its effectiveness cannot be realised. More recent protocols [13–15] have attempted to resolve some of the issues. In [13], a location-aware sensor routing (LASeR) protocol is developed to addresses reliability and latency requirements of emerging applications. In [14], the impact of route length on the rarely been utilised in the literature. The energy-efficient routing protocol featuring CQI and energy-based route selection ensures network reliability and stability. Furthermore, the work utilises unequal variable clustered topology for resolving unbalanced energy consumption network issues. Finally, the analysis of the combined energy-efficient MAC and routing protocol is done proving to be more energy conservative.

3. Proposed system

The energy consumption may high if the SINK is located too far from the CHs. So instead of having a common SINK for the entire network, multiple SINKs can be uses. All the SINKs are interconnected and the information can be shared between them. This will reduce the energy consumption of CHs due to the long distance between the CH and SINK.

In this paper, we propose an Energy-efficient MAC based Multi-sink Clustering Algorithm (EEMCA) for WSNs. We divide the sensing field into several equal clusters. Each cluster head collects data and sends it to one of the multiple sinks according to its own preference. We also propose an inter-cluster and intra-cluster routing algorithm. Therefore, it not only saves energy through clustering, but ensures that workload is dispersed so that the phenomenon of unbalanced energy consumption around one single sink can be alleviated. The network lifetime can also be prolonged.

3.1.1. Network Model:

We assume that the network is composed of N sensor nodes, denoted as: 1 2 { , ,..., }N S S S respectively. They are uniformly dispersed within a rectangle field and continuously monitor their surrounding environment. There are k sink nodes (or Base Station, BS) have been deployed with random location, represented as 1 2 { , ,..., } BS BS BSk , as is shown in Figure 2. We make the following assumptions:

（1） All nodes are homogeneous and stationary after deployment.

（2） The multiple sink nodes are pre-located within the sensing field randomly.

（3） Nodes can adjust their transmission power according to the relative distance to its receiver.

（4） Links are symmetric.

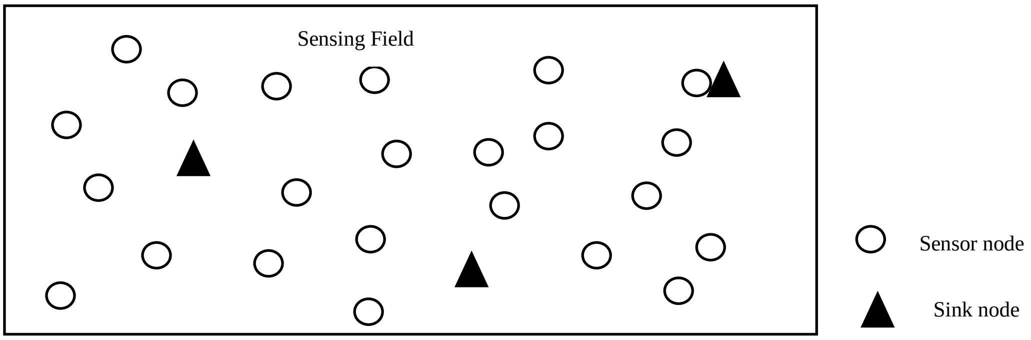


Figure 2. Network Model

3.2. Cluster Formation and Cluster Head Selection

We divide the entire network into n equal clusters, as is shown in Figure 3

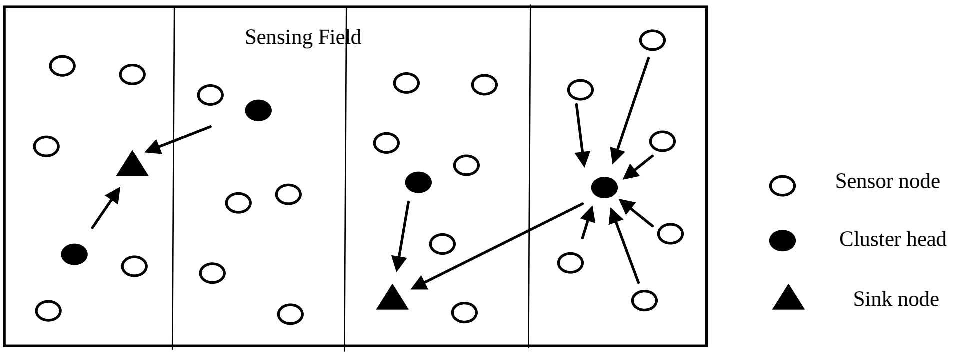


Figure 3. Cluster Formation

Each cluster has only one cluster head. The other nodes in the same cluster send data to the cluster head. Then cluster head send aggregated data to its relevant sink. The clustering method proposed in our EEMCA has various advantages. First and foremost, data aggregation reduces traffic load. Second, the cluster heads locate in a more uniform way comparing to the probabilistic deployment in LEACH. It is more suitable for the large-scale deployed networks. Last but not the least, it can prolong the network lifetime, as a majority of nodes close the communication module for relatively long time. After equally dividing the sensing field into several equal areas, we will next choose each cluster head. As the network is considered to be heterogeneous, we determine each cluster head by its residual energy. When the selection begins, we first motivate the sensor node that is located in the center of each cluster like S_i. It is regarded as the cluster head candidate. It broadcasts one message within a neighborhood of radius R. This message aims to motivate other nodes for the competition of the cluster head. It contains the node's id and its residual energy. Only the nodes within the transmission range can receive the message and become active, while the outside nodes remain idle. If any node j S has larger residual energy than i S , it becomes the new cluster head candidate and broadcasts new message with its own information to the others. If j S has equal residual energy with S_i, compare the ID. The node with a smaller ID wins. If j S has smaller residual energy than S_i, it still broadcasts the message of S_i. As soon as the comparison is done, the unchosen node becomes idle again. All nodes in the cluster should be compared only once. In this way, the node with the largest residual energy is chosen as the cluster head. The cluster-selection algorithm can be formulated as to find ( ) Max ($E_{residual}$).

3.3. Routing Procedure

3.3.1. Inter-cluster Routing:

After data fusion, the cluster heads should send aggregated data to sink nodes. We can make good use of the multi-sink topology. In our algorithm, each cluster head selects one optimal sink respectively. The minimization of energy consumption is our top concern. For any cluster head CHn , the energy consumption to sink BSk is represented as (,) E CH BS n k . Its calculation follows the energy model in equation1.

$$E(CH_n,BS_k)=\begin{cases} lE_{elec}+l\varepsilon_{fs}d(CH_n,BS_k)^2, d(CH_n,BS_k)<d_o \\ lE_{elec}+l\varepsilon_{mp}d(CH_n,BS_k)^4, d(CH_n,BS_k)\geq d_o \end{cases} \quad \text{eq.(1)}$$

Since the cluster heads send data to the sink nodes directly within one hop, from the formula we can see that the smaller (,) n k d CH BS is, the smaller (,) E CH BS n k becomes.

Therefore, we only need to compare the distances from each cluster head to different sinks and choose the shortest one. In this way, the cluster head will find the optimal sink with the least energy consumption. The inter-cluster algorithm can be formulated as to find ((,)) n k k Min d CH BS .

3.3.2. Intra-cluster Routing:

Moreover, in many clustering algorithms such as LEACH, sensor nodes in the same cluster send data directly to the cluster head. Due to the fact of their various locations, some sensor nodes may consume relative large amount of energy due to long-distance transmission. Therefore we set a multi-hop routing protocol. For any member node i S in one cluster, the energy consumption it costs to send data directly to its cluster head i CHS is represented as 1 (,) i E S CH i S .

$$E_1(S_i,CH_{S_i})=\begin{cases} lE_{elec}+l\varepsilon_{fs}d(S_i,CH_{S_i})^2, d(S_i,CH_{S_i})<d_o \\ lE_{elec}+l\varepsilon_{mp}d(S_i,CH_{S_i})^4, d(S_i,CH_{S_i})\geq d_o \end{cases}$$

eq.(2)

In the mean time, it is possible that i S tries to find another sensor node j S to relay data to save energy by avoiding directly communication with i CHS , as it is shown in Figure 4.

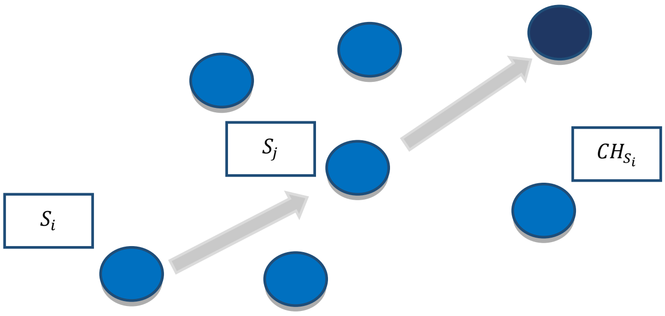


Figure 4: Communication between Sensor node and CH

To deliver a l-length packet to the cluster head, the energy consumption 2 (, ,) i E S S CH i j S is calculated as formula (5) and the optimal relay node is determined based on the smallest value of 2 (, ,) i E S S CH i j S where ε and α vary in different situations according to the energy model.

$$\begin{aligned} E_2(S_i,S_j,CH_{S_i}) &= E_{Tx}(l,d(S_i,S_j))+E_{Rx}(l)+E_{Tx}(l,d(S_j,CH_{S_i})) \\ &= l(E_{elec}+\varepsilon d^{\alpha}(S_i,S_j))+lE_{elec}+l(E_{elec}+\varepsilon d^{\alpha}(S_j,CH_{S_i})) \\ &= 3lE_{elec}+\varepsilon d^{\alpha}(S_i,S_j)+\varepsilon d^{\alpha}(S_j,CH_{S_i}) \end{aligned}$$

eq.(3)

Each i S chooses j S with the smallest value of 2 (, ,) i E S S CH i j S as the relay node if necessary.

$$E_2(S_i,CH_{S_i})=Min(E_2(S_i,S_j,CH_{S_i}))$$

eq.(4)

Compare equation 4 and equation 6, and the smaller one is chosen.

$$\begin{aligned}&E(S_i,CH_{S_i})\\&=Min(E_1(S_i,CH_{S_i}),E_2(S_i,CH_{S_i}))\\&=Min((lE_{elec}+\varepsilon d^{\alpha}(S_i,CH_{S_i})),Min(3lE_{elec}+\varepsilon d^{\alpha}(S_i,S_j)+\varepsilon d^{\alpha}(S_j,CH_{S_i})))\end{aligned}$$ eq.(5)

In our algorithm, however, the sink nodes are randomly located. Therefore, some nodes may consume less energy through sending data directly to the sink rather than to its cluster head. So it is necessary to compare (,) i E S CH i S and (,) E S BS i k and decide the final route. For simplicity, the intra-cluster algorithm can be formulated as to find ((,), (,))

Flowchart of proposed system:

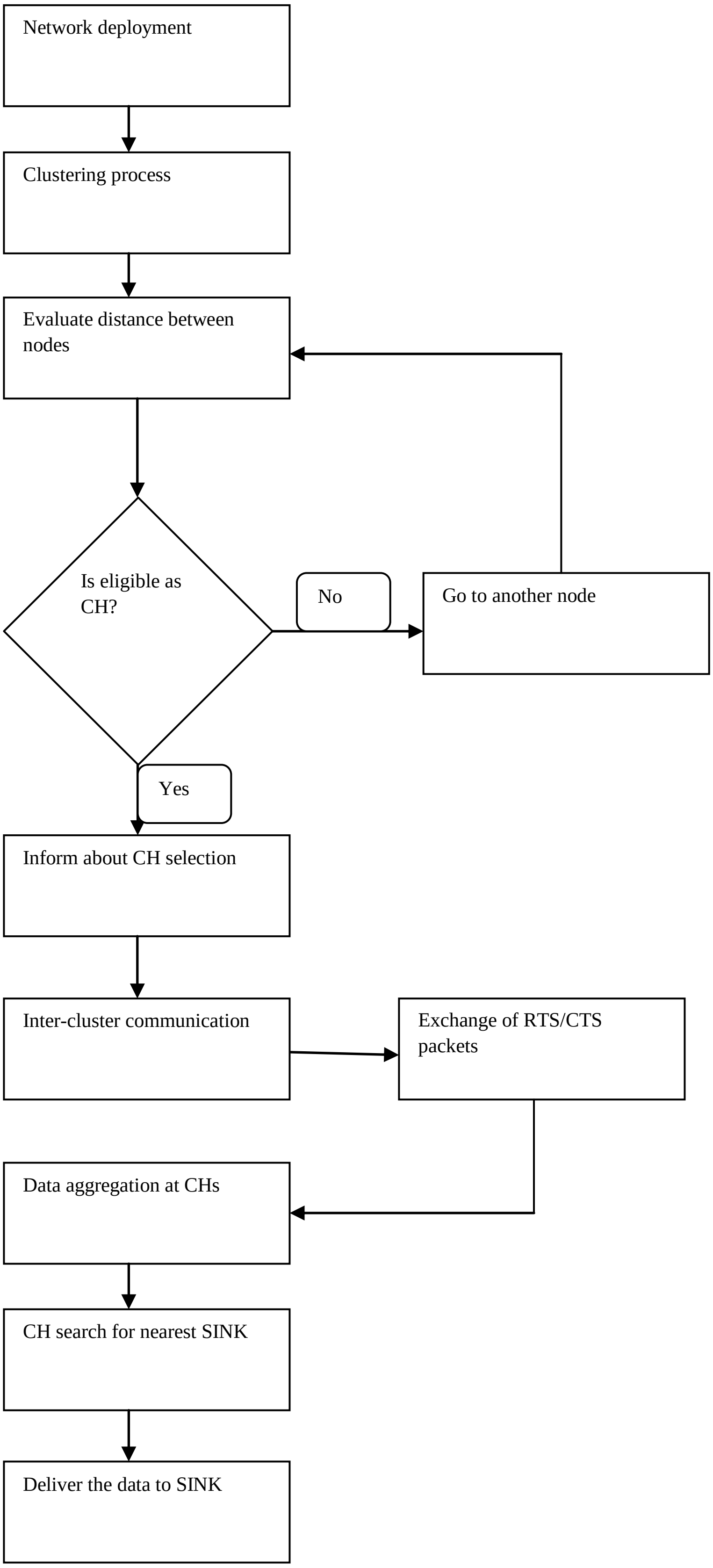


Figure5: Flowchart of Proposed system

4. Result and discussion

4.1 Simulation results:

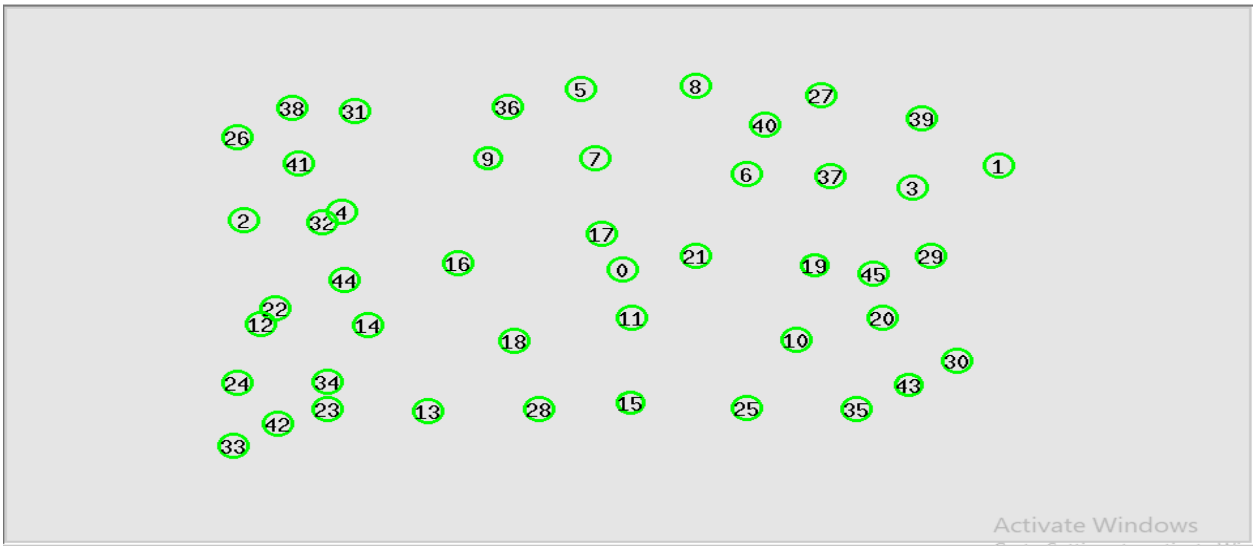
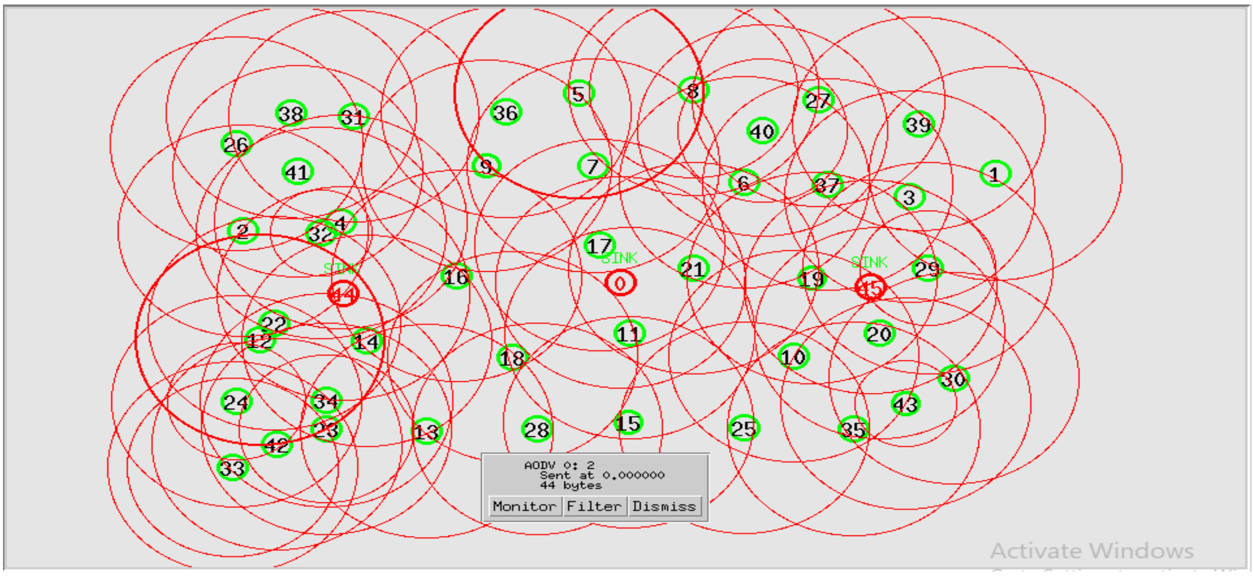


Figure6: Network deployment

In above figure 6, showing all nodes placed in network and deployment of nodes is in network properly. Here all nodes displayed based on topology values and all properties of nam window it should be mentioned.



```
AODV 0: 2
   Sent at 0.000000
   44 bytes
```

Figure7: Broadcasting process in network

In figure 7, broadcasting occur throughput the network. Here broadcasting occur for communication purpose. All nodes should be involved in this process.

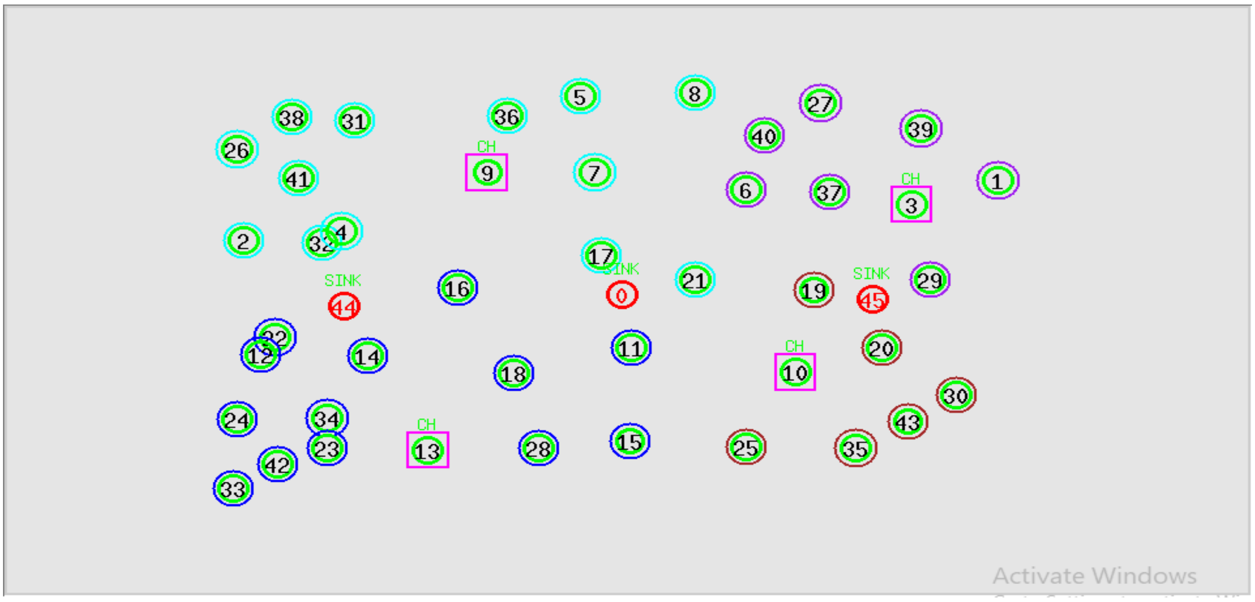
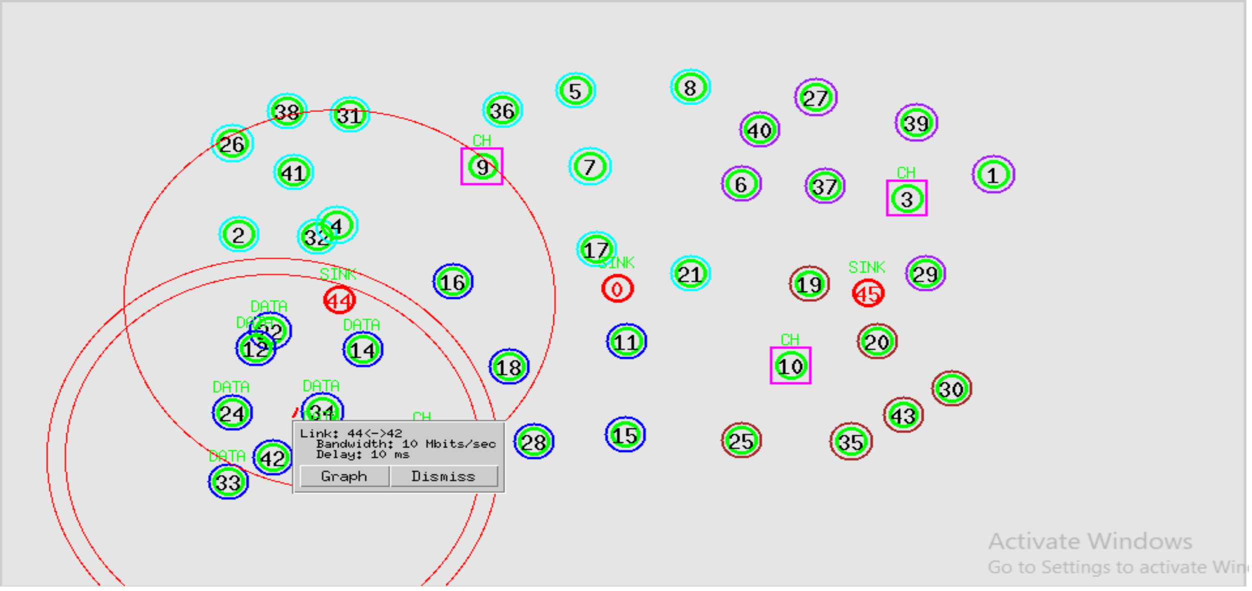


Figure8: Clustering process in network

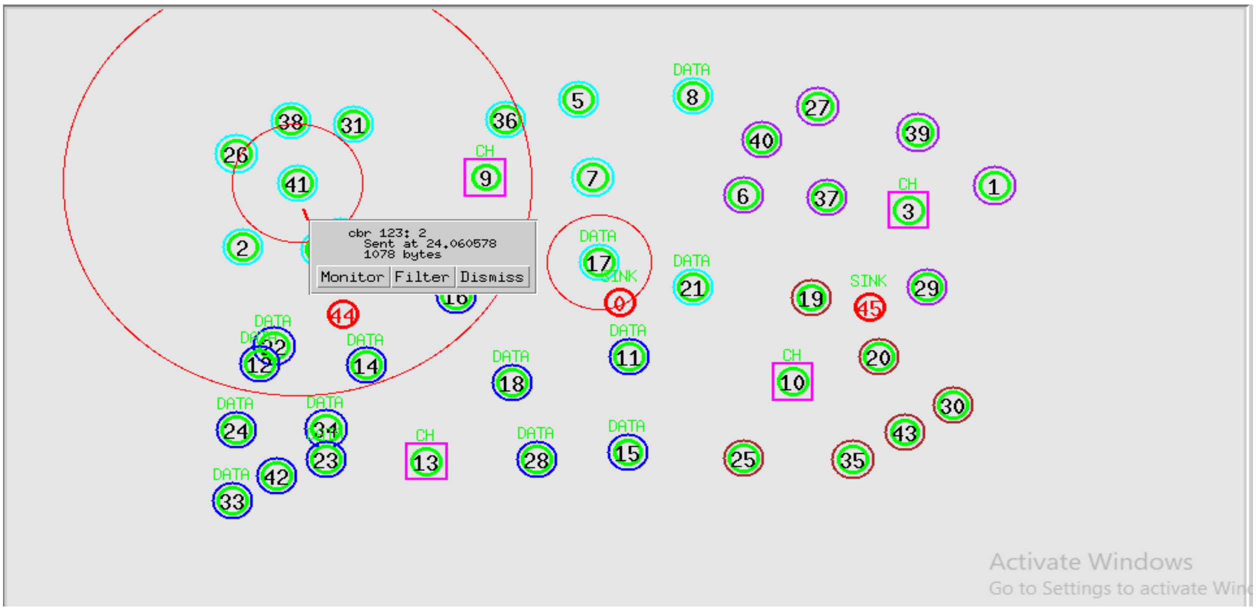
In above figure 8, all nodes labelling mentioned. Here cluster heads and sink node displayed based on formation of network. Here cluster formation occurs and link should be shows based on bandwidth and delay time. In this broadcasting the data should be applicable to all nodes in network.



```
Link: 44<->42
   Bandwidth: 10 Mbits/sec
   Delay: 10 ms
```

Figure9: Cluster level Broadcasting

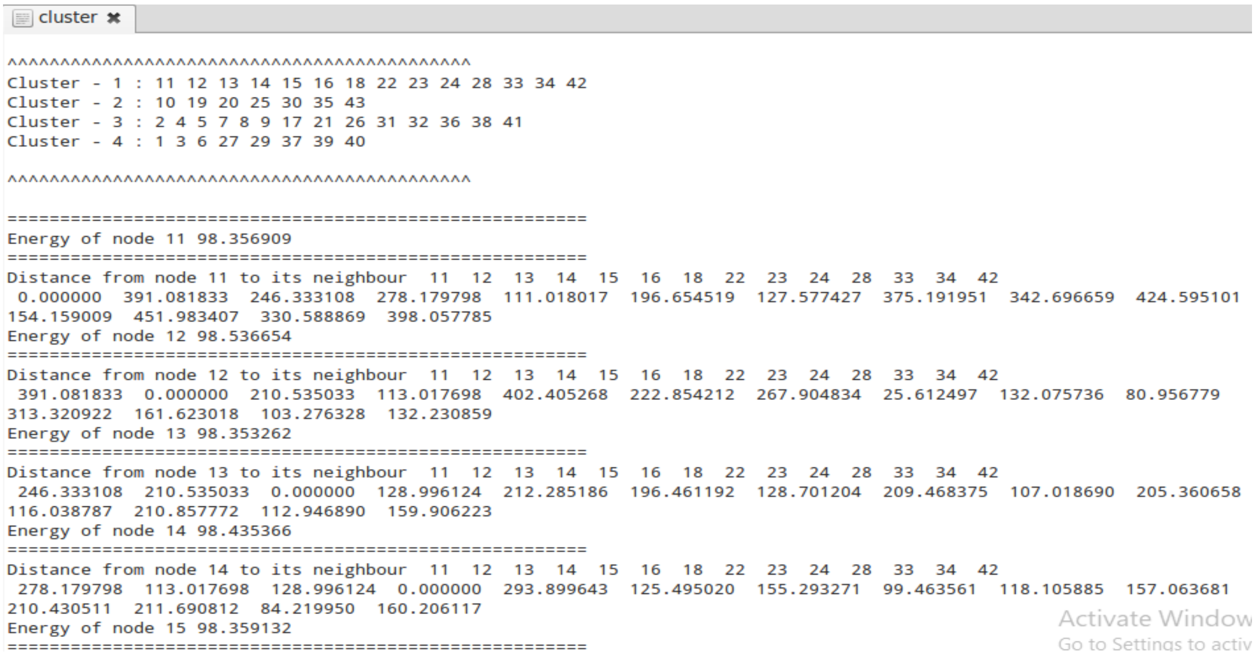
Here links between hop nodes to sink node then shows the bandwidth and delay between these two. Figure 9 represent the cluster level broadcasting level.



cbr 123: 2
Sent at 24.060578
1078 bytes

Figure 10: Cluster level data process

In above figure 10, data transmission from cluster head and sink by help of traffic protocol. Here time interval, packet size, and number of intervals represented.



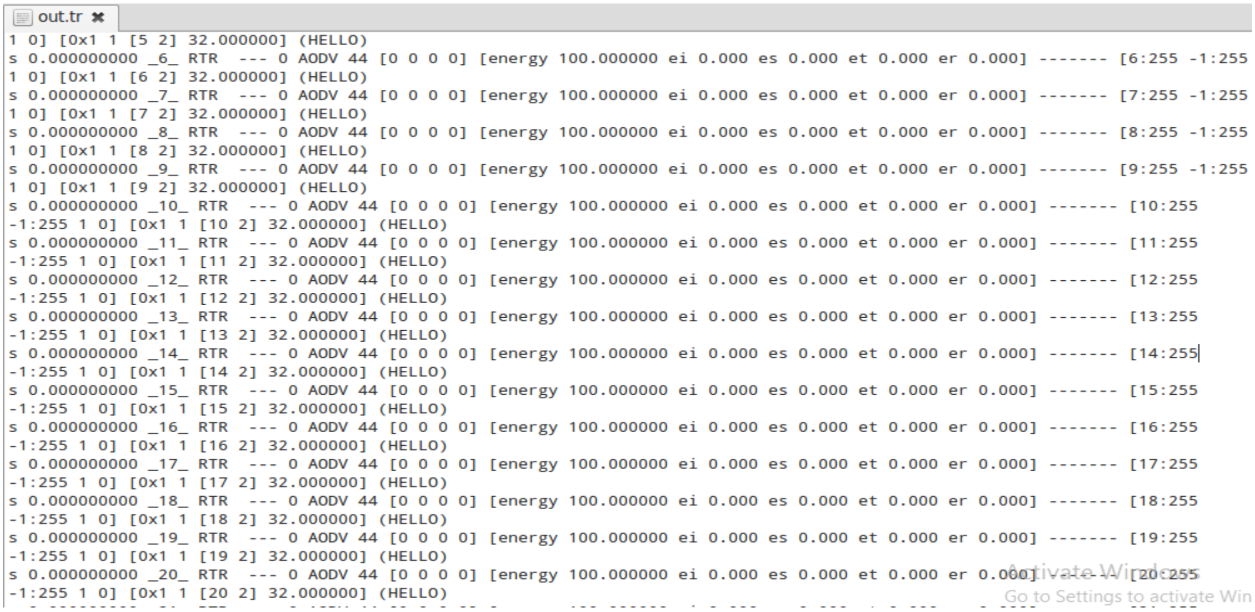
```
^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
Cluster - 1 : 11 12 13 14 15 16 18 22 23 24 28 33 34 42
Cluster - 2 : 10 19 20 25 30 35 43
Cluster - 3 : 2 4 5 7 8 9 17 21 26 31 32 36 38 41
Cluster - 4 : 1 3 6 27 29 37 39 40

^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

=======================================================
Energy of node 11 98.356909
=======================================================
Distance from node 11 to its neighbour  11  12  13  14  15  16  18  22  23  24  28  33  34  42
 0.000000  391.081833  246.333108  278.179798  111.018017  196.654519  127.577427  375.191951  342.696659  424.595101
154.159009  451.983407  330.588869  398.057785
Energy of node 12 98.536654
=======================================================
Distance from node 12 to its neighbour  11  12  13  14  15  16  18  22  23  24  28  33  34  42
 391.081833  0.000000  210.535033  113.017698  402.405268  222.854212  267.904834  25.612497  132.075736  80.956779
313.320922  161.623018  103.276328  132.230859
Energy of node 13 98.353262
=======================================================
Distance from node 13 to its neighbour  11  12  13  14  15  16  18  22  23  24  28  33  34  42
 246.333108  210.535033  0.000000  128.996124  212.285186  196.461192  128.701204  209.468375  107.018690  205.360658
116.038787  210.857772  112.946890  159.906223
Energy of node 14 98.435366
=======================================================
Distance from node 14 to its neighbour  11  12  13  14  15  16  18  22  23  24  28  33  34  42
 278.179798  113.017698  128.996124  0.000000  293.899643  125.495020  155.293271  99.463561  118.105885  157.063681
210.430511  211.690812  84.219950  160.206117
Energy of node 15 98.359132
=======================================================
```

Figure11: Cluster file

Figure11 represents the cluster formation with time update and has eight clusters in the network. The cluster head selection process is based on the distance between neighbors in the network and residual energy. After the distance calculation, the cluster head has decided by which cluster member has lowest distance in the network while compared to other members in the network.



```
1 0] [0x1 1 [5 2] 32.000000] (HELLO)
s 0.000000000 _6_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [6:255 -1:255
1 0] [0x1 1 [6 2] 32.000000] (HELLO)
s 0.000000000 _7_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [7:255 -1:255
1 0] [0x1 1 [7 2] 32.000000] (HELLO)
s 0.000000000 _8_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [8:255 -1:255
1 0] [0x1 1 [8 2] 32.000000] (HELLO)
s 0.000000000 _9_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [9:255 -1:255
1 0] [0x1 1 [9 2] 32.000000] (HELLO)
s 0.000000000 _10_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [10:255
-1:255 1 0] [0x1 1 [10 2] 32.000000] (HELLO)
s 0.000000000 _11_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [11:255
-1:255 1 0] [0x1 1 [11 2] 32.000000] (HELLO)
s 0.000000000 _12_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [12:255
-1:255 1 0] [0x1 1 [12 2] 32.000000] (HELLO)
s 0.000000000 _13_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [13:255
-1:255 1 0] [0x1 1 [13 2] 32.000000] (HELLO)
s 0.000000000 _14_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [14:255
-1:255 1 0] [0x1 1 [14 2] 32.000000] (HELLO)
s 0.000000000 _15_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [15:255
-1:255 1 0] [0x1 1 [15 2] 32.000000] (HELLO)
s 0.000000000 _16_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [16:255
-1:255 1 0] [0x1 1 [16 2] 32.000000] (HELLO)
s 0.000000000 _17_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [17:255
-1:255 1 0] [0x1 1 [17 2] 32.000000] (HELLO)
s 0.000000000 _18_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [18:255
-1:255 1 0] [0x1 1 [18 2] 32.000000] (HELLO)
s 0.000000000 _19_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [19:255
-1:255 1 0] [0x1 1 [19 2] 32.000000] (HELLO)
s 0.000000000 _20_ RTR  --- 0 AODV 44 [0 0 0 0] [energy 100.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [20:255
-1:255 1 0] [0x1 1 [20 2] 32.000000] (HELLO)
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Figure 12: Trace file

In above figure 12, trace file represented. Here all nodes data, routing process, time intervals for sending the packets, energy level updates of nodes displayed.

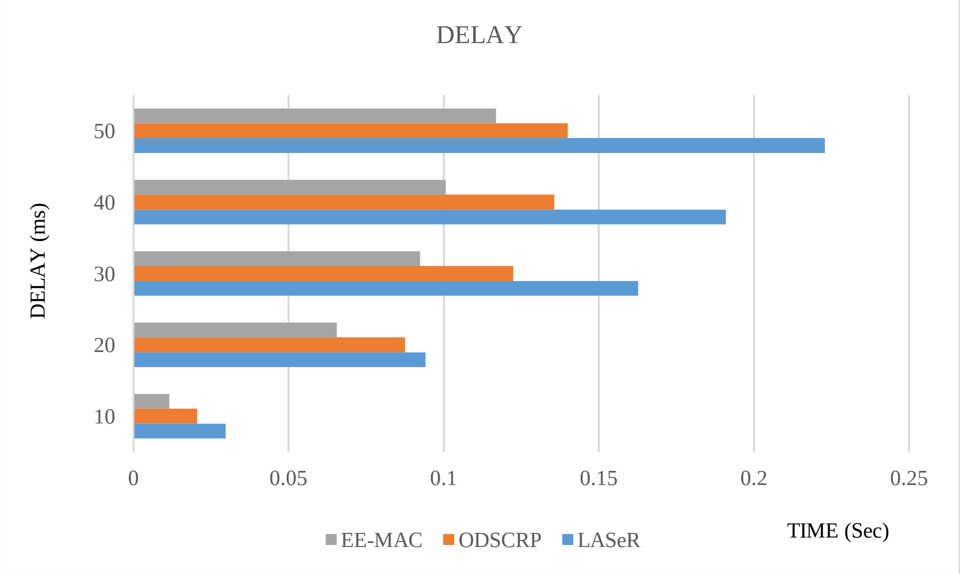

Figure 13: Delay

In figure 13 the delay is shown. In network delay should be low. But in existing method they are very high. So we proposed a method EE-MAC which performed well and gave less delay than the existing methods like ODSCRP, LASeR.

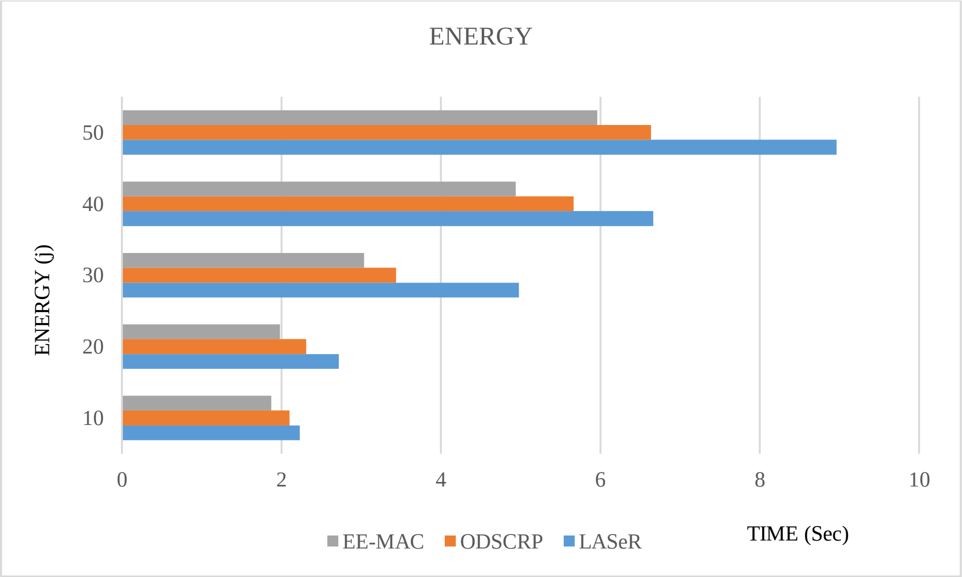

Figure 14: Energy Consumption

In figure 14, the energy consumption is shown. In network consumption of energy should be low. But in existing method they are very high. So we proposed a method EE-MAC which performed well and gave less energy consumption than the existing methods like ODSCRP, LASeR.

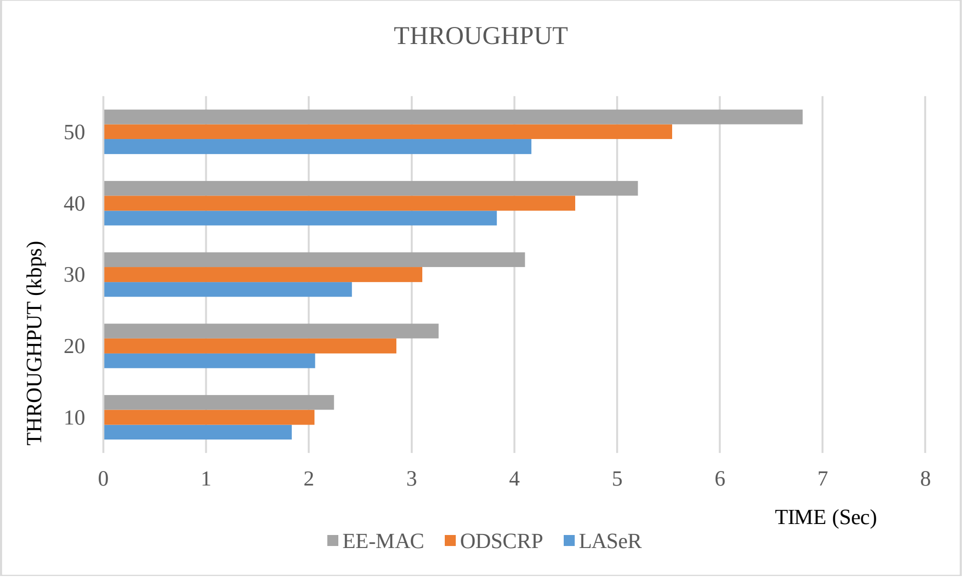

Figure 15: Throughput

In figure 15, the throughput is shown. In network throughput values should be high. But in existing method they are very less. So we proposed a method EE-MAC which performed well and gave high throughput than the existing methods like ODSCRP, LASeR.

Conclusion

This work proposes an energy-efficient MAC based multi sink clustering algorithm for multihop WSN. The MAC coordinates the sensor node radio activity between sleep, active, and back-off state according to an adaptive scheduling to conserve energy. It communicates the data between clusters and BS via multihop routes of known channel quality. The inter-cluster and intra-cluster routing algorithm is explained in details. Moreover, we deduce the deployment of the sink nodes with an optimal multiple sink number through experiments. Simulations show that the energy consumption is largely reduced than existing algorithms. The performance of the proposed framework was evaluated based on simulation and analytical studies, and they indicate improved performance on the energy consumption, throughput, and delay of wireless sensor. The improvement on energy in the network overcomes the unique design challenge in WSNs which has a direct impact on the lifetime of sensor nodes.

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