CHAPTER 4

ANALYZING ENERGY EFFICIENT CLUSTERING WITH MULTILEVEL HIERARCHICAL ROUTING

4.1 INTRODUCTION

Wireless Sensor Network is renowned as one of the emerging technologies of the 21st century. They are expected to develop an interaction between humans and environment to a new level. However the technology is still in its infancy and undergoing rapid evolution with a tremendous amount of research effort in the networking community. The main purpose of a WSN is to assist in monitoring a physical phenomenon by gathering and delivering information to the interested party. Sensor nodes are deployed in a particular field that helps in tracking and conveying information to a base station as mentioned by Heinzelman et al (2002). The main success of the operation can be attributed to the recent development of Micro-Electronic-Mechanical Systems (MEMS) and this technology has enabled the production of powerful micro sensor nodes.

WSN becomes a new technology trend when human, machines and the environment are being integrated autonomously. This is made possible by advances in processor, memory and microelectronics devices which allow the sensing and computing elements to be integrated together in small devices to perform the programmed tasks. These networks are generally used in disaster relief applications, battlefield surveillance, environmental control, habitat monitoring, intelligent buildings, facility management, machine surveillance, preventive maintenance, precision agriculture, medicines and healthcare, transport and logistics.

There are some constraints in sensor networks due to simple node architecture. Major issue of WSNs is energy because in most applications replacement of power resources are not possible or infeasible. In large or small area the sensors are deployed highly dense fashion for sensing the environment. Due to highly dense sensor network overhearing, collision and redundant transmission becomes the major problem. Hence the energy is the challenging subjects and design factor of WSNs. Moreover CH acts as intermediate router to the sink node or BS in hierarchical routing. The CH exhausts energy much faster than other nodes because CH plays the dual role of data originator and data router in WSNs. The availability of paths to the destination is reduced and serious problems are caused in the sensor network when the node failures as quoted by Karaki & Kamal (2004).

The remainder of this section is organized as follows. Section 4.2 explains about the Hierarchical Routing. Section 4.3 describes the some of the hierarchical routing techniques. Section 4.4 exhibits the details of analyzing E2C with hierarchical routing techniques and Section 4.5 evaluates the performance of E2C with hierarchical routing techniques via simulations. Finally, Section 4.6 concludes the chapter.

4.2 HIERARCHICAL ROUTING

Scalability is one of the major design attribute for sensor networks like other communication networks. When the sensor density is increased, the gateway gets overload if single-tier network is used. Due to this overloading latency in communication and inadequate tracking of events will occur. The sensors are typically not capable of long-haul communication. Hence when the single-gateway architecture is used for a larger set of sensors which covering a wider area of interest, it is not a scalable. In some routing approaches networking clustering has been pursued to allow the system to handle with additional load and to be able to cover a large area of interest without degrading the service.

Energy consumption is one of the most important issues among all other issues in WSN. Hierarchical Routing Protocols (HRPs) is found to be the best regarding energy efficiency. HRPs are found to be very energy efficient when this type of routing protocol was first introduced by Heinzelman et al (2000). The special feature of this approach is that it provides self-organization capabilities to allow large scale network deployment. Basically, in a hierarchical architecture, some nodes take responsibility to perform high energy transmission while the rest of the nodes perform normal task. To select eligible high energy nodes Power-aware algorithm is used to relay the data from normal nodes to the BS. HRPs can be categorized into two types based on the topology management, they are cluster-based HRPs and chain-based HRPs.

A HRP consists of two phases based on its operation. The first phase is the set-up phase in which the sensor nodes are organized to form hierarchical architecture either in a cluster based or chain-based manner. The data are routed from sensor nodes to the BS in the second phase known as steady state phase. The consumption of energy greatly in collecting and disseminating data is minimized by using clustering technique. Hierarchical routing protocols minimize energy consumption by dividing nodes into clusters. A node with more processing power is selected as a cluster head which aggregates the data sent by the low powered sensor nodes in each cluster. The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and to decrease the number of transmitted messages to the sink data aggregation and fusion is performed. The different schemes used in hierarchical routings are mainly differ by route selection and the behavior of the nodes in inter and intra-cluster domain.

4.3 CLUSTER BASED HIERARCHICAL ROUTING

In cluster-based HRPs, sensor nodes are grouped into clusters and each of these clusters are led by one of the nodes, called the cluster head . A CH acts as an intermediate node between cluster members and the BS as shown in Figure 4.1.

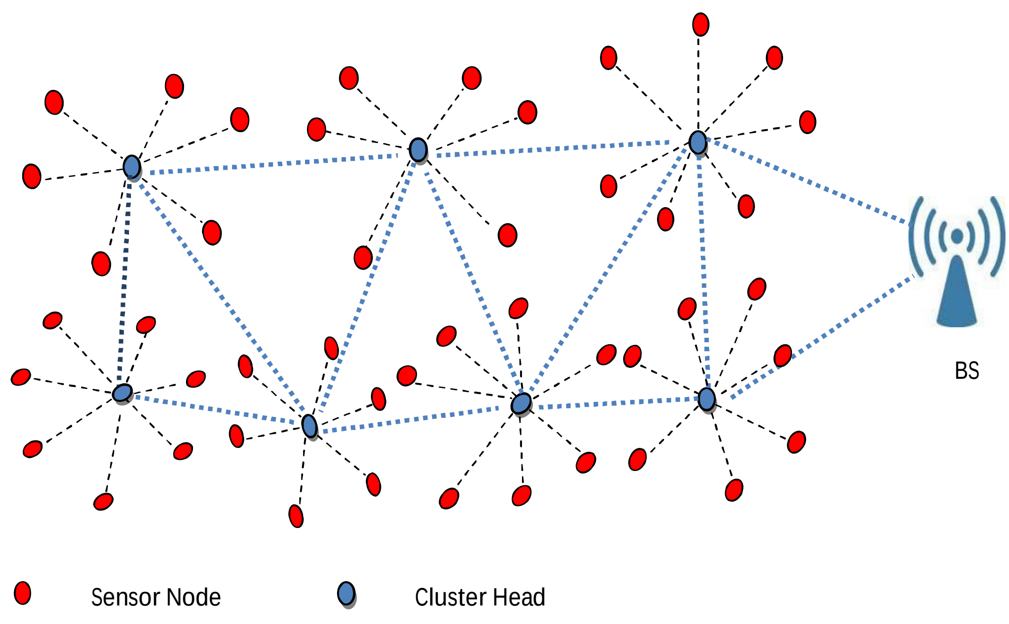


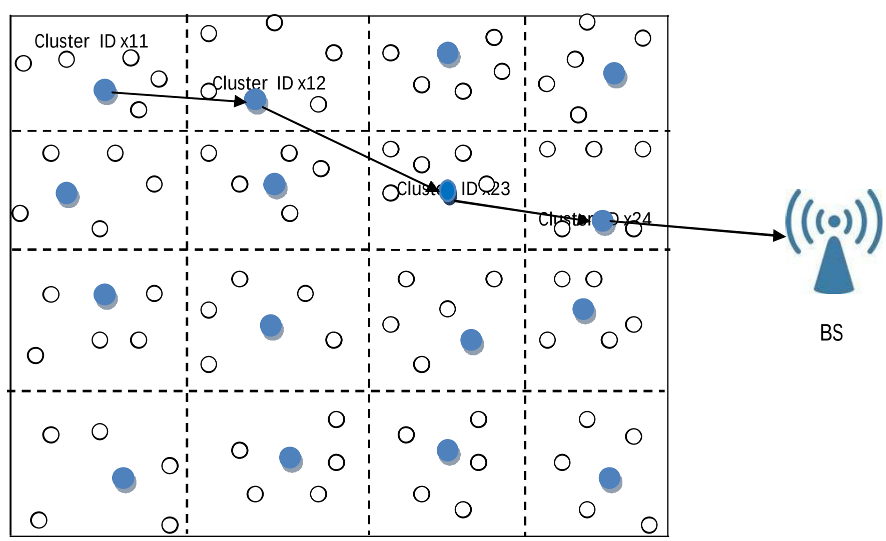
Figure 4.1 Cluster Based Hierarchical Routing

In chain-based HRPs, all nodes in the field are connected in a chain structure. The chain leader is selected based on the energy. The most energy healthy node is chosen as the chain leader to mediate the data transmission from normal nodes to the BS. To further enhance the performance such as data fusion, threshold values set up, and sleep/idle pairing in both types of

HRPs, there are other design features are applied. In this section, some of the cluster based hierarchical routing techniques are discussed.

4.3.1 Cluster ID based Hierarchical Routing

In cluster based routing, tasks are accomplished in rounds and each round consists of phases. Each round maintains routing table for CH replacement. During CH selection the routing table and routes consumes energy of each sensor node, because control messages are disseminated in network for new route selection. Due to repeated selection of CH the maximum amount of sensor nodes energy is consumed. This problem is overcome by using cluster ID instead of CH ID to maintain the routes. When cluster ID is used there is no need to re-compute routes and maintain the routing tables by sensor nodes as discussed by Ahmed et al (2007).



-Cluster Head

-Cluster Member

Figure 4.2 Cluster ID based Hierarchical Routing

The energy consumed in each round to calculate the routing table is reduced by using CIDHR (Cluster ID based Hierarchical Routing). In this approach a unique ID is assigned to each cluster and cluster ID is used as next hop for data transmission. CHs are selected on the basis of residual energy. The CH that holds the cluster ID on round forwards the cluster ID to the selected CH on next round. The cluster formation and routing phases both are only executed during the initialization of network hence the energy consumption is reduced and the network life is also increases to about 16%.

The routes are computed once when the node is powered up and recomputed if and only if any change occurs in the network. Conversely in cluster based WSN routes are recomputed periodically in each round. Every route must be re-computed for every round as the CHs are changed in each round. The CH ID used as the next hop ID in all existing cluster based routing algorithms.

Figure 4.2 explains the Cluster ID based Hierarchical Routing. In this method a unique ID is used to identify each cluster. It uses cluster ID as a next hop address in routing table. In this method the data sensed by all sensor nodes in the cluster sends to their CH x11where data aggregation takes place. Then this CH transmits the data to its neighbor CH x12. The CHx12 send to CHx23 and x23 sends the data to CHx24. Finally the data is forwarded to BS by CHx24. A cluster node keeps this cluster ID token as long as it remains the CH of this cluster. This token is transferred to new CH after the round is over. The new CH has been selected on the basis of maximum remaining energy. By using CIDHR the energy consumed in each round for routing table calculation is reduced.

4.3.2 Multi-tier Hierarchical Routing

Multi-tier Hierarchical Routing defines a multi-hop hierarchical routing, where the clusters are formed by CHs and CHs are selected from CHs. CHs which is in high level directly communicate with BS that reduces the routing complications and prolong the lifetime of the network. Multiple hops are possible in between adjacent tiers. The data from each local tile which are present in the lower tier is received by the cluster head in upper tier as discussed by Chen & Liu (2011).

Once inter-network aggregation is completed, the cluster head sends the data to upper cluster of next grade, as a result a hierarchical data aggregation tree is gradually built from the stand point of sink. When a CH detects the interesting event, it propagates that event to all its neighboring CHs by using simple flooding method. Hence, all the CHs know where the events happened. The construction of d-tree is initiated by CH only after it receives the query packet from the mobile sink.

The broadcast storm is reduced to a certain degree by defining the forwarding region with the locations of interested network and sink's local network. The diagonal line should always starts from the utmost vertex of interested network to the corresponding furthest vertex of sink network. The contention and collision is avoided and sufficient redundancy can be saved. Finally the sink will propagate the query packet to the Immediate Cluster Head (ICH) in local network of interest.

The field that is presented in the query is used to identify the location of sink and destination of CH. By using forwarding zone the ICH of sink will be the root in MTHR. As each CH constructs the d-tree, the d-tree is restricted to the forwarding zone. The d-tree starts from the ICH to the destination CH of interest network. CHs that are presented outside of the forwarding zone do not forward the packets but it can receive a packet.

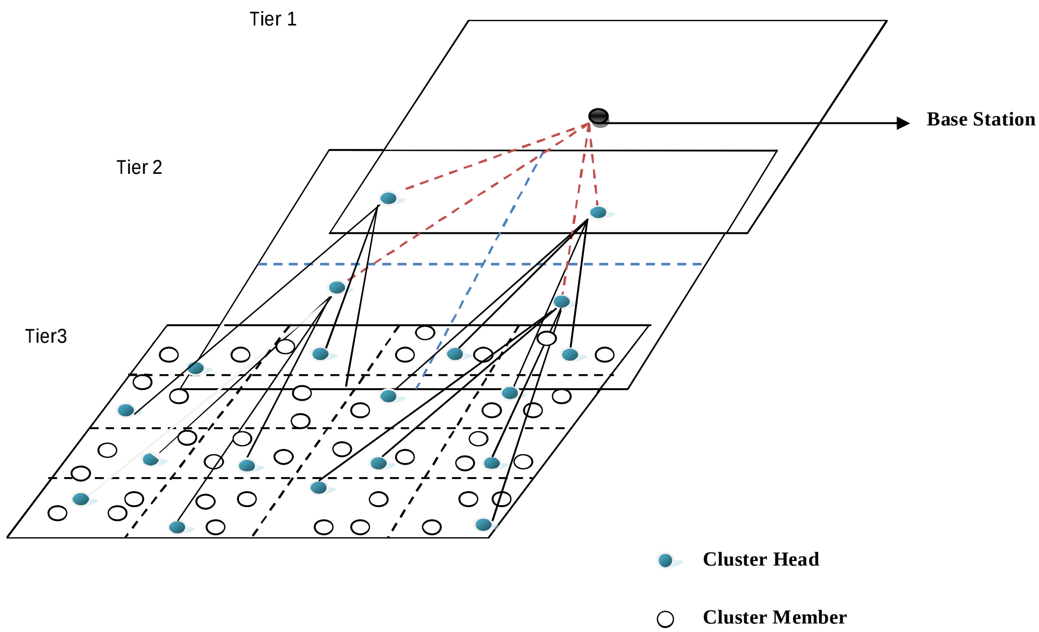


Figure 4.3 Multi-Tier Hierarchical Routing

In Figure 4.3 the sensor nodes in the each cluster network sends data to its CH. After the completion of inter-network data aggregation, the CHs in the tier3 transmits the data to the CHs present in the upper tier (i.e.) tier2. Then the data is send to the CH in tier1 from tier2. Finally the CH in tier1 transmits the data to the Base Station.

MTHR provides a direction to each CH to forward the data and it build and maintain a cost field in the forwarding zone. The packet is forwarding from each CH to the sink, for this purpose it keeps the cost. The direction of data will identify based on cost to the sink (i.e.) it follows descending order of cost. For this reason each CH will compare its cost with the sender. The receiver decides whether it should forward a packet or not based on this comparison and direction. A packet can simply travel through whichever working nodes to the sink and the routing table can be removed. When a CH forwarding a packet it inserts its own path cost into the packet. The forwarding process may be continued when the neighboring nodes with the smaller cost will receive the packet otherwise they will discard it, means that the path is abandoned. After the sink confirms the network of interest, the ICH broadcasts the query packet with cost field. The packet may be rebroadcasted by other CHs until it reaches the CHs of interested networks.

The sink and nodes creates the cost field known as artifact farther to the sink has greater cost. At first the sink node propagates an advertisement (ADV) packet to builds a cost field and it announcing the cost of 0. The cost is defined as the minimum energy overhead to forward a packet from the CH to the sink over a path. The initial cost of each CH is ∞. Let initially CH M and N has the costs as C_M and C_N respectively. After receives the ADV of N, the M computes its link cost $L_{N,M}$ to N and it also adds this cost with N's cost which gives the result as $C_N + L_{N,M}$. When $C_N+L_{N,M} < C_M$ then M should update its cost to $C_N+L_{N,M}$ and continue to rebuild the cost field for neighboring CHs. M discards the ADV packet and maintains the current link if $C_N+L_{N,M} < C_M$ is not satisfied. The d-tree can be constructed step by step by following these processes in between each network. Any CH chooses its parent CH on its minimum cost path when it receives any ADV packets.

When a CH receives multiple copies from different upstream CHs, it will search the cache for signatures of recently forwarded packets to avoid duplicates. Let a new CH i is built and it receives a downstream CH j, then it checks and identify that j may be one of its potential parents. As a result the new CH i become connected to the d-tree and makes j as its parent. If CH i is already connected to the d-tree and it has j as its parent and also when it receives a messages from downstream j', then i compares the cost through different parent and finally selected a minimum cost path by j'. Due to this, the parent of i change from j to j' in the d-tree. The Substitute CH (SCH) is the one which does not connect to the d- tree. The CHs is said to be Relaying CH (RCH) when it is connected to the d-tree. The SCHs is awakened when the energy of RCH is below E_r.

4.3.3 Multilevel Hierarchical Routing

In Multilevel Hierarchical Routing, a level is assigned to each CH when the BS disseminate through the network as discussed by Rahman et al (2011). This method employs the best way to find route between CH to BS and to selects another route when a route breaks due to node failure or other causes. It has been divided into two phases: Route Construction Phase and Data Forwarding Phase.

In the Route Construction Phase, a route construction packet (RCP) is transmitted from BS to sink nodes to disseminate the packet throughout the network. During this dissemination process, the route request packets are exchanged between sink nodes to CHs or CH to CH. Based on this process route is created between CHs and sink nodes. In the proposed model, a level is assigned for each CH during the broadcast of RCP through the network.

At starting the value of level and Hop_Count is assigned as 0 for all sink nodes and the level of all nodes is assign to a high value. The sink node which receives such RCP from the BS it updates the packet information by assigning its own ID, hop count and own level and it broadcast the packet to their neighbor CHs (neighbor CH can be one hop or multihop distances). The packet information is again updates by the CH that receives the packet from sink node by increasing the packets Sender_level by one. When the packet is moved from one node to another node then the Hop_Count of the packet will be increased. At the same time the level only increases when the packet moves from CH to CH.

The CH updates its routing table by using the RCP information after increases the packet's level and Hop_Count by one when it receives the RCP packet. The CH re-broadcast the packet to its neighbor CHs after updating its routing table. The same process is carried out by neighbor CHs and this process is going on until the RCP travels through the whole network. The CH simply discards the packet when it receives a RCP later from the same level or lower level's CH. The RCP is broadcasted only once by each CH and each CH maintains its own routing table. Our major contribution in this phase is to create a routing table for each CH which consist of two fields namely Next_Hop and Path_Cost.

The next hop address is held by Next_Hop field and the Path_Cost field contains the cost to reach the BS which is measure as follows

$$\text{Path\_Cost} = \text{Hop\_Count} \times \text{Sender\_level}$$

At first an intermediate node checks the Sender_level, if it is found to be lesser than itself, then the intermediate node increments the sender level by one and assigns this level as its own level as shown in figure 4.4. After that the intermediate node calculates the path cost of BS and updates its routing table using this Sender_ID and Path_Cost. Now the intermediate node increments the sender hop count and updates the RCP's Sender_ID, Hop_Count and Sender_level filed and broadcast the RCP to its all neighbor CHs. After broadcasting the packet the node sort its routing table based on the Path_Cost. If the intermediate node found that the Sender_level not lesser than itself, it simply drop the packet. It is assumed that the sensor node keeps only first n-level entry of the routing table as next-hop and discards all remaining entry, because it has limited memory. If a normal node, which acts as a relay node between two CHs, receives the RCP, just increment the Hop_Count by one of the packet and forwards the packet towards the next CH.

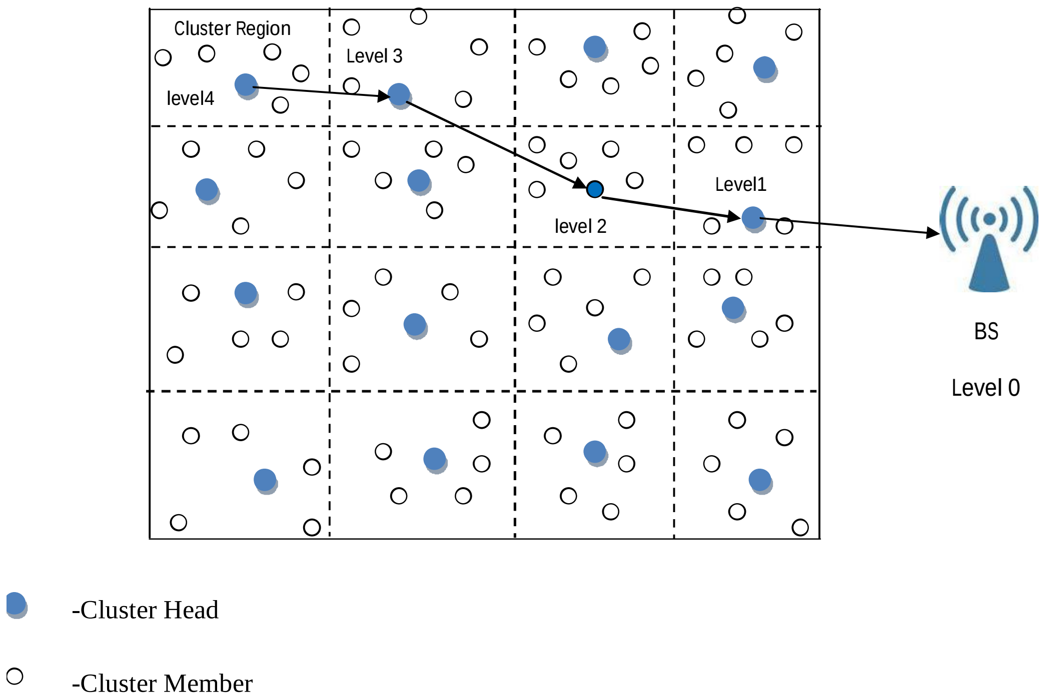


Figure 4.4 Multi Level Hierarchical Routing

BS initiates route construction phase periodically and create multiple low cost shortest paths. However, the residual energy is considered at each CH because only using the shortest path forces the nodes with low residual energy over the path to exhaust their energy, so that they cannot participate as a router in forwarding data any more. Therefore, the small number of nodes alive in the network results in reducing the availability of multiple paths and finally whole network becomes inoperable. To address the problem, when a CH picks up a next-hop node, it first checks the residual energy of the next-hop node. The CH selects a path with the next-hop node whose residual energy higher than a threshold energy value. If several next-hop nodes have same lowest path cost then it selects a next-hop node whose residual energy is the largest among the same path cost nodes towards the sink node. Each CH performs the periodic exchange of hello packet to inform its neighbor CHs of its residual energy.

If a neighbor CH nodes residual energy goes to lower than the threshold energy then it cannot participate as a router in forwarding data over a path. It just acts as a normal CH in the environment and can send only sense data of itself to the next-hop. If a CH recognizes that all next-hop nodes over the paths in its route cache lack their residual energy below the threshold energy (i.e.) they cannot take part as a router in forwarding data, the CH broadcast a Failure packet to its neighbor CHs. On receiving the Failure packet to the neighbor CH, it will exclude the next-hop node from its routing table using the sender of the packet as its next-hop node.

When a CH transmit a data packet to its next hop, it keeps the data packet for a pre-defined time and wait whether the data packet is successfully deliver to the next hop. If the CH receives a Failure packet within that pre-defined time, it recognizes that there is a broken path on that next-hop. Then the CH re-transmits the data packet to another next-hop according to its route cache and removes the Failure packet sender from its routing table as a next-hop. When the CH chooses another next-hop it must satisfy the condition of path cost and energy as described before. If the CH doesn't receive such Failure packet within that pre-defined time it recognizes that the data packet is successfully delivered to the next-hop and it simply discard the data packet. Now if a source CH receives such Failure packet and there is no another available path to the sink node then it try to acquire a route to the sink node from itself using flooding or broadcast a request to sink node or BS to setup a route construction phase for this CH by sending the RCP again.

4.4 ANALYZING E2C WITH HIERARCHICAL ROUTING

In this section, the Energy Efficient Clustering (E2C) as proposed in chapter 3 analyzed with Cluster ID based Hierarchical Routing (CIDHR), Multi-Tier Hierarchical Routing (MTHR) and Multilevel Hierarchical Routing (MLHR).

4.4.1 Analyzing E2C with Cluster ID based Hierarchical Routing

In E2C-CIDHR, the CH Election and Cluster formation are done by E2C technique. Once the cluster is formed, the Cluster ID based Hierarchical Routing is used to make the route between CH and the Base station. In this approach a unique ID is assigned to each cluster and cluster ID is used as next hop for data transmission. The CH that holds the cluster ID on round forwards the cluster ID to the selected CH on next round and CHs are selected on the basis of residual energy. When the round is over and new CH has been selected on the basis of maximum remaining energy, this token is transferred to new CH. By using CIDHR the energy consumed in each round for routing table calculation is reduced.

4.4.2 Analyzing E2C with Multi Tier Hierarchical Routing

In E2C-MTHR, E2C technique is used for CH Election and Cluster formation. After forming clusters, the route from the CH to the Base station (BS) is formed by Multi tier Hierarchical Routing (MTHR). Multi tier Hierarchical Routing defines a multi-hop hierarchical routing, where the clusters are formed by CHs and CHs are selected from CHs. CHs which is in high level directly communicate with BS that reduces the routing complications and prolong the lifetime of the network. Multiple hops are possible in between adjacent tiers. Once inter-network aggregation is completed, the cluster head sends the data to upper cluster of next grade; as a result a hierarchical data aggregation tree is gradually built from the stand point of sink. When a CH detects the interesting event, it propagates that event to all its neighboring CHs by using simple flooding method. Hence, all the CHs know where the events happened. The construction of d-tree is initiated by CH only after it receives the query packet from the mobile sink.

4.4.3 Analyzing E2C with Multi Level Hierarchical Routing

An E2C technique is used for e CH Election and Cluster formation in E2C-MLHR. After forming clusters, the route from the CH to the Base station (BS) is formed by Multi Level Hierarchical Routing (MLHR). In the Route Construction Phase, a route construction packet (RCP) is transmitted from BS to sink nodes to disseminate the packet throughout the network. During this dissemination process, the route request packets are exchanged between sink nodes to CHs or CH to CH. Based on this process route is created between CHs and sink nodes. In the proposed model, a level is assigned for each CH during the broadcast of RCP through the network. When a CH transmit a data packet to its next hop, it keeps the data packet for a pre-defined time and wait whether the data packet is successfully deliver to the next hop. If the CH receives a Failure packet within that pre-defined time, it recognizes that there is a broken path on that next-hop. Then the CH re-transmits the data packet to another next-hop according to its route cache and removes the Failure packet sender from its routing table as a next-hop.

4.5 PERFORMANCE ANALYSIS

In this section, by using series of simulation the performance of multi-level hierarchical E2C, Cluster ID based routing E2C and multi-tier hierarchical E2C have analyzed with E2C Single hop. The performance of cluster based hierarchical routing protocol is analyzed using a Network Simulator 2 (NS-2). To run experiments a base simulation setting was created and several scenarios were obtained from it. In the setting, 100 nodes are randomly placed in the area of 100m x100m to form a wireless sensor networks and BS is placed in outside the network. All parameters taken for these simulations are defined in Table 4.1.

Table 4.1 Simulation Parameters for analyzing cluster based Hierarchical routing techniques

Parameters	Parameter Values
Network size	100 m ×100 m
Number of Sensor Nodes	50,100,150,200,250
Node initial energy	2 J
Transmitter circuitry dissipation	50 nJ/bit
Data Aggregation Energy	5nJ/bit
Data packet size	512 bytes
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{mp}	0.0013 pJ/bit/m^4
d_o	87 m
Base station location	(50,150)

4.5.1 Network Lifetime

To evaluate the performance of sensor networks Lifetime is one of the important criterion. In the simulation, when the first node dies defines the lifetime of the network measured in terms of the round, because in data gathering applications once a node dies a certain area cannot be monitored anymore.

In order to measure the proposed cluster based hierarchical algorithm, two metrics are considered for the performance evaluation. There are System lifetime (the time of FND (First Node Dies) and LND (Last Node Dies)) and the numbers of a live node are applied. Because lengthening the network lifetime is an important issue in clustered WSNs.

In the experiment, the number of nodes alive in 100m x 100m network with 100 nodes for every 50 rounds was found.

Figure 4.5 shows that E2C MLHR has greater stability time among the three hierarchical routing techniques. The first node of E2C MLHR is dead after approximately 3211 rounds whereas the first node of E2C Single hop, E2C CIDHR and E2C MTHR is dead after approximately 2402, 2801 and 2730 rounds respectively as shown in Table 4.2. The network lifetime of E2C MLHR is 25.19%, 12.76% and 14.97% greater than E2C Single hop, E2C CIDHR and E2C MTHR respectively.

Table 4.2 Comparison of the network lifetime in rounds

	No. of Rounds			
	E2C Single Hop	**E2C CIDHR**	**E2C MTHR**	**E2C MLHR**
FND	2402	2801	2730	3211
LND	4610	5017	4824	4636

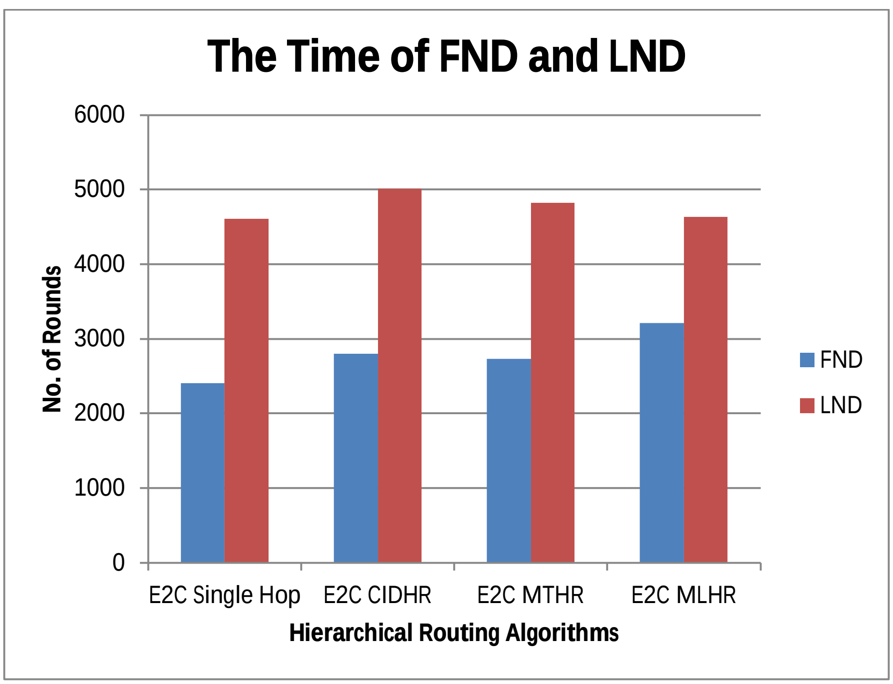


Figure 4.5 Number of rounds when First and Last Node Dies for 100m x 100m network with 100 nodes

The last node of E2C Single hop, E2C-CIDHR, E2C-MTHR and E2C-MLHR is dead after approximately 4610, 5017, 4824 and 4636 rounds respectively. From the Figure 4.6 it is clear that the performance of the multi-tier hierarchical E2C much greater in terms of network life time and number of nodes alive, which decreases with time as compared to others.

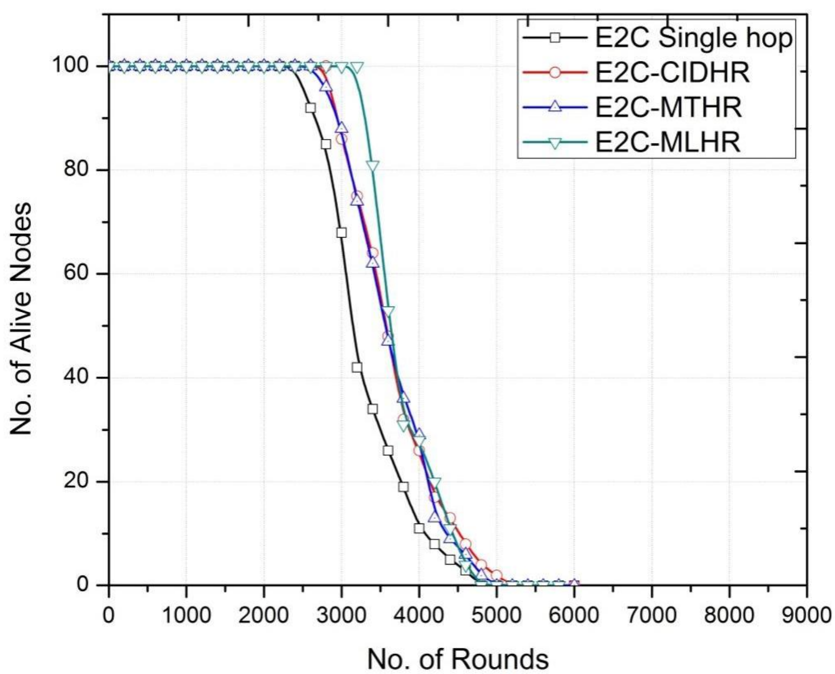


Figure 4.6 Comparison of the network lifetime for 100m x 100m network with 100 nodes

The performances of various hierarchical techniques are compared using the simulation results. From this comparison it is identified that multi-level hierarchical E2C performs best and prolongs the network lifetime significantly than single hop E2C, Cluster ID based routing E2C and multi-tier hierarchical E2C.

4.5.2 Throughput

Besides network life time, throughput is another metric to judge efficiency of a routing protocol. To confirm the efficiency of routing protocol the base station receives more data packets. Throughput depends on network life time in a sense but not always.

The number of packets received in the destination is calculated and taken as throughput. Figure 4.7 represents the effect of number of packets received with variation in the number of nodes. The E2C with hierarchical routing shows improvement in PDR over E2C single hop. From this graph it is observed that E2C MLHR guarantees about maximum of 7.7%, 2.8%, and 2.1% more packets to the base station in comparison with E2C Single hop, E2C CIDHR and E2C MTHR respectively.

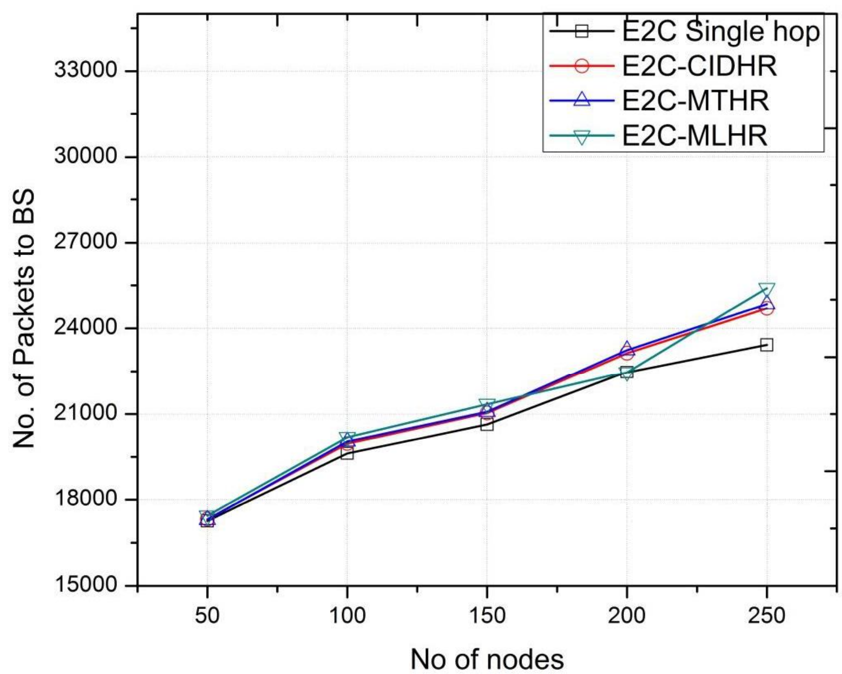


Figure 4.7 Effect of number of nodes on Throughput

Considering the simulated results as shown in Figure 4.7, it is deduced that, maximum throughput is achieved by E2C - MLHR. The two major reasons to increase throughput is better network life time and efficient path selection.

4.5.3 Packet Delivery Ratio

The ratio of total number of packets that have reached the destination node and the total number of packets originated at the source node is called as Packet Delivery Ratio. From Figure 4.8 it is shown that Packet Delivery Ratio (PDR) of E2C Single hop has the effect of number of nodes than CIDBR E2C, multi-tier E2C and multi-level hierarchal E2C.

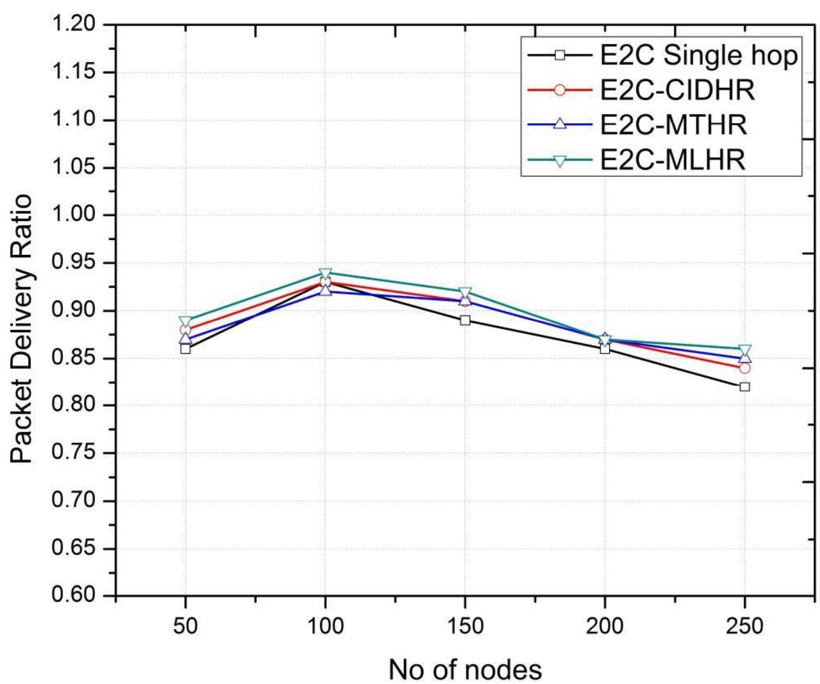


Figure 4.8 Effect of number of nodes on Packet Delivery Ratio

Due to higher traffic in the network, the PDR for the nodes from 50 to 250 is decreased when the number of nodes increases. The E2C with hierarchical routing shows improvement in PDR over E2C single hop. The E2C MLHR shows 1.1–4.6 % improvement in PDR over E2C Single hop, E2C CIDHR and E2C MTHR respectively.

4.6 CONCLUSION

Because the scarce energy resources of sensors, Energy efficiency becomes one of the main challenges in the design of routing protocols for WSNs. The energy consumption of the sensors is conquered by data transmission and reception. Hence, the routing protocols which are designed for WSNs should be energy efficient and also possible to extend the lifetime of individual sensors. Multi-hop hierarchical routing was an energy efficient technique used to route the data in Wireless Sensor Networks. In this chapter the performance of Energy Efficient Clustering (E2C) Single hop have analyzed and compared with CIDBR E2C, multi-tier E2C and multi-level hierarchical E2C. Simulation results show that multi-level hierarchical E2C minimizes and balances the energy consumption well among all sensor nodes. This analysis has tried to explore existing work done in this area.