CHAPTER 3

ENERGY EFFICIENT CLUSTERING IN WSNs

3.1 INTRODUCTION

Wireless Sensor Networks have gained increasing importance in a variety of military and civilian applications. With recent advances in wireless communications technologies, WSNs represent a great leap forward over traditional wireless networks as discussed by Akyildiz et al (2002). A WSN consists of a large number of sensor nodes, which are densely deployed over an unattended area either close to or inside the targets to be observed. These sensor nodes periodically monitor or sense the conditions of the targets, process the data, and transmit the sensed data back to the Base Station (BS). All of the sensor nodes collaborate together to form a communication network for providing reliable networking service.

The collaboration among sensor nodes is very important in WSNs for two reasons:

- Data collected from multiple sensor nodes can offer valuable inference about the environment.
- The collaboration among sensor nodes can provide trade - offs between communication cost and computation energy.

Since it is likely that the data acquired from one sensor node are highly correlated with the data from its neighbors, data aggregation can reduce the redundant information transmitted in the network. It is well known that the energy consumed for transferring one bit of data can be used to perform a large number of arithmetic operations in a sensor processor (power consumed for transferring one bit of data to a receiver 100 m away is equal to that needed to execute 3,000instructions) as discussed by Pottie & Kaiser (2000). When the base station is far away, there are significant advantages in using local data aggregation instead of direct communication. Thus, node clustering, which aggregates nodes into groups (clusters), is critical to facilitating practical deployment and operation of WSNs.

The remainder of this chapter is organized as follows. Section 3.2 provides the details of energy saving schemes in clustering. In section 3.3, the proposed Energy Efficient Clustering (E2C) method is illustrated. Section 3.4 describes the energy consumption calculations of E2C technique. Section 3.5 describes the assumptions of radio and network model. Section 3.6 evaluates the performance of E2C through simulations and compares E2C with some other clustering protocols. Finally, the conclusion is given in section 3.7.

3.2 ENERGY SAVING SCHEMES IN CLUSTERING

3.2.1 Cluster Formation and Rotation

With the evolving trend in application and management of WSN, clustering provides an efficient means of managing sensor nodes in order to prolong its lifetime. Several cluster formation techniques have been discussed by Abbasi & Younis (2007).

When cluster are formed dynamically, the reorganization is done on a periodic basis. The initiator is selected at the beginning of every period and broadcasted messages are sent out using one of the above-mentioned methods for cluster organization. The multi-hop broadcasting minimizes the problem of energy usage. This is due to the fact that there is a limit for transmission because the highest amount of energy that can be wasted is the minimum transmission energy of neighboring sensor nodes. This will create no need for the sensor nodes which are far away from each other to transmit directly. It has a disadvantage in the sense that it has more delay when compared to the former technique of broadcasting. This is because, in multi-hop broadcasting, the data are required to be processed by each sensor node along the multi-hop path, which creates delay in the formation of cluster. However, the multi-hop is much better than the direct broadcast if the problem of delay is taken care of.

3.2.2 Cluster Head Election and Rotation

After cluster formation, CHs are designated which act as a leader in each clusters. Cluster heads are saddled with the responsibility for data aggregation and performing routing for its cluster member’s information to the base station. Also, the clusters that consist of many nodes have a higher burden than clusters with fewer nodes as the CHs for those large-sized clusters have to receive, aggregate and transmit more data. A CH can be elected randomly or pre-assigned by the designer of the network. A CH can also be elected by taking into consideration the residual energy of nodes in the cluster. The CHs are known to have higher burdens than member nodes; therefore, the role of CH is rotated to share the burden and thus improving the useful lifetime of those clusters.

In random selection, a node is selected randomly as CH, based on the probability that it has never being selected during the entire lifetime of the network. This reduces the traffic burden on a CH since the role of CH is spread throughout the sensor nodes. The rotation is done at a periodic interval. Whereas, in the residual energy selection, the sensor node that has the highest amount of energy in the cluster is selected as the cluster head. It will continue to remain the CH until the energy drops below the average energy of the entire cluster. So, rotation of CH is done at every instance when its energy level drops below the average cluster energy. This rotation of CHs will lead to the overall energy of the sensor network being evenly distributed. This technique eventually improves the lifetime of the network. Another approach to cluster head selection is based on minimizing the distance to cluster nodes as this offers reduction in energy usage during data transmission to the BS. With this method of minimizing sum of distances to CH, the cluster formation is better enhance to reduce energy usage as transmission takes place. It helps in reducing the unnecessary energy which the sensor node uses in communicating with the CH by minimizing the transmission distances from sensor node to any CH as discussed by Ghiasi et al (2002). Since communication energy is an important concept to consider in wireless transmission, it is known that energy greatly depends on distance as quoted by Sohrabi et al (2000). Therefore, it is very good idea to minimize the distance in transmitting data from sensor nodes to base station via the CH, as this helps to reduce the communication energy in Wireless Sensor Network.

3.2.3 Cluster Optimization

When addressing the problem of energy consumption in Wireless Sensor Network, the size of a cluster is an important factor subject to analysis in hierarchical network. Clusters of small size save power in intra-cluster communication but it will also increase the complexity of the backbone network. Also, smaller cluster size means reduced load in the backbone and thus communication is complicated only to small extent, but the intra-cluster communication consumes more power and reduces the lifetime of the sensor network. These necessitate a trade-off in clusters formation.

One of the trade-off is mentioned in a method where a method of limiting the number of hops which a sensor node takes in communicating with its CH. Bandyopadhyay & Coyle (2003) approach makes use of the Ktree cluster framework and optimize the framework and optimize the value K to minimize power consumption within a cluster. When the sensor node is at a far distance from the CH, much energy is expended thereby reducing the lifetime of sensor network. For instance, when two sensor nodes are placed at a far distance away from each other in the same cluster but one of them is closer to the base station, it is observed that the energy consumed by the node closer to the base station is lower compared to that which is far away.

Furthermore, taking computational complexity into consideration when designing cluster with uneven data traffic in each clusters while data are being transmitted, the size of clusters seem to be random at the time of formation. Although, in some circumstances, the cluster sizes are equal which denotes equal number of nodes, and in other scenario, the size is randomly selected. When the cluster sizes are approximately equal, the clusters very close to the base station will consume more energy and die quicker than the cluster that is far away from the base station. This is because the cluster head closer to the base station collects all data from other cluster heads in the network and thereby having much data to relay to the base station. Therefore, the communication traffic between clusters is uneven.

3.3 PROPOSED ENERGY EFFICIENT CLUSTERING

In this section, a novel Energy Efficient Clustering (E2C) technique for single hop wireless sensor networks is proposed which suits better for periodical data gathering applications. E2C is a clustering technique in which the network is partitioned into a set of cluster regions with one cluster head in each cluster region. In this clustering technique, the cluster head directly communicate with the base station. In the network deployment phase, the BS broadcasts a “hello” message to all the nodes at a certain power level. By this way, each node can compute its approximate distance to the BS based on the received signal strength. It helps nodes to select the proper power level when communicating with the BS. In the proposed E2C technique, there are three phases viz Cluster head election phase, Cluster formation phase and Data transmission phase. In the cluster head election phase, well distributed cluster heads are elected with a little control overhead. In the cluster formation phase, the selected cluster head forms a group. In the data transmission phase, CH aggregates the data from the cluster members and sends it to the base station as shown in Figure 3.1.

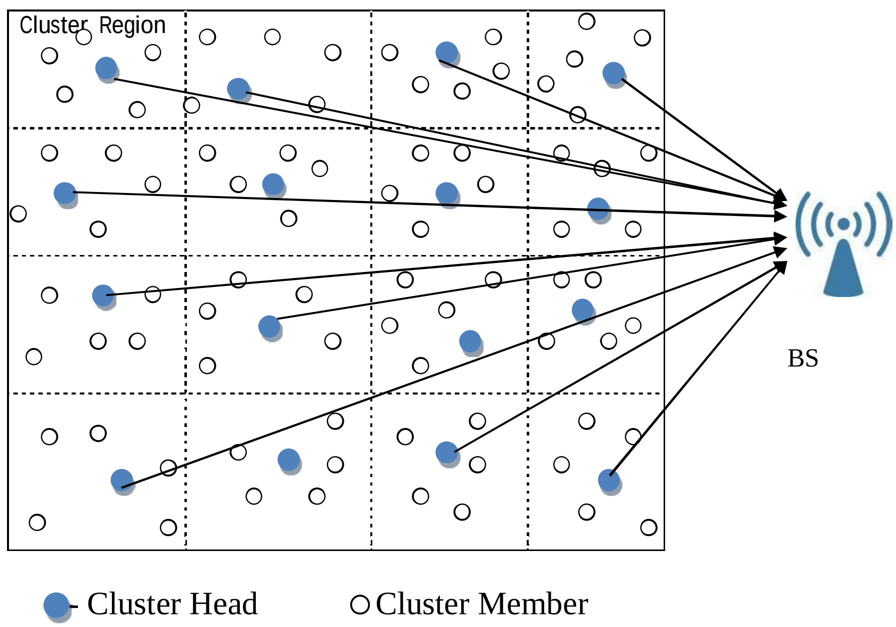

Figure 3.1 Network Partitioned into Clusters

3.3.1 Cluster Head (CH) Election

In CH election phase, the cluster head is selected and then it forms a group. After some time, the corresponding Cluster head energy will be reduced and have to rotate the cluster head selection process. In the CH election phase, the network is partitioned into a set of Cluster Regions (CR) as shown in Figure 3.2. In each CR, the nodes participate in CH election called CH Nominee (CHN) is found using a probability scale assigned to each sensor. According to this value, each sensor decides on becoming a CHN.

Basically, the probability to become a CHN is T, scaled by the ratio of initial sensor energy level to the average initial energy of the network. For a node i in region R, the resulting probability becomes

$$P_i = T * \frac{residual\ node\ energy}{average\ residual\ energy}$$

Computation of P_i is performed only once right after network initialization. At the beginning, each node elects a random number in the range between [0 1]. If the number is less than P_i, then the sensor node becomes a CHN. With this mechanism, approximately a ratio T of all nodes is elected as CHNs.

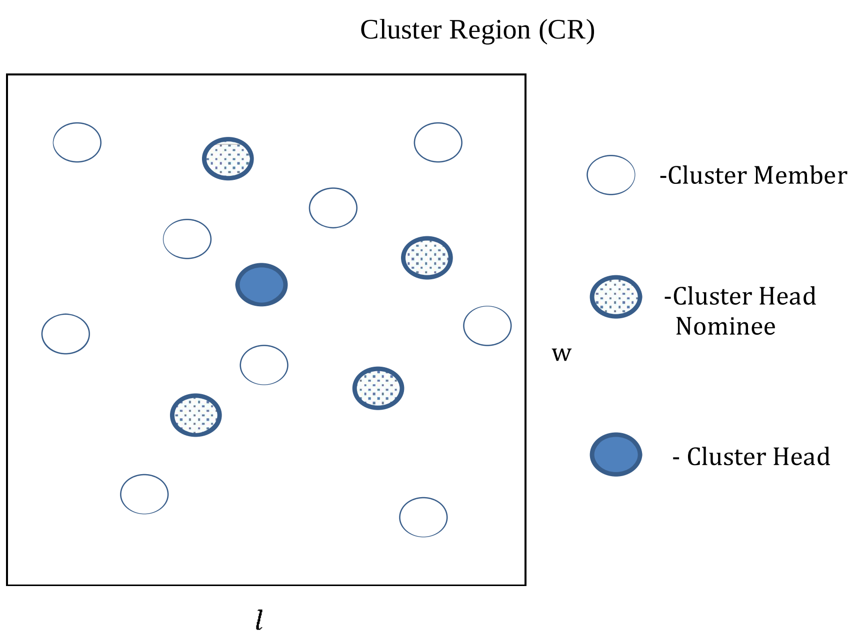

Figure 3.2 Cluster Region

However, this would require each node to notify all others in its region of its energy value, which could only be achieved by region wide broadcasts, a quite high message overhead. Alternatively, a central node in each region could gather the energy levels and then distribute the average value to all sensors in the region, which is a slightly better scheme. Nevertheless, this would add additional complexity of choosing and replacing such central node. Another method would be the use of counters at each node to keep track of the number of times they take the CH role. However, this also requires later negotiations among nodes.

To avoid all these issues, the initial energy levels for selecting the CHNs are used. Since the frequency of being selected as a CHN is proportional to the initial energy levels and the CHs are eventually selected among these nominees, the resulting frequency of having the CH-role and the corresponding energy consumption are on the average approximately proportional to the initial energy levels. Therefore, this choice is a reasonable method towards balancing energy consumption levels while preventing additional overhead.

Upon being selected, each CHN in Cluster region CR_i transmits a cluster head advertisement "CH ADV" packet and advertises its residual energy level within a neighborhood of radius $\boldsymbol{r_i}$ and it is determined by the equation,

$$r_i = \sqrt{\frac{l\,w}{\pi\,n_i}} \tag{3.1}$$

A CHN monitors the advertisements from other CHNs and defers from acting as a CH if a higher energy level is reported by another. Eventually, the candidates with the highest residual energy among their neighboring CHNs become the CHs. If a CHN receives no advertisement packets for a period of T_{wait}, it will automatically become a CH node. This mechanism enables the choice of the actual CH nodes to be based on the most recent sensor energy stocks. Additionally, d(CHN,BS) to break the tie of $E_{residual}$ during the comparisons is used. The flow chart of the CH election phase as shown in Figure 3.3.

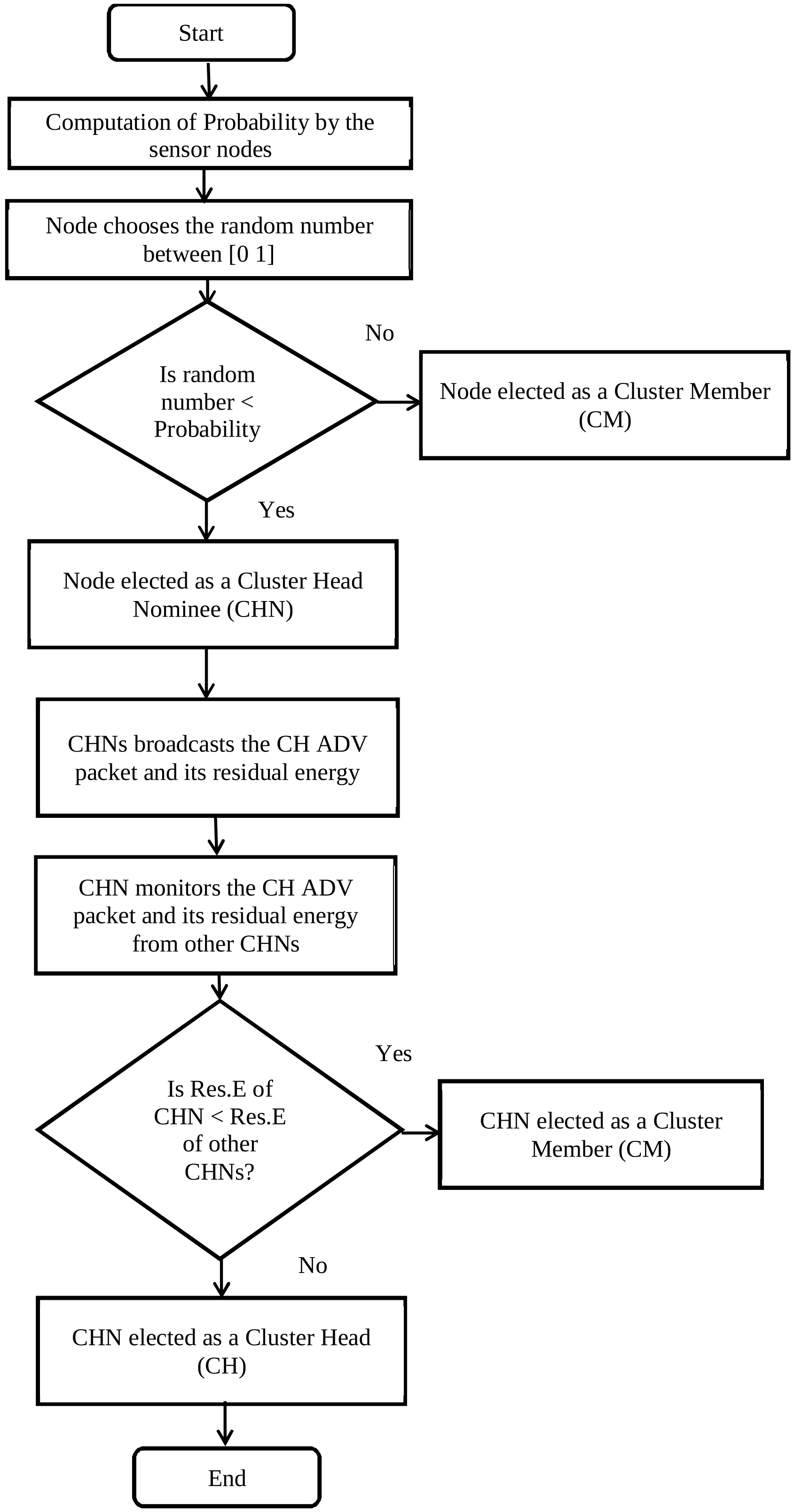

Figure 3.3 Flowchart for Cluster Head (CH) Election

3.3.2 Cluster Formation

After the CHs are elected, each CH transmits a "CH announcement" packet within an area of transmission radius $\boldsymbol{r_i}$ and informs other sensors of its availability as a CH. This CH-announcement range is a multiple of $\boldsymbol{r_i}$ selected to ensure that each CM receives at least one announcement packet and can associate to a CH. To ensure reception of announcement packets by other nodes, a straightforward method is to send region-wide broadcasts. However, this potentially causes high transmission energy cost; a fine tuned value is required. Thus, a system parameter is tuned to achieve high CH-association probability for non-CH nodes while avoiding an unnecessarily large transmission range.

Each CM nodes may collect announcement packets from multiple CHs and selects the CH that has generated the announcement packet with the highest RSSI as the ideal CH to associate to. Nodes associate to CHs via sending a "CH Joining" request and upon reception of a subsequent "CH confirmation". At the end of the cluster formation phase, there may still be few sensors that have not joined any clusters as they have not been received any announcement packets. To recover from such cases, a sensor with no CH-association gradually increases its transmission range and seeks the closest CH to associate. The flow chart of the Cluster formation phase as shown in Figure 3.4.

Synchronization between each phase should be guaranteed so that each node has enough time to complete the procedure of the first phase by choosing a proper time interval Timer according to the system parameters and wireless channel quality. In the second phase, each cluster head broadcasts a TDMA schedule within its cluster. Then the members process in the corresponding time slots and turn off the radio in the idle time to save energy further. Additionally, BS was made to periodically synchronize the nodes over the network against the time drift.

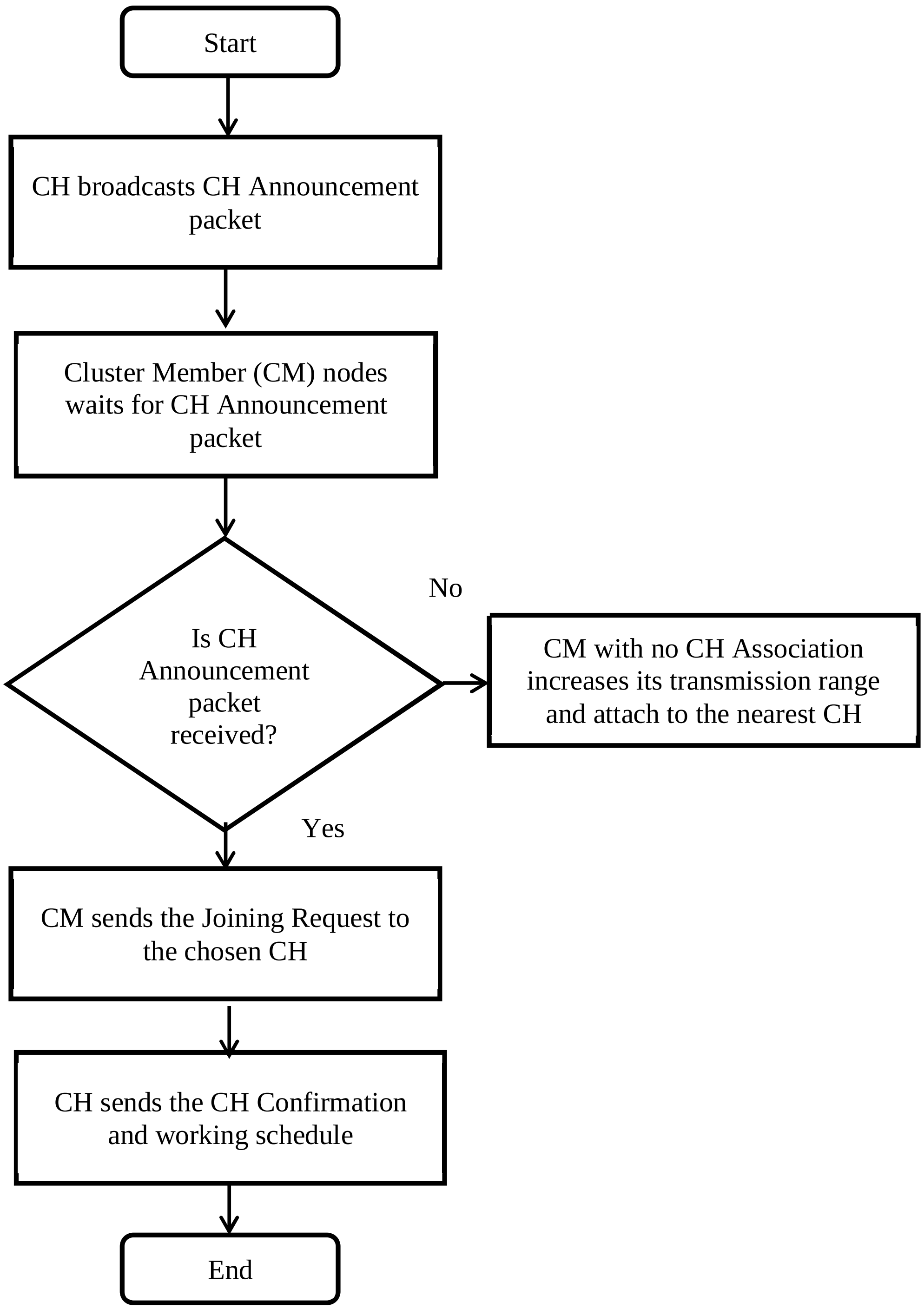

Figure 3.4 Flowchart for Cluster Formation

In WSN of N nodes, NT nodes advertise as CHNs, producing a total of NT messages. Eventually, M CH nodes are selected, which then announce their role as a CH with a total of M CH-announcement messages. Sensor nodes choose a CH to join and send CH-association requests, incurring an additional cost of $N - M$. For each request, a CH-confirmation message is generated. As a result, the total message complexity in cluster formation is approximately

$$NT + M + 2(N - M) = (2 + T)N - M = O(N)$$

3.3.3 Data Transmission

Once the clusters are created and the TDMA schedule is fixed, data transmission can begin. Assuming nodes always have data to send, they send it during their allocated transmission time to the cluster head. This transmission uses a minimal amount of energy (chosen based on the received strength of the cluster-head announcement). The radio of each non-cluster-head node can be turned off until the node's allocated transmission time, thereby minimizing energy dissipation in these nodes. The cluster-head node must keep its receiver on to receive all the data from the nodes in the cluster. When all the data has been received, the cluster head node performs signal processing functions to compress the data into a single signal. For example, if the data are audio or seismic signals, the cluster-head node can beam form the individual signals to generate a composite signal. This composite signal is sent to the base station. Since the base station is far away, this causes increased energy for transmission.

In the data transmission phase, the consumed energy of cluster head i, $\boldsymbol{E(CH_i)}$ is calculated by using the Equation (3.2) as follows, assuming the distance between the CH and the base station is greater than the cross over distance d_o.

$$E(CH_i) = n_i * k * E_{ele} + (n_i + 1)k * E_{Aggre} + k(E_{ele} + \epsilon_{mp} d^4) \tag{3.2}$$

Observing the above equation, energy consumption of $E(CH_i)$ is composed of three parts: data reception, data aggregation and data transmission. In the field, several cluster heads may be near the BS, while some are far away. The energy expended during data transmission for far away cluster heads is significant, especially in large scale networks. Since $d(CH_i, BS)$ has been fixed after cluster head election, the cluster size for each cluster head to balance their load across the network should be justified.

3.4 ENERGY CONSUMPTION CALCULATIONS

In this section, the value of energy consumption in a Cluster Region CR_i during Cluster formation, Intra-cluster communication and Data processing is calculated as follows.

3.4.1 Energy Consumption in Cluster Formation

The selection of CHs is a two-stage process and energy consumption in Cluster Formation as calculated as follows. Designating the length of a control packet as k_o, then the total clustering energy consumption in the Cluster Region CR_i as

$$E_{Cluster}(i) = lw\sigma T \left[k_0 \left(E_{ele} + \frac{\varepsilon_{fs}}{\pi\sigma\, p_i}\right) + \left(\frac{T}{p_i} - 1\right) k_0 E_{ele} \right] +$$

$$lw\sigma(1-p_i)k_0\left(E_{ele} + \frac{4\varepsilon_{fs}}{9\pi\sigma\, p_i} + E_{ele}\right) + lw\sigma p_i k_0\left[\left(E_{ele} + \frac{\varepsilon_{fs}\alpha^2}{\pi\sigma\, p_i} + \pi E_{ele}\left(\frac{\alpha^2}{\pi\sigma\, p_i}\sigma - 1\right)\right]+\right.$$

$$lw\sigma p_i k_0\left(E_{ele} + \frac{\varepsilon_{fs}\alpha^2}{\pi\sigma\, p_i}\right) + lw\sigma(1-p_i)k_0 E_{ele} \tag{3.3}$$

The above Equation (3.3) can be briefly explained as follows. A ratio T of all nodes initially are CH-candidates inside each region CR_i, hence $lw\sigma T$ candidates per region where σ is the node intensity in the Cluster Region. The CHN nodes compete with each other to become a CH and announce their contention within a competition range of radius r_i. These CHN announcements are received by CM nodes in each region, which is on the average $\pi r_i^2 \sigma T - 1$ sensors per candidate.

The first term in the above Equation is for the CHNs to announce their candidacy and for the reception of these announcements by CM nodes in the region. Upon being selected, each CH announces its role with a CH-announcement packet that is received only by the nodes inside its announcement range. The second term stands for these events. Each non-CH node needs to send a control packet to associate with a CH that then replies back with an association message, which forms the third term. Finally, the last two terms are for all CHs in region R_i to distribute their time schedules among cluster nodes.

3.4.2 Intra-cluster Communication Energy Consumption

During a Intra-cluster communication phase, each cluster member sensor nodes encapsulates its observed information in a data packet and then transmits this to the corresponding CH. The CH accumulates all observation packets and combines them in a single summary packet to summarize the observation of the area within the cluster boundaries. In the Cluster region CR_i, there are approximately $lw\sigma$ nodes. Therefore, with n_i CHs, the total number of observation packets delivered to the CHs in CR_i is $lw\sigma - n_i$.

Designating the average packet length as k, then the total intra-cluster energy consumption, $E_{Intra}(i)$, in region CR_i as

$$E_{Intra}(i) = k\left(\sum_{j \le lw\sigma - n_i}\left(E_{ele} + \epsilon_{fs}\, d_j^2\right)\right) + k(lw\sigma - n_i)E_{ele} \qquad (3.4)$$

where d_j is the distance between node j in CR_i and its associated CH.

3.4.3 Data Processing Energy Consumption at a CH

Although comparably minimal, data processing for summarizing packets at each CH consumes some sensor energy. This is linearly proportional to the number of CHs. Designating E_{bit}, as the energy necessary to process one bit of data, then the data processing energy consumption at a CH in the Cluster Region CR_i as

$$E_{proc}(i) = klw\sigma E_{bit} \qquad (3.5)$$

3.5 NETWORK AND RADIO MODEL ASSUMPTIONS

3.5.1 Network Model

Consider a homogeneous network of n sensor nodes and a base station node distributed over the area. The location of the sensors and the base station are set and known priori. Nodes are left unattended after deployment. Therefore, battery recharge is not possible. All nodes have similar capabilities and equal significance. Each sensor produces some information as it monitors its surrounding area. So it is supposed to separate the whole network into a number of clusters with each cluster having a CH. It is also supposed that after the formation of cluster, the transmission power of all nodes is adjusted in such a way that they can perform single-hop broadcast.

In this typical data gathering application, sensors periodically sense the environment and transmit the data to the Base Station (BS) which analyzes the data to draw some conclusions about the activities in the field.

For this, few assumptions are made about the network model and introduce the radio model before the problem statement.

The network architecture considers the following:

- A fixed base station is located away from the sensor field
- The sensor nodes are energy constrained with uniform initial energy allocation.
- Each node senses the environment at a fixed rate and always has data to send to the base station.
- The sensor nodes are assumed to be immobile.
- The network is homogeneous and all the nodes are equivalent, i.e., they have the same computing and communication capacity
- The network is location unaware, i.e., the physical location of nodes is not known in advance
- The transmitter can adjust its amplifier power based on the transmission distance.

The network model of hundreds of sensor nodes and distributed in a large area is considered. For simplifications, WSN system in which the data being sensed by sensor nodes is transmitted to the base station, and there is only one base station with sufficient energy near part of the sensor nodes are also taken into account. Sensor nodes have to first transmit sensed data to the CHs, so that the data fusion can be performed by the CH sensor nodes. In addition, sensor nodes are designed as cheap and with high energy efficient as possible. It is also assumed that all sensor nodes and BS use symmetric radio channel with the same transmission range in the network. They are distributed randomly and densely, and their energy is constrained.

3.5.2 Radio Model

The radio model as shown in Figure 3.5 that is used is the same adopted in LEACH as discussed by Heinzelman et al (2000). By using this approach, it is assumed that the energy loss of d^2 due to channel transmission.

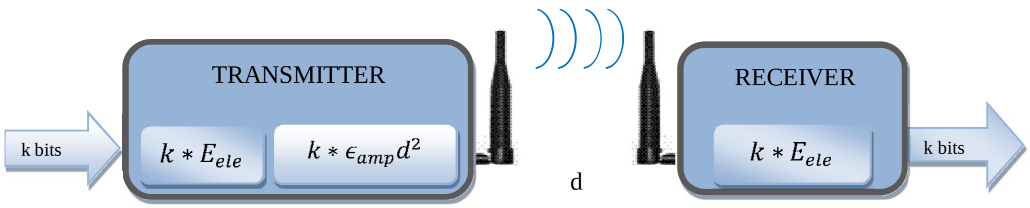

Figure 3.5 Radio model

The node dissipates the energy for the radio transmission of a message of k bits over a distance d is due to running of both transmitter circuitry and amplifier as given in the Equation (3.6) by

$$E_{Tx}(k,d) = \begin{cases} k * E_{ele} + k * \epsilon_{fs} d^2, d < d_o \\ k * E_{ele} + k * \epsilon_{mp} d^4, d \geq d_o \end{cases} \tag{3.6}$$

Where E_{ele} is the transmitter circuitry dissipation per bit, which is supposed to be equal to the corresponding receiver circuitry dissipation per bit and E_{amp} is the transmitter amplifier dissipation per bit per square meter. Depending on the transmission distance, both the free space and the multi-path fading channel models are being used.

Similarly, the energy $E_{Rx}(k)$ dissipated by a node for the reception of a k bit message is due to the run of receiver circuitry as given by

$$E_{Rx}(k) = E_{ele} * k \tag{3.7}$$

Additionally, data aggregation is adopted to save energy. It is assumed that the sensed information is highly correlated, so that the cluster head can always aggregate the data of its members into a single length fixed packet. And this operation also consumes energy E_{aggre} (nJ/bit/signal). The energy required to transmit a message from source node to destination node is equal to the energy required to transmit the same message from the destination node back to the source node for a given SNR. Finally, it is assumed that the communication environment is both contention and error-free so that there is no need for retransmission technique. Finally, IEEE 802.11b is the wireless communication standard used in the simulation tests performed. Generally, the selection of this standard enables the high rate transmission over longer distances.

3.6 PERFORMANCE EVALUATION

In this section, the performance of the E2C technique has evaluated by using NS2 (Network Simulator 2). In the simulation, the same MAC protocol as used in LEACH was adopted in E2C technique. The parameters of the simulation are listed in Table 3.1.

Table 3.1 Simulation Parameters for analyzing E2C technique

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
σ	0.005, 0.01, 0.015, 0.02, 0.025
Base station location	(50,150)

3.6.1 Network Lifetime

Lifetime is the criterion for evaluating the performance of Wireless Sensor Networks. In the simulation, the lifetime was measured in terms of the round when the First Node Dies (FND) and Last Node Dies (LND), because in data gathering applications a certain area cannot be monitored any more once a node dies.

In order to measure performance of the proposed E2C technique, two metrics are considered for the performance evaluation. System lifetime (the time of FND and LND) and the number of alive nodes are found, because lengthening the network lifetime is an important issue in clustered WSNs.

- **System lifetime (the time of FND and LND)** - The definition of system lifetime can be used to determine how alive a system is. There exist many lifetime definitions, such as the time when the first node dies, time when the Last Node Dies, the time when half of the nodes die or the time that the network breaks in two or more segments. The most general definition of the lifetime is used in this work, the time of FND and LND. Therefore, in order to maximize the system lifetime, the time of FND and LND is to be maximized in a WSN system.

- **The number of alive nodes** - To keep the ability of sensing and gathering data in a WSN, it is essential to find how many sensor nodes are still functional in the entire network. The ability of a WSN depends on the set of alive nodes (nodes that have not dead). Therefore, the functionality of the WSN system was evaluated depending on the count of the number of alive nodes in the network.

The number of nodes alive in 100m x 100m network with 100 nodes for every 50 rounds was found.

Table 3.2 Comparison of the network lifetime in rounds

	No. of Rounds				
	Direct Transmission	**LEACH**	**HEED**	**EECS**	**E2C**
FND	216	663	1052	1854	2402
LND	684	1806	4413	3802	4610

Table 3.2 shows that E2C has greater stability time as compared to Direct Transmission, LEACH, HEED and EECS. The first node of E2C is dead after approximately 2402 rounds whereas the first node of Direct Transmission, LEACH, HEED and EECS is dead after approximately 216, 663, 1052 and 1854 rounds respectively as shown in Figure 3.6.

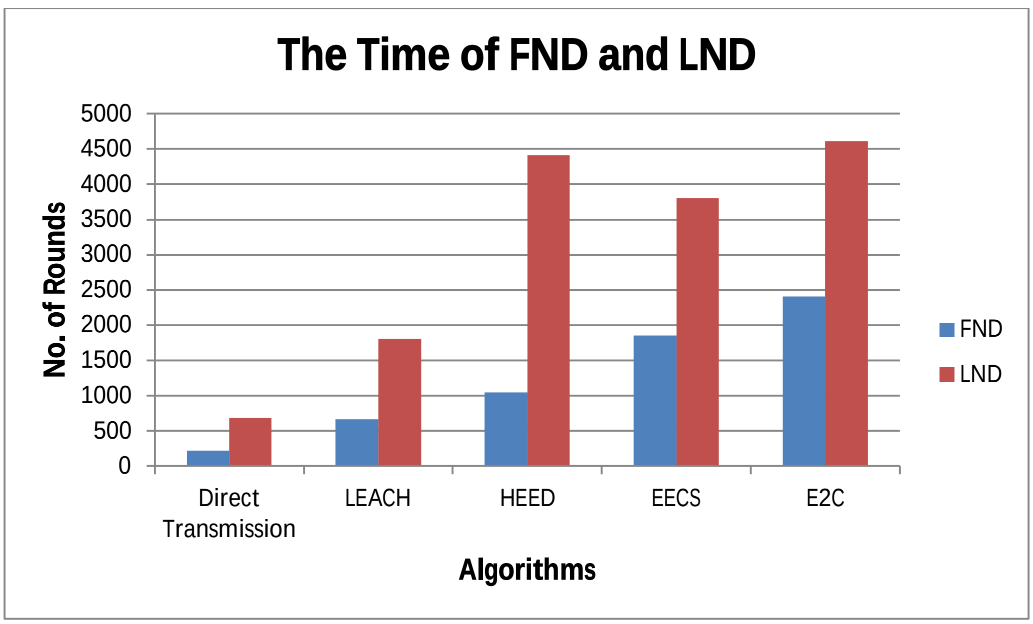

Figure 3.6 Comparison of the FND and LND in rounds

The last node of Direct Transmission, LEACH, HEED, EECS and E2C is dead after approximately 684, 1806, 4413, 3802 and 4610 rounds respectively. The network lifetime of E2C is 85.16%, 60.82%, 4.27% and 17.52% greater than Direct Transmission, LEACH, HEED and EECS respectively as depicted in Figure 3.6.

Comparing with LEACH, HEED, EECS the simulation results show that E2C performs best and prolongs the network lifetime significantly as shown in Figure 3.7.

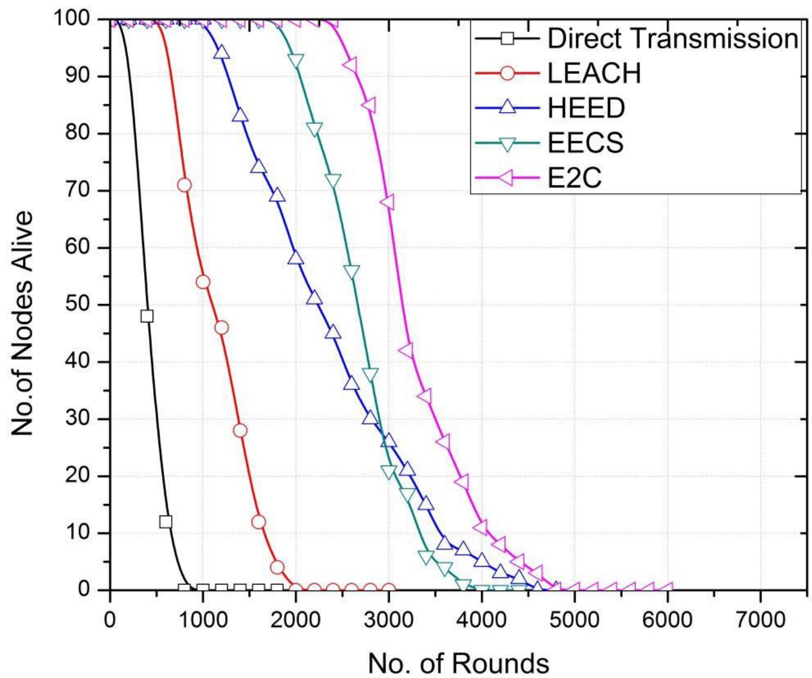

Figure 3.7 Comparison of the network lifetime for 100m x 100m network with 100 nodes

In Figure 3.7, it was observed that the HEED performs better than LEACH, EECS perform better than HEED and E2C performs the best in terms of no. of rounds. Thus it has been concluded that E2C performs better than EECS and HEED. By this, E2C always achieves well distributed cluster heads according to the network lifetime by balancing the load among the cluster heads.

3.6.2 Residual Energy

It is measured as the total amount (in joules) of remaining battery energy at the end of the simulation. It is obvious that E2C reserve much more energy than Direct Transmission, LEACH , HEED and EECS. The simulation result also prove that E2C can achieve much better energy efficiency than Direct Transmission, LEACH , HEED and EECS, which in turn extends the lifetime of the whole wireless sensor networks.

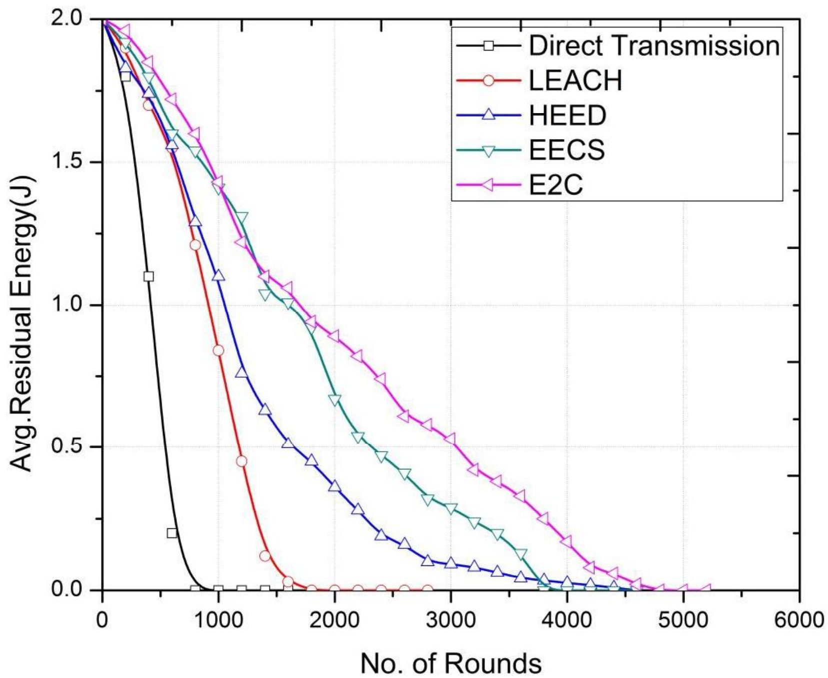

Figure 3.8 Effect of average residual energy on Number of rounds

Figure 3.8 shows that the residual energy of E2C reaches zero after approximately 4610 rounds whereas the residual energy of Direct Transmission, LEACH, HEED and EECS reaches zero after approximately 684, 1806, 4413, 3802 rounds respectively. All other algorithms maintain a certain level of residual energy due to the energy dissipation in different rounds but only E2C reaches to zero after 4500 rounds.

3.6.3 Packet Delivery Ratio

It is defined as the ratio of total number of packets that have reached the destination node and the total number of packets originated at the source node. Figure 3.9 shows the effect of number of nodes on Packet Delivery Ratio (PDR) of LEACH, HEED, EECS and the proposed E2C.

$$PDR = \frac{Number\ of\ Received\ Packets\ at\ Sink\ Node}{Number\ of\ Generated\ Packets\ at\ Sensor\ Nodes}$$

The PDR for number of nodes from 50 to 250 is found to decrease when the number of nodes increases. This is due to higher traffic in the network. The E2C shows 2 - 15 % improvement in PDR over LEACH, HEED and EECS as shown in Figure 3.9.

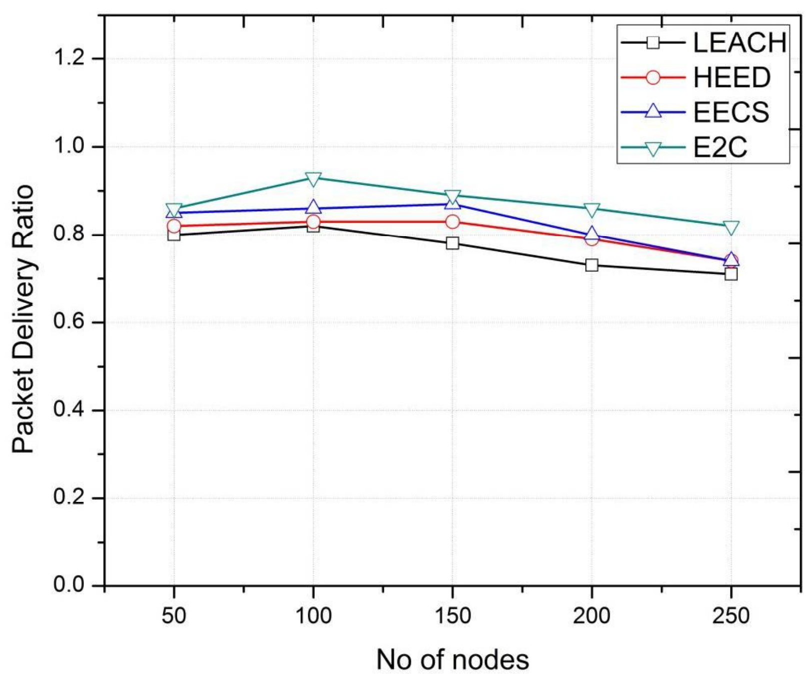

Figure 3.9 Effect of Number of Nodes on Packet Delivery Ratio

3.6.4 Throughput

The number of packets received in the destination is calculated and taken as throughput. Figure 3.10 represents the effect of number of packets received with variation in the number of nodes. Figure 3.10 shows that throughput of E2C is significantly greater as compared to LEACH, HEED and EECS in stable and unstable regions. The graph shows that E2C guarantees about 23.39%, 31.51%, and 47.42% more packets to the base station in comparison with LEACH, HEED and EECS respectively. Thus, it proves that E2C has higher throughput as compared to LEACH, HEED and EECS.

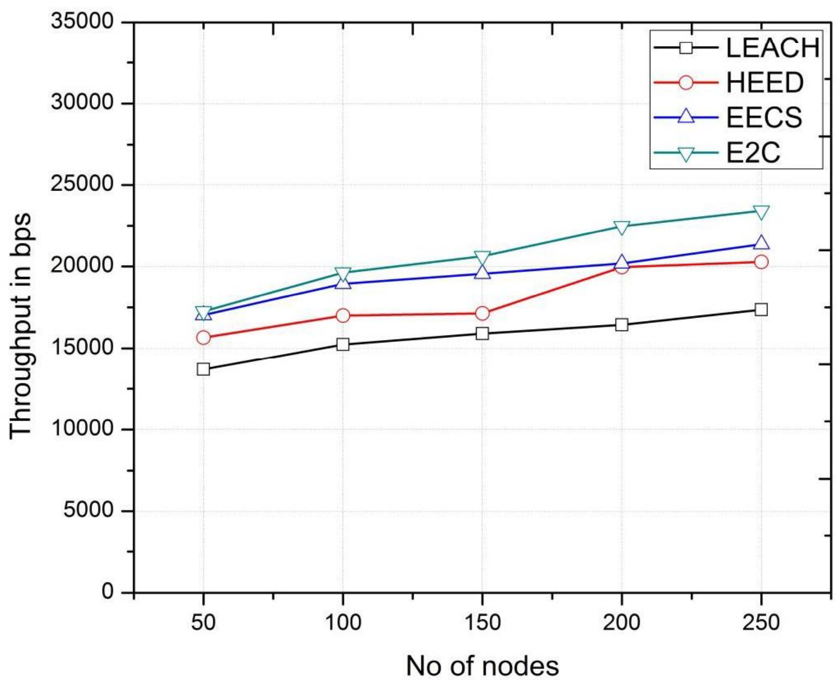

Figure 3.10 Effect of Number of Nodes on Throughput

3.7 CONCLUSION

In this chapter, an energy efficient and load balanced clustering technique E2C has been proposed for periodical data gathering. Performance results demonstrate that E2C extends network lifetime and provides equalization of node energy levels. Compared with well known and popular clustering algorithms such as LEACH, HEED and EECS, E2C outperforms in terms of energy conservation and equalization. All of the contributions in this chapter are focused on the cluster setup stage. There is still much space to improve the performance of data transmission. In the large scale sensor networks, multi hop hierarchical routing is a mainstream technique for energy saving. Hence the multi hop hierarchical routing techniques for inter cluster communication will be discussed in the next chapter.