CHAPTER 6

MULTI-HOP CLUSTERED PROTOCOLS FOR HWSNS

Effective energy management in HWSNs is a more challenging issue compared to homogeneous WSNs. Much of the existing research has often assumed homogeneous sensor nodes in the networks. The energy preservation schemes for the homogeneous WSNs do not perform efficiently when applied to heterogeneous WSNs. This chapter presents new energy-efficient multi-hop communication routing protocols in order to address the traditional problem of load balance, lifetime and energy efficiency in the WSNs. These protocols are based on dividing the network into dynamic clusters. The CHs are randomly chosen for each round by using weighted probability. The CH nodes communicate with an elected node called CH, and the CHs communicate the information to the BS via multi-hop communication approach.

6.1. Protocol 7: Multi-hop Energy Efficient Heterogeneous Clustered (MEEHC) protocol for WSNs

Research on WSNs has been studied and employed in many applications such as medical monitoring, automotive safety, and many more. Typically, sensor nodes have several issues such as limited battery life, short radio transmission range and small memory speed. However, the most severe constraint of the nodes is their limited battery energy resource because they cease to function when their battery deplete.

In development of MEEHC, we have considered three types of sensor nodes, primarily with different energy levels. To analyze the lifetime of the network, we have assumed a multi-hop topology. MEEHC protocol using some heterogeneous nodes to extend the network lifetime by balancing energy consumption of the network. The election probabilities of nodes to become CHs are weighted by the initial energy of a node relative to that of other nodes in the network. Once the CHs are elected, all non-CH nodes would associate one of the existing CHs to build a return path to the BS. The MEEHC protocol efficiently resolves different technical aspects such as energy
efficiency, network lifetime and stability of the network for different applications. The radio model for energy dissipation used in the analysis of MEEHC protocol. The system model, the CH election approach and multi-hop approach used to evaluate the performance of the proposed protocol.

6.1.1. System model

We make some assumptions about the sensor nodes and underlying network model, which are as follows: 1) $n$ sensor nodes are uniformly dispersed within a square field. 2) All sensor nodes and BS are stationary after deployment. 3) The communication is based on the multi-hop. 4) The WSN consists of heterogeneous nodes in terms of node energy. 5) All sensors are of equal significance. 6) CHs perform data aggregation. 7) The BS is not energy limited in comparison with the energy of other nodes in the network. Here, we have used the simplified first order radio model presented in {5.1.1}.

6.1.2. Setup phase

In this phase, the proposed protocol performed the following steps: 1) CH election, 2) cluster formation and 3) multi-hop routing.

The CHs election mechanism is same as in protocol 4 {5.3}. At present, there are two types of inter-transmission mode, single hop and multi-hop. We have adapted the multi-hop mode to achieve the inter-cluster transmission. It means that the CHs transmit their aggregated data to the sink node by passing several other CHs. When the furthest CHs want to transmit their own aggregated data to the BS, they have to calculate the shortest path energy cost to the BS node.

6.1.3. Steady state phase

In the steady state phase, the CHs turn their receiver unit on for receiving messages from their member nodes. The selected CH aggregates the received messages with its own message and then aggregated message is either forwarded to the next hop receiver (i.e., CH) or to the sink based on routing information calculated by the optimal path approach.
We have carried out a comparison among MEEHC, MRACHC [41], LEACH and DT through simulations. The results indicate that the network energy depletion rate is fast in LEACH and MRACHC as compared with MEEHC because the number of dead nodes increases quickly after the death of the normal nodes in the network.

The overall throughput in terms of the number of data packets received at the BS from CHs, which is greater in MEEHC as compared with LEACH and MRACHC protocol in the stable region and for most of the unstable region. The reason is that due to extended stability, the throughput of MEEHC is also higher than that of the current clustering protocols. There is an improvement in stability of MEEHC as compared with LEACH, MRACHC and DT as the first node die earlier in case of DT, LEACH, and MRACHC.

The simulation results indicate that the last node die earlier in DT, LEACH and MRACHC protocol as compared to MEEHC. The nodes death rate is substantial in DT, LEACH, and MRACHC as compared with MEEHC. Therefore, MEEHC survives longer than DT, LEACH and MRACHC protocol.

6.2. Protocol 8: Multi-hop Communication Scheme (MCS) for maximizing network lifetime in HWSNs

MCS reduce the energy consumption in HWSNs. When CHs deliver their data to the BS, each CH first aggregates the data and then sends the aggregated data packet to the BS via multi-hop communication approach. MCS describes the CH election method and multi-hop communication scheme. Each round consists of a setup phase and a steady state phase.

In the set up phase, CHs are elected and then clusters are formed. After the election of CHs, each CH establishes energy cost path based on multi-hop approach among the CHs and BS. During the steady state phase, the sensor nodes transmit the sensed data to the sink according to minimum energy cost path link. Finally, the path with the lowest energy cost link is considering the path for data transmission from CHs to the sink that saves the energy of the network.
6.2.1. Setup phase

In this phase, the proposed protocol performed the following steps: 1) optimal CH election, 2) CH election for heterogeneous node and 3) energy based shortest-path link for multi-hop routing.

6.2.2. Optimal CH selection

The CHs election mechanism is same as in protocol 2 and protocol 3 which are presented in {5.1} and {5.2}, respectively.

6.2.3. Steady state phase

In the steady state phase, the CHs turn their receiver unit on for receiving messages from their members while non CH nodes are always placed into sleep mode in order to save their battery energy. In each cluster, the CH first aggregates the data from its cluster member and sends the aggregated data packet to the BS via multi-hop communication scheme. In some proposed protocols like LEACH, the CH directly sends the packet to the BS via single hop communication. But this method increases the energy consumption of CH. In PEGASIS [7], each CH can aggregate the incoming data from other CH together with its data. This method uses multi-hop communication, but is unpractical because the sensed data correlation between different clusters is relatively low.

In WSNs, energy efficient design is very important issue because nodes are operated by battery energy. Most of the previous work deals with the routing problem to maximize the network lifetime by balancing the power consumption of nodes. MCS improves the network performance by maintaining remaining energy distribution relatively uniform among the nodes. Simulation results show that MCS successfully extends the stable region by being aware of heterogeneity through assigning probabilities of CH election weighted by the relative initial energy of nodes. Therefore, MCS extends the network lifetime by a factor of 70% and improves the stability by a factor of 60% as compared with LEACH and HEED [42].
6.3. Protocol 9: Energy Efficient Clustering and Data Aggregation (EECDA) protocol for HWSNs

This is a novel EECDA protocol is developed for heterogeneous WSNs which combine the ideas of energy efficient cluster based routing and data aggregation to achieve a better performance in terms of lifetime and stability. EECDA protocol includes a novel CH election technique and a path would be selected with maximum sum of energy residues for data transmission instead of the path with minimum energy consumption.

The election probabilities of nodes to become CHs are weighted by the initial energy of a node relative to that of other nodes in the network. Once the CHs are elected, all non-CH nodes would associate one of the existing CHs to build a return path to the BS. A path with maximum sum of energy residues would be selected for data transmission instead of the path with minimum energy consumption. EECDA protocol efficiently resolves different technical aspects such as energy efficiency, network lifetime and stability of the network for different applications.

After the CHs election process is finished, each CH estimates the energy residue after transmission and broadcast this information to the neighboring area to allow non-CH to associate with it. For each non-CH, it chooses a CH such that the sum of the energy residues of both would be maximum instead of chooses the closest CH which minimizes the energy consumption to that CH. The operation of route election phase as follows.

The elected CH first estimates its energy residue \((E_{CHR})_s\) and broadcast this information with its CH role to the neighbor nodes. \((E_{CHR})_s\) is computed by Equation 6.1.

\[
(E_{CHR})_s = (E_{CH_{rem}})_s - (E_{BS})_s \quad s \in G_c
\]  

\[\text{(6.1)}\]

where \(G_c\) is the set of elected CHs per round. \((E_{CH_{rem}})_s\) indicates the remaining energy of \(CH_s\) in current round and \((E_{BS})_s\) indicates the communication energy dissipated from \(CH_s\) to the BS. Then, each CH records the value of \((E_{CHR})_s\) in advertisement message and broadcasts advertisement message to the rest of the nodes in the WSN. During the CH election phase, each non-CH node receives all
advertisement messages, and extracts all of energy residue data of CHs from the advertisement messages.

Moreover, each non-CH node calculates energy residues \((E_{N\_CHR})_i\) to every CH respectively is given by Equation 6.2.

\[
(E_{N\_CHR})_i = (E_{N\_CH\_rem})_i - (E_{CH})_is \quad i \in G_n
\]  

(6.2)

where \(G_n\) is the set of non-CH nodes. \((E_{N\_CH\_rem})_i\) indicates the remainder energy of non CH node \(i\) in the current round and \((E_{CH})_s\) indicates the communication energy from non-CH node \(i\) to CH node \(s\). Finally, each non-CH node chooses to join a CH according to maximum energy residue is given by Equation 6.3.

\[
Max \left\{ (E_{CH})_s + (E_{N\_CHR})_i \right\} \quad s \in G_c, i \in G_n
\]  

(6.3)

In data communication phase, each non-CH node transmits its data to the associated CH and each CH will receive sensed data from its associated non CH nodes. After that, each CH node aggregates the received data and sends to the BS.

6.3.1. Performance measurement metrics

The following performance metrics are used to evaluate the performance of developed clustering protocols.

- **Network lifetime**: We examine energy efficiency of different protocols by evaluating the time interval from the start of the operation until the first node dies and the time until the last node dies.
- **Stability Period**: This is the time interval from the start of network operation until the death of the first alive node. This period is called stable region or period.
- **Instability Period**: This is the time interval from the death of the first alive node until the death of the last alive sensor node. We call this period as unstable region.
- **Number of alive nodes per round**: This is the instantaneous measure reflects that the total number of alive nodes per round that have not yet expended all of their energy.

LEACH protocol and EEHCA [43] protocol fails to take the full advantage of the heterogeneity as in both the scenarios the first node and last dead node dies earlier as
compared with EECDA protocol. The simulation results show that EECDA protocol prolongs the network lifetime significantly against the other existing protocols such as Low-Energy Adaptive Clustering Hierarchy (LEACH) and Energy Efficient Hierarchical Clustering Algorithm (EEHCA). Under general instance, EECDA prolongs the network lifetime by 51% against LEACH and by 25% against EEHCA.

6.3.2. Summary

This chapter presented few new developed multi-hop routing schemes for HWSNs. All the proposed protocols/schemes are compared with existing schemes/protocols by evaluating different performances metrics. In the next chapter, we will see fault tolerance protocol for HWSNs.