CHAPTER 4

OPTIMAL CDS CONSTRUCTION ALGORITHM WITH ACTIVITY SCHEDULING

4.1 INTRODUCTION

The two algorithms CH-MCDS and CH-KM-CDS suit for the highly mobile MANETs. For a low mobile environment, convex hull based MCDS is not required, because they suffer from little high time and message complexities which is inevitable for high mobile environment. A new energy efficient optimal Connected Dominating Set (CDS) algorithm with activity scheduling for mobile ad-hoc networks (MANETs) which suits for low mobile MANETs is proposed in this chapter. This algorithm achieves energy efficiency by minimizing the broadcast storm problem and at the same time balancing the energy consumption among the nodes. This is required since the node’s energy has more impact than the mobility in deciding the performance of the MANET. It is suitable for sparse as well as dense networks with low node mobility and transmission ranges. The lifetime of a CDS can be significantly increased by allowing some of the neighbouring dominators to sleep intermittently (Yardibi & Karasan 2010, Emre et al 2014).

Activity scheduling balances the energy among the dominators by rotating the states of active and sleep among the adjacent dominators. Besides providing connectivity and coverage it is a must for the activity scheduling based CDS algorithm to minimize the energy consumption among the nodes and thereby to improve the lifetime of the network. These scheduling
algorithms are classified into centralized and distributed and they are further classified into scheduled wakeups and on demand wakeups. Distributed scheduling suits for mobile ad hoc networks since MANETs lack infrastructure and centralized authority (Yardibi & Karasan 2010, Wang & Xiao 2006). Here we have designed an activity scheduling that suits for MANETs and also the scheduling happens between dominators only. At a time dominator node may be either in active mode (WAKEUP) or in promiscuous mode (SLEEP). The dominating node in promiscuous mode sniffs the channel for WAKEUP signal at regular intervals. Moreover, the proposed activity scheduling algorithm in this research work considers energy of the dominators by calculating the residual energy of the dominator nodes.

4.2 PRELIMINARIES

Some important definitions, mathematical equations and notations used in this work are discussed here. Basic definitions like UDG, dominator, dominatee, Connected Dominating Set (CDS) etc. are similar to chapter 3.

4.2.1 Mathematical Calculations for Node’s Energy

The energy calculations and equations used in this work are described here. All calculations are in joules. In the network, only the energy of dominator nodes are considered because they consume more energy when compared to the dominatees. Dominators consume more power than dominatees because the set of dominators acts as the backbone. Moreover there are many power consuming roles performed by dominators. First a dominator has to rebroadcast the messages in its transmission range. Second it has to keep track of its connectors to other dominators. Third it has to maintain a table for list of active neighbours. Fourth it has to perform local repairs. Finally it has to perform activity scheduling with its counterparts. All these indulge in high message exchange and in turn energy consumption.
More over the dominatees are considered to be in promiscuous mode while exchanging control packets alone where they consume very low power to receive the control messages. We considered only the transmission of control packets and not data packets. The dominatees don’t have much role in the construction of the CDS and hence throughout the construction phase dominatees remain in promiscuous mode. The power consumption at various modes are shown in Table 4.1. The Equations (4.4), (4.5), (4.6) and (4.7) give a clear picture of how energy is consumed for each bit. When compared to the rate at which energy is depleted in the dominators, the rate at which energy is depleted in the dominatees is negligible. In order to increase the lifetime of the dominator as well as network we have performed the activity scheduling to balance the energy consumption. At the same time we can make the network fault tolerant to some extent.

The dominator node’s energy ‘E_d’ is a function of the residual energy (RE) and Dissipated Energy (DE) as given in Equation (4.1) and the energy dissipation rate (D) is given in Equation (4.2)

\[ E_d = f(RE,DE) \]  \hspace{1cm} (4.1)

The dissipation rate at a random time,

\[ D_i(t) = \frac{E_{di(0)} - E_{di(t)}}{t} \]  \hspace{1cm} (4.2)

where,  \( E_{di(0)} = \) Energy of node i at time T=0

\( E_{di(t)} = \) Energy of node i at time T=t

Let the initial energy of the dominator be ‘E_{max}’. Once the dominator starts functioning, the energy is consumed and the available energy is reduced. The energy available at a particular instant of time is called Residual Energy (RE). Let ‘s’ be the initial duration for which the dominator
has functioned. After the time duration ‘s’ the residual energy available at the dominator is computed as in Equation (4.3).

\[ RE_{dl} = E_{max} - DE_s \] (4.3)

where ‘RE_{dl}’ is the residual energy of the dominator and ‘DE_s’ is the energy dissipated during duration s.

The dissipated energy DE_s is calculated as follows.

Let ‘B_t’ be the energy required to transmit a bit and ‘B_r’ be the energy required to receive a bit. Let ‘B_p’ be the energy consumed during the promiscuous mode of operation in one time unit. ‘B_r’ is nearly half of ‘B_t’ and ‘B_p’ is one tenth of ‘B_t’. Let ‘m’ be the number of bits transmitted during ‘s’ and ‘n’ be the number of bits received during ‘s’. The depleted energy during duration ‘s’ is computed as in Equation (4.4)

\[ DE_s = m*B_t + n*B_r + s*B_p \] (4.4)

For the subsequent time intervals of duration ‘s’ the available energy is computed as in Equations (4.5) and (4.6).

\[ E_{cur} = RE_{dl} \] (4.5)

\[ RE_{dl} = E_{cur} - DE_s \] (4.6)

where \( E_{cur} \) is the residual energy available at a particular instant in time.

The overall remaining energy of the backbone network is computed as in Equation (4.7)

\[ \sum_{i=0}^{n} RE_n = (E_{cur} - DE_s) \] (4.7)
where \( R_{En} \) is the residual energy of the backbone network.

\[ \text{RE} \text{ is calculated at regular intervals. If this ratio for the dominator becomes less than the threshold (TH) then it will choose another equivalent node and performs activity scheduling. Here in this algorithm we have put TH as 10\% of } E_{\text{max}} \text{ because of energy requirement. We have simulated the network with various values of threshold TH (5\%, 10\%, 20\%) of } E_{\text{max}} \text{ and observed that when TH = 10\% of } E_{\text{max}} \text{ the algorithm maintains optimal trade-off between network lifetime and message cost. When TH = 20\% of } E_{\text{max}} \text{ frequent disconnections occur which results in high message cost and low network lifetime. When TH = 5\% of } E_{\text{max}} \text{ network lifetime increases but the dominator node becomes unavailable since the node’s energy completely drains out.} \]

So threshold is kept as 10\% of \( E_{\text{max}} \) as shown in Equation (4.8)

\[
i.e. TH = 0.1(E_{\text{max}}) \quad (4.8)
\]

\[ \text{RE ratio is given as in Equation (4.9)} \]

\[
\text{RE (ratio)} = (E_{\text{max}} - \text{RE}_{i-1}) / E_{\text{max}} \quad (4.9)
\]

\[ \text{Generally, } 0 < \text{RE(ratio)} < 1 \]

4.2.2 Activity Scheduling

In CDS based backbone networks the majority of the load will be on the dominators which may consume the energy of the dominator nodes and drain them out very quickly and hence the lifetime of the MANET will decrease. In order to overcome this problem one of the best solutions is to shift the role of the dominators among a number of redundant dominator nodes i.e. the lifetime of a CDS can be significantly increased by allowing
some of the neighbouring dominators to sleep intermittently which is called as activity scheduling. When a node is in the SLEEP mode, it is shut down except that a low-power timer is on to wake up the node at a later time. Hence it consumes only a small quantity of the energy in the active mode. Generally activity scheduling must fulfill three requirements: connectivity, coverage and minimization of the energy utilization. These activity scheduling algorithms are classified into centralized and distributed, where distributed scheduling suits for mobile ad-hoc networks since MANETs lack infrastructure and centralized authority.

In this research work we have proposed an activity scheduling that suits for MANETs and also the scheduling happens between dominators only. At a time a dominator node may be in active mode (WAKEUP) or promiscuous mode (SLEEP). The dominating node in promiscuous mode sniffs the channel for wakeup signal or sleep signal at regular intervals. Moreover, the proposed activity scheduling algorithm also considers energy of the dominators. A new energy efficient optimal Connected Dominating Set (CDS) algorithm with activity scheduling for mobile ad-hoc networks (MANET) has been proposed in this research work. This algorithm achieves energy efficiency by minimizing the BSP and at the same time balances the energy consumption among the nodes. It is suitable for sparse as well as dense networks with low as well as high node mobility and transmission ranges. Activity scheduling balances the energy among the dominators by rotating the states of active and sleep among the adjacent dominators.

The actual algorithm is divided into following phases: dominator election, obtaining the connectors across the network and forming redundant CDS, construction of optimal CDS along with activity scheduling among dominators and the maintenance of CDS. Activity scheduling performs localized scheduling among different dominators with same set so that the
energy of the dominators sustain. Initially all the adjacent dominators are in active mode. Dominator with high Residual Energy (RE) value turns itself into WAKEUP and sends SLEEP message to the counterparts and starts the timer T. After receiving the SLEEP message the adjacent dominators start their own timer with a higher value and goes in to promiscuous mode. In promiscuous mode dominators listen to the messages. If either the received message is WAKEUP or timer becomes zero, then it turns itself to WAKEUP state and sends SLEEP message to its counter parts. This is to balance the energy among the dominator nodes.

4.3 CD\textit{S} CONSTRUCTION ALGORITHM WITH ACTIVITY SCHEDULING

The proposed energy efficient optimal CDS algorithm with activity scheduling is a distributed algorithm. All nodes are assumed to be of equal energy and equal transmission range initially. The proposed work considers both energy and mobility of the nodes in the construction of MCDS. In addition, we employ activity scheduling algorithm to spend the energy in a more economical way. The actual algorithm is divided into five phases. Phase 1 (Dominator Election Phase) deals with dominator election. Phase 2 (Connector Establishment Phase) is about obtaining the connectors across the network and forming redundant CDS. Phase 3 (CDS Formation Phase) and phase 4 (Activity Scheduling Phase) deal with the construction of optimal CDS along with activity scheduling among dominators to increase the life time of dominators and in turn increase the lifetime of the network. Activity scheduling performs localized scheduling among different dominators with same set of 1-hop neighbor (N$_1$) list so that the energy of the dominators sustain. Phase 5 (Maintenance Phase) is about the maintenance of the CDS at frequent intervals. Generally the CDS is disturbed when a dominator moves away or a new node joins the network or the energy and transmission range of the existing dominator goes below the threshold (TH) value. Here the residual energy and the transmission range of a dominator is calculated at regular
intervals since initially all nodes have equal energy and the energy of nodes reduces according to the Equations (4.1), (4.2), (4.3) and (4.4) as the MANET continues to function.

4.3.1 Dominator Election Phase

This phase is the initial phase, executed distributively over the network. Initially all nodes are in WHITE colour and have equal energy and transmission range. So, residual energy (RE) has no role in selecting the dominating set but in later stages of reconstruction or maintenance of CDS, RE plays an important role in selecting energy efficient CDS algorithm.

Dominator Election Phase Algorithm

1. WHILE (Number of WHITE nodes ≠ NULL)
2. BEGIN
3. Every node exchange its unique ID and Residual Energy RE value with in its transmission range and obtains 1-hop neighbour list, N₁
4. Every node again exchanges the list N₁ to obtain the 2-hop neighbour list which also includes the RE energy values
5. A node with highest number of neighbours and lowest ID is elected as dominator initially.
6. Now the dominator changes its color to BLACK and all its neighbours turn to GREY and broadcast this information
7. IF an uncovered WHITE node receives this information from a GREY neighbour
8. THEN
9. Convert to GREY and its GREY neighbour to BLACK
10. END IF
11. END WHILE
This phase is illustrated with a sample MANET topology as shown in Figure 4.1. After the exchange of IDs and RE (initially not counted) as shown in Figure 4.2, the nodes with highest number of neighbours and lowest IDs form as dominating set, DS (Black nodes) = {5, 13, 18} as shown in Figure 4.3. After this algorithm, phase 2 is implemented.
4.3.2 Connector Establishment Phase

In this phase the connectors are selected in a distributive manner. These connectors are joined to obtain connected backbone DS called CDS.

Connector Establishment Phase Algorithm

1. EveryGREY node checks its neighbour list $N_1$ for more than one BLACK node.
2. IF (Number of BLACK nodes > 1)
3. THEN
4. Convert its color to BLACK (connector) and exchange this information
5. ELSE
6. Two nearest GREY nodes of different BLACK nodes turns themselves as BLACK to establish the connection (these are connectors)
7. END IF
This phase is illustrated here in the example MANET. Here the GREY nodes with two different BLACK nodes are node 1, node 17 and node 30. Now nodes 1, 17 & 30 will turn to BLACK as shown in Figure 4.3 and connections are established. After this phase CDS is formed as shown in Figure 4.4. In the next phase equivalent counterparts are selected locally by these dominators for activity scheduling.

**Figure 4.4** Connectors are selected after algorithm phase 2 and \((ID, RE, N_1)\) are exchanged to get equivalent node for performing activity scheduling

### 4.3.3 CDS Formation and Activity Scheduling Phase

This phase plays a crucial role where it prunes the previous CDS to obtain optimal CDS as well as it performs activity scheduling (Phase 4) among different adjacent Dominators (Black nodes) with at most same 1-hop neighbour list \((N_1)\) list to conserve the dominator’s energy. Activity scheduling shifts the role of dominators at intervals, \(\delta T\) and their residual energies \(RE\)s are also calculated as shown in, Equation 4.3. That is the equivalent adjacent dominators turns ON (WAKEUP) & OFF (SLEEP)
alternatively to conserve the energy and increase the life time without compromising the delivery ratio. Here a new regular interval based activity scheduling algorithm is designed to suit the mobility of nodes. Here we maintained a trade-off between optimal CDS and the number of dominators to perform the activity scheduling.

**CDS Formation Phase Algorithm**

1. Every BLACK node exchanges its $N_1$ list in its transmission range.
2. All its neighbours exchange their $N_{i1}$ list, where $i=1,2,\ldots,n$.
3. Every BLACK node performs intersection of $N_{i1}$ list with its own $N_1$, i.e. $(N_1 \cap N_{i1})$.
4. Nodes with at most similar $N_1$, i.e. $(N_1 \cap N_{i1} \equiv \Phi)$ and $(RE > TH)$ are selected and turned BLACK.
5. Perform Activity scheduling (phase 4) between neighbouring BLACK nodes at regular time interval $\delta T$.
6. Black nodes also calculate RE at regular intervals.
7. IF (RE $\leq$ TH)
8. THEN
9. Repeat steps 1, 2, 3, 4 & 5
10. ELSE
11. Continue.
12. END IF
**Activity Scheduling Phase Algorithm**

1. Initially all the adjacent dominators are in active mode
2. Dominator1 turns itself into WAKEUP, sends SLEEP message to the counterparts and starts the timer TI.
3. After receiving the SLEEP message the adjacent dominators start their own timer with a higher value and goes in to promiscuous mode.
4. In promiscuous mode dominators listen to the messages
5. WHILE (RE > TH)
6. BEGIN
7. IF ( message = WAKEUP or Timer =0)
8. THEN
9. Turns itself to WAKEUP and sends SLEEP message to its counterparts and EXIT// this is to balance the energy among the nodes
10. ELSE
11. RE\_d = E\_cur – DE\_s
12. TI = TI-1
13. END IF
14. END WHILE

These phases are illustrated in Figure4.5 and Figure4.6. According to the algorithm, all the dominators (BLACK) select the counterparts locally and perform activity scheduling. Here the MANET node 5 selects node 2 as the counterpart, node 1 selects the union of node 8 and node 24 as
counterparts, because their combined $N_1$ list is equivalent to the neighbour list of node 1. Similarly node 17 and node 30 are counterparts. Node 18 selects union of node 25 and node 23 as the counterparts. Node 13 has no equivalent node or union of nodes with similar $N_1$ list, in this case node 13 will not perform activity scheduling locally until an equivalent node / nodes join. When compared to other nodes node 13 drains out quickly. These cases are handled by maintenance phase. Activity scheduling is performed as shown in Figure 4.6. Nodes \{(2,5), (1, (8,24), (17,30), (18, (23,25))\} perform activity scheduling locally. Black slashed lines (active connection) and red slashed lines (inactive connection) indicate the scheduling. When compared to other algorithms the dominators will not run out of energy quickly and lifetime of the network increases as shown in Figure 4.5.

![Figure 4.5 CDS with Activity Scheduling](image-url)
4.3.4 Repair Phase

This phase is called repair / maintenance phase. Here the mobility of the node and the residual energy (RE) are considered for maintaining the optimal CDS. Here four cases are considered when a new node joins the network, existing node moves away, existing dominator moves away, existing dominator runs out of energy. Every dominator executes this phase at frequent ΔT time intervals. A black (dominator) node turns itself to RED when its energy becomes less than Threshold TH, i.e. drains out.
**Repair Phase Algorithm**

1. IF a BLACK node (Dominator) moves away
2. THEN
3. Immediate GREY node with highest $N_1$ and RE value is turned BLACK and execute Activity Scheduling Phase
4. END IF
5. IF a GREY node (Dominatee) moves away
6. THEN
7. No change
8. END IF
9. IF a BLACK node’s RE \( \leq TH \)
10. THEN
11. Turn BLACK node to RED and handover the dominator status to equivalent counterpart and execute Activity Scheduling Phase
12. END IF
13. IF a new WHITE node joins the network
14. THEN
15. IF it has BLACK node (dominator) in its range
16. THEN
17. Convert itself to GREY (dominatee)
18. ELSE
19. Convert itself to GREY and its GREY neighbour to BLACK (as connector) and execute Activity Scheduling Phase
20. END IF
21. END IF
Repair phase algorithm is illustrated in Figure 4.6. Here the dominator node 17 moved away, so the counterpart node 30 has become the black node as shown in Figure 4.7. Node 5 has drained out and turned itself into RED and exchanged locally. So node 2 has become the dominator as shown in Figure 4.7. Two new nodes 29 & 31 have joined the network, where node 29 near the nodes 23 and 25 and node 31 joined near the nodes 11 and 12. Nodes exchange their IDs locally. Now node 12 will become the additional new dominator. Node 29 is already adjacent to two dominators and hence it turns itself into grey as shown in Figure 4.7. The final optimal repaired CDS \{2, (1, (8,24)), 13, 12, 30, (18, (23,25))\} is shown in Figure 4.7. Here only nodes (1, (8,24)), (18, (23,25)) perform the activity scheduling.

**Figure 4.7 The Final Repaired CDS with Minimal Activity Scheduling**
4.4 CONCLUSION

A new energy efficient optimal Connected Dominating Set (CDS) algorithm with activity scheduling for mobile ad-hoc networks (MANET) is constructed which suits for low mobile MANETs. This algorithm achieves energy efficiency by minimizing the broadcast storm problem and at the same time balancing the energy consumption among the nodes. The performance evaluation also gives good results which is discussed in chapter 5. This algorithm is evaluated at dense and sparse environments. It is also compared with normal AODV protocol, which yields better results. The time and message complexities are also less when compared to existing CDS algorithms. As the activity scheduling balances the energy among the dominators by rotating the states of active and sleep among the adjacent dominators, the MANET life time is improved a lot when compared to other normal CDS algorithms. Moreover, the proposed activity scheduling algorithm in this work also considers energy of the dominators. It calculates the residual energy of the dominator nodes. Thus this algorithm achieves overall better results when compared to other CDS algorithms.