CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 INTRODUCTION

In a typical WSN scenario, all the data are routed back to the static sink. Therefore, those sensor nodes near the sink have to forward all the data from nodes that are away from the sink and thus carry a heavier traffic load. Consequently, the sensor nodes near the sink drain their energy faster and are more susceptible to energy exhaustion. When these sensor nodes use up all their energy (called energy hole), no more data can be transmitted back to the sink, causing dysfunctional or disconnected network or premature lifetime of WSN. The main objective of this dissertation is to ease the formation of energy hole near the static sink by employing various techniques so as to reduce the burden on the nodes near the static sink. The three strategies or techniques considered in the thesis are K-level based transmission range scheme using corona model, optimum predefined path for Beacon based data collection(BBDC) scheme using mobile sink and Grid based clustering(GBC) with dual cluster heads to improve energy balance in the network thereby extending network lifetime. The significant contribution of the work along with major findings is dealt in subsequent section. The performance improvement of the proposed work is calculated using the performance evaluation expression given in chapter 1.
6.2 CONTRIBUTIONS OF THE WORK

This section highlights the main contributions of the dissertation. Each of the work along with important findings is given in this section.

6.2.1 Performance Comparison of K-level based Transmission Range Scheme with Fixed Transmission Range Scheme

Chapter 2 presents K-level based transmission range scheme to ease the formation of energy hole near the static sink by distributing the energy consumption uniformly across the network. A combination of controlled region selection strategy along with maximum residual energy node selection is employed. In this scheme, a sensor node determines its possible next hop nodes using a controlled region selection strategy based on value of K where K indicates the number of corona level jump. From among the possible next hop nodes, a node whose residual energy is maximum is chosen as the next hop. Using K-level based transmission range scheme a new set of next hop nodes is selected every time a different K value is chosen during the renewal phase. By this the burden on nodes near the sink decreases and also energy balance among the nodes in the network is achieved thereby extending network lifetime.

In the simulation results, the proposed K-level based transmission range scheme and normal fixed transmission range scheme are compared. In case of fixed transmission range all the nodes in the network have fixed transmission range and the data is transmitted from one corona to next adjacent corona. It is seen that the end-to-end delay is lesser by 16.82% for K-level based transmission range scheme compared to normal fixed transmission range scheme. This is due to data reaching the sink with lesser number of hops compared to fixed transmission range scheme. In case of
network lifetime, K-level based transmission range scheme has an improvement of 18.83% over normal fixed transmission range scheme. There is more energy balance in the network in case of K-level scheme compared to fixed transmission range scheme. It is seen that K-level based transmission range scheme is more efficient than normal fixed transmission range scheme due to controlled region selection scheme along with the selection of maximum residual energy node among them. This avoids repeated and random selection of same node which occurs in normal fixed transmission range scheme. Also for higher values of K, the burden of forwarding the data to sink shifts from corona 1 to higher level of coronas. This ensures that energy dissipation takes place equally in higher set of coronas as well as lower set of coronas. It is seen that energy dissipated at network lifetime in corona 1 and corona 2 is higher by 8.5% and 13% respectively for K-level based transmission range scheme compared to fixed transmission range. This indicates that energy balance in K-level scheme is higher compared to fixed range scheme. In other words the energy spent is more evenly distributed in K-level based transmission range scheme.

Finally it could be concluded that even though the unbalanced energy depletion among the nodes near the sink is inevitable due to intrinsic many to one traffic pattern in WSN, but by employing K-level based transmission range scheme it is possible to significantly assuage uneven energy consumption thereby extending Network lifetime. The drawback or limitation of this approach is that for higher number of nodes per corona (above 35 nodes per corona) packet delivery ratio becomes lesser or in other words congestion becomes higher at the static sink.
6.2.2 Performance Comparison of BBDC Scheme for Various Sink Mobility

Chapter 3 proposes BBDC algorithm using a mobile sink in order to distribute the energy consumption uniformly across the network. Various types of sink mobility were explored to find an optimum path for improving network performance. The main objective of this BBDC algorithm is to overcome the formation of energy hole and achieve better energy balance in the network by efficient data collection scheme using mobile sink. Finding the optimum path for mobile sink, impact of increasing the pause points and the effect of increasing the number of mobile sinks on BBDC scheme to improve network lifetime is analyzed.

From the simulation results it is seen that mid-square path shows an improvement of 19.11% over random path in terms of network lifetime for varying pause points. It is observed that for random mobility and predefined path mobility, average energy dissipated increases with increase in pause points. But average energy dissipated for random mobility is higher compared to predefined path. This is due to energy spent by the nodes for broadcasting the beacon messages from the sink every time it pauses to collect data from the network in case of random mobility. In case of predefined paths the nodes broadcast beacon messages only during first round trip of data collection. Another important aspect is the minimum number of pause points needed to collect data. The number of pause points needed is 4 since data collection has to be done from all the 4 quadrants of the square network area.

From the simulation analysis it is seen that among the predefined paths, mid-square path has minimum end-to-end delay and diagonal cross has maximum end-to-end delay. By theoretical calculation, the total travel time...
for one round trip for the various predefined paths follows decreasing order as given below.

\[ t_{s-\text{Diagonal cross}} > t_{s-\text{Midcross}} > t_{s-\text{Midcrosssquare}} > t_{s-\text{Midsquare}} \]

The end-to-end delay is least in case of static sink which is due to absence of travel time, pause time and number of pause points. Further, it is observed that predefined mid-square path performs better compared to other predefined paths in terms of network lifetime and energy dissipation. It is concluded that among the predefined paths, mid-square path is the optimum predefined path.

The impact of number of mobile sinks on network performance is compared between random mobility and predefined mid-square path. It is seen that the end-to-end delay is reduced with increase in number of mobile sinks. Further it is seen that end-to-end delay is lower for mid-square path compared to random mobility. Network lifetime increases as the number of mobile sink increases in case of predefined mid-square path but decreases in case of random mobility. It is seen that predefined mid-square path has packet delivery ratio of 3% to 4% higher compared to random mobility.

It could be concluded that BBDC algorithm using mobile sink with predefined mid-square path performs better in terms of network lifetime and energy dissipation. This approach not only removes the burden on nodes closer to sink but also reduce the congestion near the sink. But the limitation in using the mobile sink approach is that end-to-end delay is higher compared to static sink approach which is due to absence of travel time, pause time and number of pause points in case of static sink.
6.2.3 Performance Comparison of GBC-SS with LEACH and UCR

Chapter 4 presents a very innovative approach using clustering technique to alleviate the energy hole problem. Grid based Centralized Cluster Configuration using static sink along with dual cluster heads is used to achieve enhanced energy balance in the network thereby extending network lifetime. The system design consists of the following tasks namely Centralized Cluster Configuration, Secondary Cluster Head Selection, Determining Neighbouring Cluster heads, Data Collection Phase and Renewal Phase. The static sink is responsible for initial cluster configuration by centralized algorithm. It involves grid formation, finding the mid point of each grid cell, identification of nodes for each grid cells by node-Id and grid-Id, cluster head selection and finally broadcast of grid cell information by sink.

From simulation results, it is seen that in general, GBC or GBC-SS scheme with uniform node distribution performs better compared to non-uniform node distribution. This is due to better energy balance achieved inherently by even distribution of nodes in the network for uniform node distribution. It is observed that the network lifetime is higher for uniform node distribution compared to non-uniform node distribution. This could be due to uneven node distribution where in some grid cells the node density could be very less and in some grid cells where node density being very high. Because of this there could be higher intra-cluster communication cost in case of non-uniform node distribution.

The effect of number of grid cells on the network performance indicates the effectiveness of grid formation for clustering. It is seen that the performance is better when the number of grid cells is 25. This could be an optimum value for creating number of grid cells. When the number of grid
cells is very less (g=4) then intra cluster communication cost would be mainly
dominating the inter cluster communication thereby creating imbalance in the
utilization of energy in the grid cells. When the number of grid cells is very
large (g=100) then inter cluster communication cost would be very high and
intra cluster communication cost would be very less. This again would lead to
imbalance in energy consumption in the network. Therefore the performance
is optimum when the number of grid cells is 25. This is due to better balance
of inter-cluster and intra-cluster communication.

The performance of grid based clustering model is compared with
LEACH and UCR for uniform and non-uniform node distribution. The Grid
based clustering improves over LEACH by 19.94% and 13.81% for non-
uniform and uniform node distribution respectively in terms of network
lifetime. Similarly GBC improves over UCR by 11.73% and 9.35% for non-
uniform and uniform node distribution respectively in terms of network
lifetime.

In terms of data collection by sink, GBC improves over UCR by
3% and 3.7% for non-uniform and uniform node distribution respectively.
Again GBC improves over LEACH by 6.31% and 6% for non-uniform and
uniform node distribution respectively. In case of GBC the burden of inter
cluster and intra cluster communication is dealt separately by primary and
secondary cluster heads. Another advantage of GBC is that the primary and
secondary cluster heads are chosen which have higher residual energy and
close to the centre of the grid cell at every renewal phase. Another unique
feature in GBC scheme is the ease of grid cell formation and selection of
primary cluster heads by centralized cluster configuration using static sink.
By this equal sized grid cells are formed, which in turn facilitate creation of
clusters that contain equal number of nodes per grid cell for uniform node
distribution which is unlike in the other schemes. Also another improvement
in GBC clustering is that the intra-cluster data collection is done mainly through single hop to the secondary cluster head. These reasons are very crucial in making GBC scheme better than LEACH and UCR.

The important contribution of the GBC scheme is the ease of grid cell formation and selection of cluster heads by centralized cluster configuration. Secondly, Grid based clustering address the constraints in clustering schemes like choosing the cluster heads at the start up of the operation and to have equal sized clusters for better energy balance in the network.

6.2.4 Performance Comparison of GBC-HS with GBC-SS and GBC-MS

Chapter 5 presents the extension of the work done in chapter 4. In this Grid based clustering algorithm using mobile sink and hybrid sink for data collection to alleviate energy hole problem is dealt separately. The performance of grid based clustering schemes GBC-SS, GBC-MS and GBC-HS is compared with LEACH and UCR for uniform and non-uniform node distribution. It was already seen in chapter 4 that GBC-SS performs better than LEACH and UCR. Further improvement is done to grid based clustering by having two other variants namely GBC-MS and GBC-HS.

It is seen that GBC-MS improves over GBC-SS by 19.41% and 14.94% for non-uniform and uniform node distribution respectively in terms of network lifetime. This could be due to mobile sink collecting data at 4 pause points whereas in case of static sink there is single point for data collection and therefore the cluster head nodes near the sink would have lesser burden in case of mobile sink scenario. Further it is seen that GBC-HS improves over GBC-MS by 5.5% and 6.2% for non-uniform and uniform
node distribution respectively in terms of network lifetime. This could be due to GBC-HS having 2 sinks for data collection. It is further seen that energy dissipation is lesser in case of GBC-MS compared to GBC-SS. This could be due to less number of hop counts needed by cluster head node to reach mobile sink as it travels to collect data. Also the cluster head nodes near the immediate vicinity of the mobile sink always changes and therefore better energy balance in the network achieved using mobile sink. It is seen that energy dissipated for GBC-HS is less by 4.48% compared to GBC-MS for non-uniform node distribution. Similarly energy dissipated for GBC-HS is less by 3.96% compared to GBC-MS for uniform node distribution. GBC-HS has lower energy dissipation compared to GBC-MS since more energy balance is achieved due to addition of data collection centre through static sink.

In general, it is observed that network performance for uniform node distribution is better compared to non-uniform node distribution for all the schemes. This is due to more energy balance achieved inherently by even distribution of nodes in the network. Another important observation is seen that the disparity in performance between the uniform and non-uniform node distribution is very insignificant in case of GBC-MS compared to GBC-SS. In other words the performance is equally same for both uniform and non-uniform node distributions in case of GBC-MS. This is evident for both network lifetime and energy dissipation. The reasoning could be that there is more energy balancing in case of GBC-MS compared to GBC-SS. It is evident from theoretical analysis that in case of GBC-MS using mobile sink there is less hop count to reach the sink as well as fewer burdens near the vicinity of the sink. This is in addition to more balance in inter-cluster and intra-cluster communication by primary and secondary cluster heads respectively. Similarly due to the above mentioned reasons there is more
energy balance in the network for GBC-HS than GBC-MS. This is evident with less energy dissipated for higher network lifetime which is seen for both uniform and non-uniform node distributions.

GBC-MS performs better than GBC-SS in terms of network lifetime and energy dissipation. But one limitation of using the GBC-MS is that end-to-end delay is very much higher compared to GBC-SS which is a constraint in case of delay sensitive applications. GBC-HS overcomes this limitation along with better energy balance in the network. It could be concluded that GBC-HS out performs GBC-SS, GBC-MS and other clustering schemes like LEACH and UCR.

The conclusion from the afore-mentioned chapters shows that the different techniques employed to alleviate energy hole problem has better performance compared to other existing methods.

6.2.5 Performance comparison between the proposed K-level transmission range, BBDC and GBC schemes

This section provides the performance comparison between the various proposed schemes and to identify how important each factor namely transmission range, sink mobility and clustering would contribute to the overall goal of extending network lifetime. Even though, each approach uses different techniques, a comparison is made between them in terms of data collection by sink, end-to-end delay, network lifetime and average energy dissipation at network lifetime. Table 6.1 compares the various proposed schemes. The values are obtained from the tables of chapters 2, 3, 4 and 5. The performance metrics values of GBC schemes are for uniform node distribution.
Table 6.1 Summary of performance comparison between the various proposed schemes K-level transmission range, BBDC and GBC schemes

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Performance metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data collection by sink (%)</td>
</tr>
<tr>
<td>K-level transmission range scheme (50-250 nodes)</td>
<td>88.32</td>
</tr>
<tr>
<td>BBDC (Mid-square path) (50-200 nodes)</td>
<td>96.45</td>
</tr>
<tr>
<td>GBC-SS (50-200 nodes)</td>
<td>96.89</td>
</tr>
<tr>
<td>GBC-MS (50-200 nodes)</td>
<td>98.19</td>
</tr>
<tr>
<td>GBC-HS (50-200 nodes)</td>
<td>99.29</td>
</tr>
</tbody>
</table>

It was already seen earlier that K-level based transmission range scheme improves over fixed transmission range scheme by 18.83% in terms of network lifetime. From the Table 6.1, the BBDC scheme (with optimum mid-square path) using mobile sink performs much better than K-level based transmission range scheme using static sink in terms of network lifetime and data collection. The BBDC scheme using mobile sink has a performance improvement of 48.98% compared to K-level based transmission range scheme in terms of network lifetime. This indicates that BBDC scheme using mobility of the sink has higher impact over transmission range variation using K-level transmission range scheme in the improvement of the network lifetime. In other words the effect of mobility of sink is higher compared to effect of transmission range variation for achieving energy balance in the network. The reasoning is that, as the mobile sink collects data from the
network while moving within the monitored area, energy spent for relaying data to the sink is considerably reduced. As the mobile sink moves from one point to another, the nodes near the sink also changes, which prevents burdening of the nodes near the sink. Also the data collection by sink for BBDC scheme is better compared to K-level scheme using static sink, since the congestion near the sink is reduced considerably as it traverses in the network area to collect data. One major drawback is that the end-to-end delay is very much higher in BBDC scheme using mobile sink, which is a critical issue in case of delay sensitive applications.

The GBC-SS scheme with dual cluster heads has lesser network lifetime compared to BBDC scheme but has improvement in terms of end-to-end delay and data collection by sink. Also the GBC-SS scheme improves over K-level based transmission range scheme in terms of network lifetime and data collection. The GBC-SS scheme has a network lifetime improvement of 34.45% over K-level based transmission range scheme. This indicates that there is significant improvement in network lifetime due to the presence of dual cluster heads taking care of inter-cluster and intra-cluster communications. This shows that the effect of grid based clustering technique has higher impact compared to K-level transmission range scheme but has lesser impact compared to sink mobility.

The GBC-MS scheme which employs a combination of grid based clustering and sink mobility has significant improvement in performance in terms of network lifetime and energy dissipation over GBC-SS. There is a performance improvement of 14.94% and 44.17% in terms of network lifetime for GBC-MS over GBC-SS and K-level based transmission range scheme respectively. This shows that there is a performance improvement of 14.94% for GBC-MS over GBC-SS scheme due to introduction of sink mobility. Finally, GBC-HS a hybrid combination of static sink and mobile
sink overcomes the limitation of end-to-end delay in GBC-MS. It is seen that GBC-HS performs significantly among all other GBC schemes. The GBC-HS scheme improves over K-level based transmission range scheme by 47.63% and GBC-MS scheme by 6.2%.

From the above analysis, it could be concluded that the effect of mobility is very much dominant in increasing the network lifetime. The effect of Grid based Clustering has slightly lesser impact compared to mobility scheme. The transmission range variation scheme which is employed only in case of static sink has still lesser impact on network lifetime compared to mobility and clustering technique. The end-to-end delay is reduced significantly in GBC-HS by the combination of static and mobile sink. Another important conclusion is that there is significant improvement in data collection by the use of clustering with dual cluster heads compared to mobility and transmission range variation techniques which is evident in all GBC schemes.

6.3 SCOPE FOR FUTURE WORK

This section focuses on future directions and possible enhancement to the current research work presented here on alleviating energy hole problem in WSN. Some of the issues are given in subsequent sections.

6.3.1 K-level based Transmission Range Scheme

In this work, it is found that K-level based transmission range scheme has a drawback that for higher number of nodes per corona (above 35 nodes per corona) packet delivery ratio decreases. This is due to nodes in higher coronas directly transmitting data to sink for higher values of K. Even though for higher values of K, the burden of forwarding to sink shifts from
corona 1 to higher level of coronas but traffic load or congestion becomes higher at the static sink. Hence a mathematical model could be arrived for optimal K value for each corona such that a balance could be maintained between traffic load at sink as well as achieving energy balance in the network. This is an open issue for future work.

6.3.2 BBDC Scheme for Sink Mobility

Various types of sink mobility were explored to find optimal predefined path for mobile sink. It was seen that predefined path performs better compared to random path in terms of energy dissipation and network lifetime. This is due to energy spent by the nodes for broadcasting the beacon messages from the sink every time it pauses to collect data from the network in case of random mobility. In case of predefined paths the nodes broadcast beacon messages only during first round trip of data collection. Hence some energy is saved in the predefined path. But there are two limitations in using predefined path. One is that the sensor node has to buffer the data until the mobile sink visits its vicinity. If there is very higher traffic (could be video signal) then there is a chance that buffer may be overrun with its data and neighboring nodes data. Secondly due to repeated round trip path, the data collection takes place at the same location. This could again lead to draining of energy by nodes near the mobile sink. A simple solution could be to change the predefined path after a period of time. By this energy hole could be prevented near the mobile sink. Similarly to prevent overrun of buffer a mechanism has to be proposed which is another issue for future work.

6.3.3 Grid based Clustering

It was found that GBC scheme performs better compared to other clustering schemes LEACH and UCR. An improvement that could be done is
to find out optimal cluster size or grid cell size for any given network area. In this thesis the network area considered is of square region. Hence to find optimal grid cells for network area of rectangular region can be considered for future work. Further inter-cluster and intra-cluster traffic could be analyzed in depth to study the burden on primary and secondary cluster heads. Further innovation could be, is to place one primary cluster head placed at the intersection point of 4 grid cells instead of in each grid cell. By this each cluster head could collect data from each of the 4 grid cells. This could reduce the inter-cluster traffic thereby reducing energy dissipation. Another improvement for energy saving could be to put the nodes to sleep till the mobile sink reaches the pause point for predefined path data collection. So a proper scheduling of active and sleep is to be implemented such that there is co-ordination between cluster heads for data transmission. These are issues which could be considered for future work.