CHAPTER 7

CONCLUSIONS

7.1 GENERAL

The wireless sensor network is an important research area that has recently attracted considerable attention of research community. The WSNs are used in many applications like precision agriculture, environment monitoring, habitat monitoring, disaster rescue operations, battle field surveillance etc. Due to the potentially harsh, unpredictable environments in which sensor networks are expected to work, apart from the energy and the bandwidth constraints, sensor networks pose several technical challenges to the researchers. The wireless sensor networks must deal with limited resources that are often dynamically changing. The network also needs to deal with unreliable communication links that are easily affected by interference, and yet it should provide the required reliability.

There has been various research efforts conducted in sensor networks focusing on several key issues; they include but are not limited to the following:

- Data dissemination and routing research for data propagation and routing in wireless sensor networks.
- Efficient sleep/duty cycle schemes to provide energy saving while maintaining network connectivity.
- Collaborative signal and information processing researches for reliable event detection and distributed information fusion.
- Energy-efficient MAC schemes for low-power, energy conserving and energy-efficient communications.
- Distributed time synchronization schemes and lightweight geographic localization mechanisms.
- Distributed tasking and querying techniques for query and task compilation/placement, data organization, and caching.

Despite the diverse nature of sensor network based applications, the primary goals of these applications are (i) to prolong the longevity of the network and (ii) to reliably gather as much information as possible from the sensing field. Several researchers have focused their attention on this area, but still there are many unresolved issues and technical challenges. Providing plausible solutions to overcome all these problems and deploying an efficient large-scale wireless sensor network still remains as an intricate task. However, on going research efforts in this direction are surely taking us towards realizing the vision of any time, any where ubiquitous computing.

7.2 CONTRIBUTIONS OF THE THESIS

In the direction of enhancing the performance of energy and reliability constrained wireless sensor networks, four different solution methodologies have been developed and the simulation results are presented in this dissertation report. The excerpts of the major findings and conclusions arrived at are discussed in this section.
7.2.1 Energy and Stability Aware Clustering (ESAC)

A fully distributed and light weight clustering technique for heterogeneous wireless sensor networks is developed and presented in this thesis as the first proposal. The main feature of ESAC is that it is not only energy efficient but also prolongs the stability period of the network by balancing the relay load offered at the various cluster head nodes. By means of extending the stability period, the network gets the ability to provide more complete and dependable sensing reports that are generated from the entire sensing area.

The ESAC algorithm does not make any assumptions about the node density or distribution of the nodes across the sensing area. The algorithm ensures complete association of nodes with the cluster heads and terminates in $O(1)$ iterations. Simulation results show that ESAC improves the stability period of the network substantially (by 300 rounds on the average) when compared to the class of unbalanced clustering techniques.

7.2.2 Communication Efficient Framework for Data Gathering Sensor Networks

In the wireless sensor networks, the power of the energy constrained sensor nodes is largely drained by data communication tasks. Designing energy-efficient data communication mechanisms is therefore a major key to maximizing the life-time of wireless sensor networks. Motivated by this challenge, the second proposal presented in the thesis strives to reduce the communication overhead by making use of the spatial-temporal correlations existing in the sensory data. The time series sensor data is regressed using the AR(3) model and only the model coefficients are reported to the sink instead of sending a vast quantity of raw sensor data. This is how the temporal correlation is utilized.
Spatial similarity is used to build feature regions that represent the geographical delineation of the phenomenon under study. A leader node from each feature region reports only model coefficients to its corresponding CH. Each node chooses to update the model whenever the model ceases to properly fit the data. A CH uses the model parameters to predict the measured readings to answer queries from the base station. Since feature regions are clearly demarcated, any topographic query will be appropriately routed to the relevant feature region.

Environmental data set consisting of real world temperature readings taken every 30 seconds from 20 different sensor nodes is used for the purpose of the study. The communication framework proposed in this thesis helps in immensely reducing the communication overhead involved in continuously reporting the vast quantity of raw data generated from numerous sensor nodes.

7.2.3 Outlier Detection using Modified z-score Technique

The outliers are inharmonious observations resulting from faulty or misbehaving sensor nodes. Outlier cleaning is an important step in improving the quality of the aggregation process in collaborative sensing applications. A simple yet robust sensor data aggregation technique that uses a statistical technique called modified z-score test is adopted in this thesis to accurately label the outliers. This technique uses Median of Absolute Deviation (MAD) in place of the outlier sensitive parameters like mean and the standard deviation which are used by the standard z-score test. Simulations results show that the proposed aggregation strategy yields a very good performance for up to 40% of the faulty node density for target detection applications and for up to 35% of the above in continuous data gathering applications.
7.2.4 Congestion Free Routing Component (CF-LAR)

Event detection applications require sufficient amount of event related packets to know the minutiae of the event occurred. When significant changes in the environment are recognized, all the sensors discovering this anomaly will start sending traces about this event in a burst transmission. This makes the common paths leading to the sink become congested and thus leading to packet drops. This affects the reliability obtained at the end applications. Hence, a Congestion Free, Location Aware Routing scheme called CF-LAR is proposed in this thesis to improve the packet delivery efficiency in congested network conditions.

Simulation results show that when CF-LAR is included as a routing component of ESRT, the packet delivery efficiency of ESRT improves by 45%. The performance of the proposed technique was tested for varying error rates and in all the cases it was found to show very good delivery efficiency.

7.3 FUTURE DIRECTIONS

There are several intriguing issues for pursuing further research in this area. The two major issues considered in the thesis viz. improving the energy efficiency and the reliability of the wireless sensor network can be extended in many different dimensions.

Most importantly, the current dissertation work has not attempted the cross layer optimization approach in its full sense where a given problem is tackled with the cooperation from multiple layer levels. For instance,

(i) at the hardware level, sensor nodes provide multiple sleep modes and coding techniques to allow the end users to tailor
the power consumption according to the intended application’s requirements.

(ii) MAC layer protocols take advantage of turning nodes on/off on demand by allowing nodes to sleep when they are not involved in any communication activity.

(iii) the network layer can balance power through the distribution of messages among various paths from source to destination.

Therefore exploiting such cross layer interactions to meet the required objective of improving the network life time by formulating a joint optimization problem appears as the most promising alternative.

The implementation of ESAC continues in this direction - the choice of the transmission mode, the role and the location of a given node play a vital role in determining its lifetime. In the clustered network architecture considered in the thesis, where the CHs take the responsibility of sending the aggregated reports to the base station, it is obvious that if single hop communication mode is selected, then the cluster head nodes far away from the base station expend a high amount of energy in reaching the sink, while in the multi hop communication mode, the nodes closer to the base station expire very soon because they are the ‘last hop’ nodes and hence have the highest amount of relaying burden. So both single and multi hop communication modes cause a non uniform energy drainage pattern or energy imbalance in the network. The same energy imbalance problem occurs in the intra cluster communication too. Intelligent solutions like transmission power control, movement of the sink etc are sought to mitigate the above said problem.

The performance of the proposed congestion free routing component CF-LAR is currently tested only in association with ESRT.
However, being a pluggable routing component, it can be used to work with other WSN transport protocols also, after thorough verification of its efficacy. Besides, the performance of CF-LAR is not verified for continuous data gathering applications in the current work.

7.4 SUMMARY

The solution methodologies proposed in this dissertation report for optimizing the performance of energy and reliability constrained wireless sensor networks viz.

(i) the Energy and Stability Aware Clustering technique (ESAC)
(ii) the energy efficient feature region construction module
(iii) the outlier detection module and
(iv) the Congestion Free Location Aware Routing Technique called CF-LAR.

will achieve the aim of improving the stability period of the network, reducing the communication overhead, cleaning the fraudulent/ inconsistent sensor reports and enhancing the packet delivery efficiency. The performance of all the proposed methodologies are tested using standard simulation models. The performances of the proposed modules have been published and are compared with related techniques in terms of the appropriate performance metrics.

From the dissertation, it can be well concluded that the four techniques projected herein would prove to be of immense help to the sensor network based applications.