Chapter 8

Conclusion and Future Scope

At the end of the thesis, before reaching to the conclusion, we will first summarize the thesis. Future scope gives further possibilities of research in this direction.

8.1 Summary

In this thesis, we have suggested a coordinated adaptive power management (CAPM) technique for wireless sensor nodes. Power optimization technique DVFS for processor and DMS for transmitter are coordinated together w.r.t. the input buffer occupancy (workload). With CAPM, we are trying to increase the lifetime of individual sensor nodes, which in turn improves the lifetime of Wireless Sensor Network (WSN). For the rare event monitoring and detection applications, data traffic in the network is non uniform and unpredictable. In this scenario, it is important to have WSN alive when the event of interest occurs. In order to have WSN alive, sufficiently high number of sensor nodes must be alive in the network. So, increasing the lifetime of individual sensor node is important in view of a long lived WSN. Low power hardware and sleep scheduling schemes are helpful in increasing
lifetime of sensor nodes. Further power saving can be achieved by applying CAPM during ON period of sensor nodes.

We are aiming to increase the lifetime by power optimization at sensor node level but at the same time we are concerned with the QoS. Here QoS parameter considered is data loss due to buffer overflow. Due to very small size and limited hardware capabilities sensor nodes are highly prone to this kind of data loss. Purpose of CAP management technique is to use the optimum power to handle the workload with QoS. Wireless sensor networks are mainly deployed for special event detection and monitoring of such events and hence need to handle a very non uniform traffic pattern. Sensor nodes use multihop communication due to limited battery power available for transmission. Hence when an event gets detected at one corner of the sensing field, other sensor nodes far away in the field need to forward the detected data towards the sink. So, aim of this research is two fold- Saving the power during no event period (normal period) and reducing the data loss due to buffer congestion at the cost of increased power consumption when event occurs (catastrophic period).

A wireless sensor node with discrete rates has been considered as practically it is not possible to have a continuous rate adaptation due to hardware constraints. Rate adaptation helps to adjust the power consumption of a sensor node as per the actual workload requirement. Figure 3.5 shows the conceptual block schematic for CAPM technique. In Chapter 4, tandem queue model of sensor node has been considered with various capabilities and MATLAB simulation results have shown. We have modeled, analyzed and simulated a sensor node with fixed service rate, with only DVFS, with only DMS technique and with both DVFS and DMS implemented together. Table 4.1 shows the simulation results for a sensor node with fixed service rate. It shows that, during normal period, sensor node remains idle over large period (25% to 58% of ON time). So, obviously idle power wastage is more. During catastrophic period, idle period has minimized (6% and below) but over-
flow probability at input buffer ($OV_1$) is very large (above 25%). It means increased data traffic is dropped before entering the node, so power is saved but data of interest has lost. Figure 4.6, Figure 4.7 and Figure 4.8 show the comparison between sensor nodes with various capabilities. A sensor node with only DVFS facility implemented on it can control the overflow probability of input buffer by increasing the clock frequency of the processor. Increased service rate of the processor increases the data arrival rate in the output buffer but since transmitter works with fixed service rate, overflow probability of the output queue ($OV_2$) increases. This situation is highly undesirable as the processed data gets lost and power used for processing that data also goes waste. Similarly, when only DMS is implemented, it results in decreasing the output buffer overflow probability at the cost of increased power but as the first server works with fixed service rate, input buffer overflow can not be controlled. Integrating both DVFS and DMS on a sensor node results in controlling the overflow probabilities of both the buffers. Though more power is consumed by DVFS and DMS during catastrophe by working with higher service rates data loss due to buffer overflow is reduced and can be kept within the tolerance limit which is the highest priority QoS parameter during catastrophe.

As the data arrival rate is very small during normal periods, buffer overflow possibilities are negligible but possibilities of servers remaining idle are more. More the idle period, more is the power wastage. So, for power constrained wireless sensor nodes power saving becomes highest priority QoS parameter during normal periods is reducing the idle period. It is achieved by reducing the service rates of the servers. Fixed service rate sensor nodes are designed to handle worst case conditions and hence their service rates are set quite high. During normal periods these servers remain idle most of the time and large amount of power is wasted but there is negligible chance of buffer overflow. Power saved during normal periods can be used during catastrophic periods to reduce data loss due to buffer
overflows. As compared to fixed service rate sensor node lifetime increase of 15% was seen when only DVFS was implemented on a sensor node while implementing only DMS it was 17.5% but DVFS and DMS together applied on a sensor node resulted in 27.22% lifetime increase.

After analyzing a sensor node as a tandem queue, CAPM found giving better results in terms of lifetime and overflow probability. We have considered a sensor node as a single entity (server) inside which DVFS and DMS works in a coordinated manner. Changing the service rate of sensor node will internally select a specific processing rate and a specific number of bits per symbol in a look up table manner. This single server model of sensor node we have tried to capture using Markov chain (Refer Figure 5.4. This is a bulk arrival and batch service $M^{[x]}/M/1/N$ model. Flow chart for a sensor node with CAPM and having two active states (active Low and active High) is shown in Figure 5.3.

Analysis of Markov chain model on paper has become a tedious job due to large number of equations involved in it. So, we have carried out the analysis with the GSPN models using software analysis tool, SHARPE. Chapter 6, gives all the GSPN models and their sensitivity analysis. Figures 6.11 and Figure 6.12 shows the comparison between a sensor node with fixed service rate and with multiple service rates (CAPM). From all the above comparison graphs, a multi rate (CAPM) sensor node seems to outperform the one with fixed service rate in view of lifetime, buffer overflow probability, latency, throughput etc.

8.2 Conclusion

Non uniformity of traffic in WSN can be exploited to increase the lifetime of sensor nodes. Sensor node with only DVFS or only DMS capability does not give required QoS. DVFS and DMS implementation on a sensor node with coordinated manner can give us better
results. Selected service rates are considered to satisfy the latency constraint. Data loss due to buffer overflows can be reduced with CAPM technique along with lifetime improvement.

Both DVFS and DMS integrated together on a sensor node can effectively suffice the purpose of power optimization as well as data loss reduction. DVFS and DMS techniques coordinated with input buffer makes the sensor node operation more effective. Markov model of sensor node, Matlab simulation results and Generalized Stochastic Petri Net (GSPN) model of sensor node simulated using SHARPE, support the concept of CAP management. We have analyzed a sensor node as a tandem queue model to capture the internal functioning of a sensor node and effect of DVFS and DMS on various parameters. After coordinating DVFS and DMS together with actual workload to be handled, we prepared a look up table which gives values of processing frequency and transmission rate for a specific value of data arrival rate which reduces data loss. Each pair of processing frequency and constellation size (transmission rate) is assigned with a specific value of service rate of a sensor node.

### 8.3 Future scope

This thesis provides the performance analysis of a sensor node which supports only two service rates (active high and active low). With the availability of hardware, such N number of discrete service rates can be possible. Study of CAPM with such N number of service rates may result in better power optimization and better QoS, where switching from one rate to the next rate will be much faster and with minimal overheads. Along with performance analysis, reliability analysis of the model can be carried out.

Another thing that can be done further is a WSN can be simulated with every sensor node
with CAPM capability. For some real life application effect of CAPM on the lifetime of WSN can be studied. This thesis has studied the effect of CAPM on the lifetime of a sensor node. When lifetime of all the sensor nodes in a WSN will be increased using CAPM technique, what is the aggregate effect on the lifetime of WSN can be studied.

This thesis presents modeling and simulation of wireless sensor node with CAPM. It will be interesting to implement on real hardware. Currently no radio hardware available in the market supports DMS technique. Design of a low power radio with DMS capability will ensure the actual gain with CAPM.