CHAPTER 1: INTRODUCTION

1.1 WIRELESS SENSOR NETWORKS

Recent advancements in wireless communications and electronics have enabled the development of low-cost sensor networks. The wireless sensor networks (WSN) are used in various application areas such as environmental monitoring, health care, military, etc. For different application, there are different technical issues and technical challenges that researchers are currently resolving. A WSN is a network consisting of number of sensor nodes with sensing, wireless communications, and computing capabilities. The nodes are resource constrained in terms of battery power, memory, and processing. Wireless sensor network is a type of Adhoc network with unique features [1].

The characteristics of WSN [2] include the following:

- Power consumption constraints for nodes using batteries
- Ability to cope with node failures
- Mobility of nodes
- Communication failures
- Heterogeneity of nodes
- Scalability to large scale deployment
- Ability to withstand harsh environmental conditions
- Ease of use
1.1.1 WSN Architecture

The sensor nodes are scattered in an unattended environment to sense the environmental parameters such as temperature, pressure, humidity, etc. The sensed information is collected by a master node called sink node. The sink node communicates with outside world through Internet. The architecture of WSN is shown in Figure 1.1.

The large number of nodes deployed in sensor network applications, and the random deployment strategy used in WSN introduces scalability and reliability issues. Networking of these sensor nodes is the real challenge in any real time WSN applications. Routing in WSNs is also challenging because of the inherent characteristics which distinguish WSN from other wireless networks such as mobile adhoc networks or cellular networks. Also, data management needs to be performed collaboratively in sensor networks to maximize energy savings.

Figure 1.1 Architecture of Wireless Sensor Network
A sensor node used in WSN application consists of the following four components: Sensing unit, Processing unit, Transceiver unit, and Power unit. Also, a sensor node may have additional components such as location finding system, power generator, and mobilizer. The sensor network protocol stack is much similar to the traditional protocol stack, with the following layers: Application, Transport, Network, Data Link, and Physical. The wireless sensor network has three management planes viz., Task, Mobility, and Power Management Planes in order to function efficiently.

1.1.2 Applications of WSN

The advent of intelligent sensors and the use of pervasive networking technology lead to WSNs to be used for various new applications. Deploying nodes in an unattended environment provides more possibilities for the exploration of new applications. WSNs are ubiquitous and due to new opportunities for the interaction between humans and their physical world, WSNs are expected to contribute significantly to pervasive computing.

The various applications of WSN [3] include the following:

- Environmental and habitat monitoring
- Precision agriculture
- Surveillance
- Medical diagnostics
- Disaster management
- Asset tracking
- Healthcare
1.1.3 Node deployment Strategies in WSN

WSN is deployed to measure environment parameters in Region of Interest (ROI) and to send it to a central controller called sink node. Deploying nodes in WSNs depends on application and environment. The node deployment options influence the performance of routing protocol in terms of energy consumption.

The following are the three deployment strategies used in WSN applications:

- **Regular Deployment** - Sensor nodes are deployed in a well planned, fixed manner; not necessarily geometric structure, but that is often a convenient assumption. In this type of deployment data is routed through a predefined path.
  Applications: Medical and health, Industrial sector, Home networks, etc.

- **Random Deployment** – Sensor nodes are scattered randomly. When the deployment of nodes is not predefined, optimal positioning of cluster head becomes a critical issue to enable energy efficient network operation. Random deployment is generally used in rescue operations.
  Applications: Environmental and Habitual monitoring, etc.

- **Sensor Nodes with Mobility** – The deployed sensor nodes move around by some external forces, such as wind, water, vehicle, etc.
  Applications: Battle field surveillances, Emergency situations (Fire, Volcano, Tsunami), etc.
1.2 LIFETIME OF WSN

The network lifetime is a critical issue in the design of WSN application. Various energy efficient protocols have been proposed to prolong network lifetime. Lifetime analysis is difficult because the network lifetime depends on many factors including network architecture and protocols, data collection initiation, lifetime definition, channel characteristics, and energy consumption model [4].

Energy efficiency is an important measure for battery powered WSN nodes to increase the lifetime of WSN application. The total energy consumption of WSN node is contributed by sensor, processor, and radio module of WSN node [5]. More energy is consumed by radio module when it is used for sending or receiving data or control message. WSN node is idle most of the lifetime when it is not communicating. The battery energy can be conserved by putting radio in sleep state when the node is idle.

1.2.1 Factors influencing lifetime

There are many factors affecting the lifetime of the WSN applications such as number of nodes, data rate, deployment strategies, MAC protocols, routing protocols, hardware used, sampling rate, etc.

The number of nodes and nature of deployment of sensor node depends on the application and the environment where the network is going to operate. Deployment of sensor nodes can be random or pre-determined. In random deployment nodes are randomly deployed. In pre-determined deployment, the locations of the nodes are specified. The deployment strategy used in a particular application should aim at
increasing the network lifetime while maintaining coverage and connectivity of the network with the given number of nodes.

Nodes in wireless sensor network have limited energy and the node’s lifetime depends on how energy is conserved during communication. Hence conserving energy is the important design objective of MAC protocol used in WSN as significant portion of the node’s energy is spent on transmissions and on listening to the medium for packet reception. MAC protocol should eliminate the various sources of energy depletion such as packet collisions, idle listening, overhearing, and overhead [6].

Routing protocol used in WSN should be energy efficient to setup a path between regular nodes to sink node. In contrast to other wireless networks, the goal of routing protocol used in WSN is to minimize the energy required for communication rather than minimizing delay. So the routing protocol must be light-weight and has simple processing requirements [7].

The hardware motes used in WSN applications are TelosB, MicaZ, etc. The use of hardware also influences the lifetime. The reason is that the varying consumption of current by these hardware motes for the activities such as processing, sending, and receiving. Also, the current drawn during idle mode and sleep mode varies. So use of proper hardware for the particular application plays a vital role in prolonging the lifetime of WSN.

The sampling rate of the sensors in WSNs determines the rate of its energy consumption since most of the energy is used in sampling and transmission. A low sampling rate leads to reduced energy consumption and hence increases lifetime in the resource-constrained wireless sensor networks [8].
1.3 SIMULATION ENVIRONMENT FOR WSN APPLICATIONS

In case of real time WSN application design, it is not practically feasible to verify the modifications done on existing protocols or new proposed implementation using real WSN hardware as it requires more efforts of time and costs. One option for testing is to use simulation environments to simplify this process instead of implementing everything on real hardware sensor nodes. To determine the lifetime of WSN apriori to real time deployment, simulator software is used for evaluating the impact of various parameters influencing the lifetime. Using the parameters influencing lifetime if the lifetime is precomputed and made known to the application designers then the appropriate parameters can be chosen which maximize the network lifetime. This necessitates the use of simulator software before the actual deployment.

There are many simulation environments which can be used for WSN simulation. These simulation environments differ significantly in their structure and the provided features such as models and protocols. In contrast to wired and traditional wireless networks, WSNs have certain requirements, which have to be considered for the choice of a simulator. Global Mobile Simulator is one such text based simulator software used for simulating wireless networks.

1.3.1 Limitations of GloMoSim for WSN simulation

The various reasons for choosing GloMoSim for this research work are as follows:

1. GloMoSim is a open source software.
2. It is easy to simulate wireless adhoc networks in GloMoSim.
3. It supports scalability which is considered as an important design issue in WSN application development. It allows the simulation up to thousand nodes.

The main limitations of GloMoSim with respect to WSN simulation are as follows:

1. No GUI support
2. No support for WSN Protocol in data link layer
3. Non availability of library of WSN routing protocol
4. No energy model support for lifetime estimation
5. No tool for viewing necessary application level statistics
6. No charting utility for lifetime analysis
1.4 OBJECTIVE OF THE RESEARCH

- To extend the GloMoSim Simulator for use in WSN simulation
- To perform lifetime based analysis of MAC protocols of wireless adhoc networks in WSN application
- To design and develop a network lifetime predictor tool incorporating an energy model using GloMoSim
- To do lifetime based analysis of various MAC and routing protocols, number of nodes, traffic pattern, and sampling rate using network lifetime predictor tool
- To design and develop a novel easy to use sensor network framework with energy model support on top of GloMoSim
- To provide useful tools for WSN simulation on top of GloMoSim
- To do performance analysis of lifetime related parameters using this framework

1.5 PROPOSED TOOL AND FRAMEWORK

The evolution of this research work is shown in Figure 1.2. The thesis consolidates three research proposals of this work and their results. In the Research Work 1, lifetime based analysis of MAC protocols of wireless adhoc networks in WSN is performed by proposing a energy model in GloMoSim for lifetime estimation. Research Work 2 is concerned with design and development of a tool wherein the proposed energy model is integrated for lifetime estimation. The designed tool was tested by analyzing the various parameters affecting lifetime. An easy to use sensor network framework for WSN simulation with refined energy model and proposal for various tools have been the focus in Research Work 3.
1.5.1. Research Work 1

In this research work, with the focus of analyzing the MAC protocols used in wireless adhoc networks to WSN, simulation experiments were conducted using Global Mobile Simulator (GloMoSim) software. Number of packets sent by regular nodes, and received by sink node in different deployment strategies, total energy spent, and the network lifetime have been chosen as the metrics for comparison. The energy model based on processing, sensing, and receiving energy is considered for lifetime estimation.

The data rates used in this experiment were 2 Mbps, 200 Kbps, and 20 Kbps. The various deployment strategies used were application specific, grid, and random deployment. The main objective of this experiment was to analyze the performance of MAC protocols of Adhoc networks to WSN in various data rates and deployment strategies. Two different analysis performed were:

a) Performance comparison of MAC protocols in terms of number of packets received

In this, a network with 4 and 10 nodes with CBR traffic were simulated and the number of packets received by the sink node in three different deployment strategies using CSMA, MACA, and IEEE 802.11 protocols at different data rates were determined and compared.

b) Performance comparison of MAC protocols in terms of energy spent

In order to compare MAC protocols, the energy for sending the sensed information by the regular nodes, the energy for receiving the data by the sink node, the total energy for 100 second simulation time were calculated.
1.5.2 Research Work 2

The tool proposed in this thesis ‘Wireless Energy Calculator (WECalc)’ is a sophisticated GUI based software tool designed to accept user inputs, invoke GloMoSim and estimate lifetime. The advantages of WECalc tool are threefold:

1) Easy simulation of WSN applications through this GUI. 2) Flexible changes to various parameters that influence the lifetime and calculation of network lifetime prior to real time deployment and 3) A value addition to GloMoSim for WSN applications.

The designed tool was experimented with changes in number of nodes, node position, MAC protocol, routing protocol, traffic pattern, etc., and the network lifetime was calculated which extends the utility of GloMoSim to WSN applications also. The main contributions in WECalc are: 1) Embedded energy model which is used for lifetime estimation and 2) AWK program and shell script to extract the necessary information from the application layer statistics of glomo.stat and to calculate total number of packets sent by regular nodes and received by sink node.

1.5.3 Research Work 3

The design of novel easy to use GUI with Energy model based Lifetime estimation supported Sensor network framework with Visualization, Application statistics, and Charting facility tools, GELSenVAC, has been the third focus of this thesis. The aim is to identify the limitations of GloMoSim with respect to WSN simulation and to come out with open source framework with various tools for WSN simulation. GloMoSim supports protocols for a wireless adhoc networks. The current version of GloMoSim does not offer any sensor network specific features in the default package.
This implies that without any further efforts no WSNs can be simulated meaningfully, using GloMoSim.

GELSenVAC framework consists of hardware support for TelosB, MicaZ motes, Sensor MAC (S-MAC) protocol support in data link layer, energy model for lifetime estimation, facility to view application level statistics, and charting facility to generate lifetime charts, on top of GloMoSim environment. By using this framework, designers can easily simulate their own WSN, estimate the lifetime, and select suitable parameters to increase the lifetime of the network. The designed framework is tested by simulating a WSN.

The main advantages of this framework are as follows:

1. Support for various WSN motes TelosB and MicaZ.
2. Flexible changes to various parameters that influence the lifetime and calculation of network lifetime prior to real time deployment though sophisticated GUI.
3. WSN protocol Sensor MAC (S-MAC) support in data link layer.
4. Support for energy model based on processing, sending, receiving energy, and idle listening energy.
5. Support for utility to view application level statistics such as, packets sent by regular nodes and received by sink node.
6. Support for charting tool by which users can analyze the impact of various parameters influencing lifetime of the network.
7. Support for visualization tool.
1.6 SUMMARY OF THE KEY CONTRIBUTIONS

The contributions in this thesis include the following:

- Energy model based on processing, sending, and receiving energy for analyzing MAC protocols of wireless adhoc networks in WSN in terms of lifetime.

- Proposition and implementation of a tool WECalc, with integrated energy model, AWK program, and shell script.

- Lifetime analysis of MAC, Routing Protocols, number of nodes, and sampling rate using WECalc tool.

- Proposition and implementation of the framework GELSenVAC, a novel easy to use GUI based open source framework for WSN simulation.

- Refined energy model based on active energy, sending and receiving energy, energy consumed during idle listening and sleep mode.

- Interfacing of important tools used for lifetime estimation and charting facility with GELSenVAC.

- Performance analysis of MAC protocol, Routing protocol, number of nodes, hardware used, sampling rate, and sampling time using GELSenVAC.

1.7 ORGANISATION OF THE DISSERTATION

The rest of this thesis is organized in the following manner: Chapter 2 provides the description about Wireless adhoc networks and Wireless Sensor Networks, the
difference between Adhoc networks and WSN in terms of communication architecture, various issues of hardware, protocol stack, and issues in quality of service. Chapter 3 presents the literature review on Simulators. It discusses the need for simulation environment for WSN, existing simulation software/framework for WSN simulation. The motivation for the current proposal is dealt in Section 3.3.

Chapter 4 presents Lifetime based analysis of MAC protocols of wireless adhoc networks in WSN applications. The results obtained during the experimentation are discussed in Section 4.5 and Section 4.6. Chapter 5 presents the design and implementation of the proposed tool WEcalc: A Network Lifetime Predictor tool for WSN Applications. It discusses the motivation for current design and key components of the tool. The results obtained using this tool are discussed in Section 5.4.

In Chapter 6, the design and implementation of GELSenVAC: A Novel Sensor Network Framework for WSN Simulation is presented. The features of this framework are given in Section 6.3. The results obtained during various experimentation are discussed in Section 6.8. Finally, Chapter 7 concludes the thesis with summary of this research work, key contributions in this thesis, and future work.