Chapter 1

Introduction

1.1 Introduction to wireless sensor network

A wireless sensor network (WSN) consists of a large number of energy constrained nodes that are deployed for monitoring multiple phenomena of interest. A sensor node consists of a sensing unit, a processing unit, a radio transceiver and a power management unit [Aky'02]. Fig. 1.1.1 depicts the block diagram of a typical wireless sensor node. Sensor nodes produce some measurable responses to changes in physical or chemical conditions and transmit these responses to a common sink in the form of packets of data over a wireless channel. The processing unit processes the generated data before transmitting or forwarding if necessary. Radio communication is done by the transceiver unit to make available monitoring data at the data sink or access point or base station. In a greater sense the three terms data sink, access point and base station have the same purpose of deployment. Thus in the remaining part of this thesis these terms will be used interchangeably. The data sink may be connected to the outside world through the internet where the data sink acts as the gateway node. The power management unit provides necessary power supply to the node for sensing, processing and communication.

WSN has been classified according to data collection initiative or network architecture [Che'05]. A classification of WSN is presented in Fig. 1.1.2. Based on data collection initiative, sensor networks may be classified into four categories. They are–

(i) **Data gathering**: Data collection is initiated by internal clock of the node. This is also known as clock-driven. Depending on the nature of applications, nodes periodically collect raw data and report to the data sink. Application includes periodic update of data for e.g., temperature monitoring inside a plant.

(ii) **Event-driven**: Here, data collection is triggered by event of interest. Most of the time nodes will be in sleep state and wake up only when an event occurs. This method requires efficient node scheduling technique so that battery energy of sensor nodes can be saved. In order to detect an event of interest, it is required to turn on sensing unit periodically while allowing other units (processing and radio transceiver) to remain in sleep state. The processing unit and subsequently transceiver unit will turn on when the sensing unit finds some interesting event. Applications include forest fire detection, intruder detection etc.

(iii) **Demand-driven**: This is similar to event-driven network with the exception that data collection is triggered by a request from user. The request is broadcasted by the sink as beacon signals over the whole network.

(iv) **Any hybrid class such as event and demand-driven**: Data collection is triggered by either an event or a request from user. It is basically capable of gathering data if an event of interest occurs or a request is made from the sink.

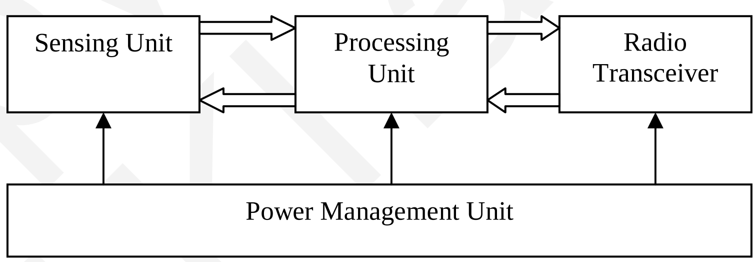

Fig. 1.1.1: Block diagram of a typical wireless sensor node

Another classification of sensor network on the basis of network architecture is shown in Fig. 1.1.2. Network architecture describes how sensor nodes send their data to the sink. Three types of network architecture have been reported in the literature. They are–

(i) **Flat ad-hoc network**: In this case, generated raw-data or collected data in a node is sent to the sink directly (single hop) or using intermediate nodes as relay nodes (multi-hop). A suitable medium access control (MAC) protocol is required for this architecture.

(ii) **Hierarchical or cluster-based network**: Here, the network is divided into several groups, popularly known as clusters. Each cluster has one cluster head (CH). The CH is responsible for collecting data inside the cluster and sending it to the final data sink. A scalable system can be designed for hierarchical network.

(iii) **Sensor network with mobile access point (SENMA)**: In this architecture, a moving access point (AP) directly collects data from the nodes while moving around the network. SENMA reduces energy consumption of nodes for reporting data to AP while incurs some unavoidable latency in gathering data. Thus there is a trade-off between latency in data collection and energy consumption.

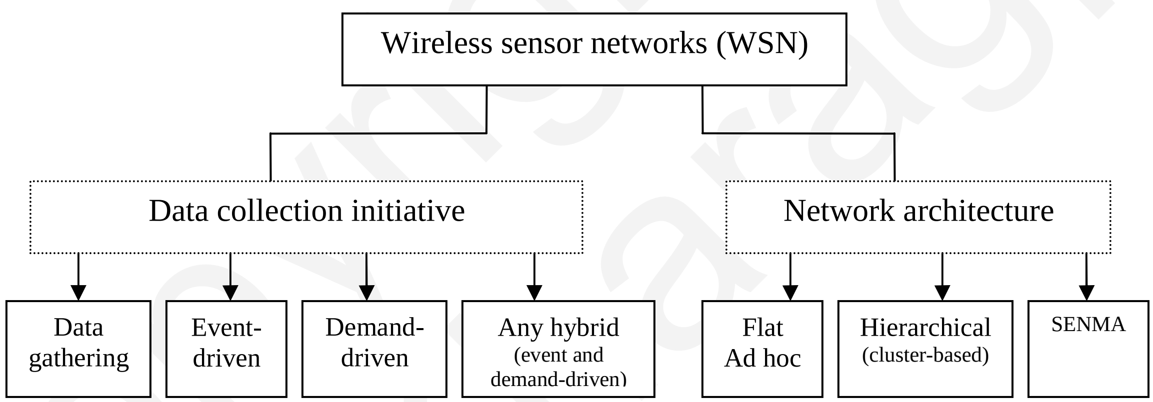

Fig. 1.1.2: Wireless sensor networks (WSN): A classification

All these categories of WSN have been widely considered for studying several issues such as assessment of network lifetime, network coverage, energy-aware routing procedures, data aggregation and traffic modeling [Aky'02], [Aky'04], [Ana'09], [Bac'10], [Cho'03], [Cul'04], [Fan'07], [Lia'10], [Men'10], [Nic'05], [Puc'05], [Rom'04], [Wan'06a], [Wan'10], [Zha'09]. WSN has the potential to monitor a wide variety of ambient conditions for e.g., temperature, humidity, pressure, seismic etc. By deploying a wireless sensor network one can extract information about an area of interest which is far away from the user. Typical military and civilian applications include remote surveillance of battle fields, intruder detection, tracking moving objects, border line surveillance, environment monitoring, habitat monitoring, highway traffic monitoring, hazardous area monitoring, forest fire detection etc. [Aky'02], [Cho'03], [Hu'10], [Puc'05].

1.2 Motivation

Wireless sensor networks differ from a traditional ad-hoc network in many ways. The number of nodes in WSN is several orders of magnitude higher than the conventional ad-hoc network [Aky'02]. The nodes in a wireless sensor network are generally energy constrained, as the battery of a node may not be recharged or replaced. The lifetime of such a network is limited by the energy dissipated by individual nodes during signal processing and communication with other nodes. The sensor nodes are also limited in computational capacities and memory. They are prone to be non-functional and as a result network topology is always dynamic. The communication paradigm is many-to-one while for ad-hoc network it is any-to-any. Thus the existing network protocol for ad-hoc network is not suitable for WSN. A sensor network must have a specialized medium access control (MAC) and routing protocols to address the issues of energy conservation. The sensor network must be energy-aware at all the layers of protocol stack to configure nodes and link for best possible services while ensuring maximum network lifetime.

An accepted definition of lifetime of a sensor network is the time span from the instant when the network is deployed to the instant when the network is considered to be impaired. A network is considered to be impaired (a) even when a single sensor node dies, or (b) a percentage of nodes die or (c) when a loss of coverage occurs due to mobility of nodes or due to failure of nodes [Che'05]. In this thesis, the first definition of network lifetime has been adopted for simplicity of analysis.

The issues of modeling a sensor network and assessment of its lifetime have received considerable attention in recent years. Network lifetime for WSN has been studied by several authors [Ban'03], [Ban'10], [Bha'01], [Don'05], [Erg'05], [Gao'06], [Hei'02], [Mar'09], [She'05], [Wan'08b], [Yan'10]. The communication range of a sensor node is not large to cover a long distance. Thus, mode of communication is multi-hop to reach base station (BS). It has been observed that nodes near the BS have more relaying traffic. As a result nodes near the BS die at the early stage of network deployment. This has been reported as energy hole [Li'05], [Mel'02], [Ola'06], [Wu'06a]. However, distant nodes from the BS have significant unused energy. Thus, non-uniform energy drainage pattern exists in the network. Haenggi [Hae'03] has shown how to balance energy consumption in multi-hop WSN. However, the energy dissipation model used in [Hae'03] is not an exhaustive one. Thus, there is a need to study WSN for maintaining equal energy dissipation condition for an exhaustive energy dissipation model. Once the equal energy consumption is established, the network will be energy-efficient. This approach will ensure maximization of network lifetime.

Mhatre and Rosenberg [Mha'04] have provided guidelines for achieving guaranteed lifetime in WSN. Guaranteed lifetime means a network will survive for a desired period of time. The whole analysis is done on the basis of circular clusters. However, it is quite difficult to cover an area of interest by circular clusters without overlapping.

Image sensor network has potential applications in surveillance [San'08], [Wu'05], [Wu'07]. However, the main drawback is huge data load in image data [Lec'07]. Thus, it is important to design an energy-efficient image transmission in sensor network. Also, it is important to maximize network lifetime for wireless image sensor network.

Another performance metric in WSN is network coverage. It indicates how well an area of interest is being monitored by a deployed network. Network coverage depends on several factors including sensing model that has been used to design the network model. The reported work has considered Boolean sensing model and shadow-fading sensing model to analyze network coverage [Bai'06], [Liu'04], [Liu'05], [Tsa'08].

However, network coverage for Elfes sensing model [Elf'91] has not been analyzed. Also, sensor nodes are prone to be non-functional due to noise, battery energy depletion, software and hardware problems etc. [Mic'09]. Thus, it is important to investigate how node failure affects network coverage. Also, temporal variation of network coverage is important. We need to propose a strategy to maintain constant network coverage for a time period as long as possible.

1.3 Problem formulation

The previous section highlights the importance of designing an energy-efficient sensor network. There is a need to design a sensor network for satisfying user requirements. We have identified that non-uniform energy dissipation should be eliminated for improving network lifetime. Motivated by the drawbacks of existing work, we formulate the following research problems:

a) Elimination of non-uniform energy drainage pattern and study of network lifetime for an exhaustive energy dissipation model of sensor nodes. Design guidelines for obtaining maximum and guaranteed lifetime.
b) Study of network coverage for exhaustive sensing models. Also study of impact of node failure on network coverage. Study of temporal variation of network coverage and strategy to obtain constant coverage.
c) Study of wavelet-based image transmission in wireless sensor network.

1.4 Contributions made in the Thesis

The overall contributions made in the thesis are summarized below.

a) Design guidelines are provided to obtain guaranteed lifetime in a hexagonal cluster-based WSN. A comparative study between circular cluster and hexagonal cluster is done for data gathering WSN.

b) Equal energy consumption condition has been established for a linear array of wireless sensor nodes such that each node dissipates equal energy per data gathering cycle. An exhaustive energy consumption model has been used to calculate energy expenditure. The issue of random node placement has been studied. The analytical results are validated through simulation. Equal energy consumption condition has been extended to a planar network by the combination of linear and Y-shaped array of sensor nodes.

c) Equal energy consumption condition is extended to a wireless image sensor network (WISN). Wavelet-based image transmission in wireless sensor network has been studied. 2-D discrete wavelet transform (2D-DWT) is applied to the raw image. Network lifetime has been derived while considering energy dissipation model for radio communication and image processing. Peak signal-to-noise ratio (PSNR) of the reconstructed image at the sink node is calculated.

d) Network coverage for Elfes sensing model is analyzed. Also, network coverage for major sensing models is derived in the event of node failure. A comparative study between regular and random placement of nodes is presented. Temporal variation of network coverage is investigated. A strategy to maintain constant coverage is proposed.

1.5 Outline of the Thesis

In this section we present the organization of the Thesis.

In **Chapter 2**, the literature review on wireless sensor network is presented. This chapter describes the reported work on coverage, clustering, lifetime, node scheduling, data aggregation, MAC and routing protocols. The general description and possible scopes of wireless passive sensor network (WPSN) and wireless image sensor network (WISN) are also presented in this chapter.

In **Chapter 3**, we present an analysis on guaranteed network lifetime for cluster-based wireless sensor network. A data gathering wireless sensor network is considered. This study assumes hexagonal clusters to cover an area of interest. An energy consumption model of sensor node is assumed to calculate network energy per data gathering cycle. Optimal number of cluster heads is derived for a given number of sensor nodes to provide a guaranteed lifetime. Battery energies for ordinary sensor nodes and cluster head (CH) nodes are derived for a given set of parameters. Single hop, multi-hop and hybrid mode of communications are analyzed for guaranteed lifetime. Our result is compared with circular cluster.

In **Chapter 4**, we address the issue of lifetime enhancement by ensuring equal energy consumption by all the nodes over a data gathering cycle. This approach helps to eliminate non-uniform energy consumption pattern in the network. We give an explicit analysis of node placement strategy ensuring equal energy dissipation by all the nodes in a data gathering cycle. An expression for network lifetime is also developed. A comparative study with reported work is also presented. We also address the issue of random placement of nodes to obtain statistics of energy consumption of nodes. The analytical results are validated through simulation studies using MATLAB. We also extend the idea of equal energy dissipation condition for a planar network.

In **Chapter 5**, we consider a linear array of wireless camera sensor nodes over a given distance. An exact placement of camera nodes has been obtained in order to ensure equal energy dissipation by each camera node in a data gathering cycle. The raw image captured by each camera is processed by 2D-DWT to identify important components. The important components are forwarded to the sink using the intermediate nodes for analyzing the activity over the area of interest. Energy consumption model for image processing and radio communication is considered to calculate network lifetime. PSNR of the reconstructed image is also calculated at the sink node for several test images.

In **Chapter 6**, we show the impact of node failure on network coverage. The network coverage for Elfes sensing model has been derived. Also, network coverage has been derived for three sensing models viz. Boolean, shadow-fading and Elfes sensing model in the event of node failure. We present a comparative study of network coverage among the different sensing models to show the impact of sensing models on network coverage. Temporal variation of network coverage is analyzed for both single hop and multi-hop mode of communications. A strategy for maintaining constant coverage is also presented.

The major outcomes and observations of the thesis are summarized in **Chapter 7** with indicative directions of future research.