CHAPTER 1

INTRODUCTION

This chapter is to provide an introduction about wireless sensor networks and its prevailing design challenges. The need for power aware routing in wireless sensor networks and a brief review of literature concerning to the present work is also provided in this chapter.

1.1 WIRELESS SENSOR NETWORKS

Wireless sensor networks are formed by small independent devices communicating over wireless links without using a fixed network infrastructure. Due to the limited transmission range, communication between any two devices require collaborating intermediate forwarding network nodes, i.e. hop-nodes or forwarder nodes. This communication may be trivially based on simply flooding the entire network. However, more elegant routing algorithms are essential for the applicability of such wireless networks, since energy has to be conserved in low powered devices and wireless communication always lead to increased energy consumption.

The network enables its users to instrument, detect and react to events in any environment. The major work of wireless sensor network is to consistently detect and estimate event features from the collective information provided by sensor nodes. Power saving is a key concern in sensor networks. Some environment might be in hospitalized terrain, forest and building fire, volcanic mountain and underwater. Nobody would like to recharge or change batteries of sensor nodes in the network. Thus, the most challenging design issue in sensor networks is the limited and non-renewable energy provision. It is needed to develop power-efficient routing protocols to minimize both the power requirements across all levels of the protocol stack and the amount of control messages passing through the network control and its coordination. In order to perform
the WSNs applications in a successful manner, it is necessary to design the power-aware routing schemes that play a prominent role in WSNs for maximizing the network lifetime.

The limited battery power, heterogeneity in the network, flooding of collected messages, and the large number of nodes in a euclidean plane may elevate several design challenges for the routing protocols in sensor networks. Meanwhile, owing to dynamic sparse environments and the inherent limitation of various hardware and software resources, no single topology will always be best for all WSN applications. Recently many new algorithms have been proposed for the routing problems in wireless sensor networks. To optimize power consumption, data aggregation and in-network processing, grouping or clustering, genetic algorithms and ant colony and fuzzy logic based optimization algorithms are hired in routing techniques proposed in the literature.

In order to maximize the network lifetime, it is necessary to derive a power-efficient and power aware routing solution. To perform the various WSNs applications work successfully, it is necessary to design the power-aware routing schemes that play prominent role in WSNs in maximizing the network lifetime.

1.2 DESIGN CHALLENGES OF WIRELESS SENSOR NETWORKS

The following design factors need to be considered in designing a reliable routing protocol in wireless sensor networks.

**Basic hardware design oriented:** The challenge of designing a robust protocol begins with the design of sensor hardware. Sensor hardware platforms include the use of Micro Electro-Mechanical Systems (MEMS), sensor technology, digital circuit design, system integration for low power consumption and a low-power sophisticated radio frequency front-end and associated control circuitry (Asada et al 1998; Sohrabi et al 2000). The basic design of a sensor node requires a combination of micro-sensor
technology, low power signal processing, low power computation and low cost wireless networking capability.

**Wireless network oriented:** The challenge of designing routing protocols is to provide a robust and energy-efficient communication mechanism for meeting the application requirements in a wireless sensor network. Wireless networking includes the design of physical layer methods such as modulation, source and channel coding, channel access methods, routing issues and mobility management issues.

**Application oriented:** Wireless sensor network applications require an efficient extraction, manipulation, transport and representation of information. The end-information is derived from the collected sensor data. Different systems have a variety of functional components such as detection and data collection components, signal processing components, data fusion and notification components. So a robust routing protocol needs to be aware of the specific application and the environment where the sensors are deployed to collect the data.

### 1.3 NEED FOR POWER-AWARE ROUTING IN WIRELESS SENSOR NETWORKS

WSNs are an emerging technology of real time embedded systems for a variety of applications. Energy efficiency is one of the most important performance measures in WSNs. A promising strategy for reducing energy consumption in such networks is to introduce diversity through cooperative communications technique. The lifetime of a sensor node typically exhibits a strong dependency in battery life. Sensor nodes have a limited power source, and replenishment of power is both limited or impossible. The power management and power conservation are critical functions for sensor networks, and designing power-aware protocols and algorithms is thus needed. The function of a sensor node in a sensor field is to detect events, perform local data
processing, and transmit raw processed data. Power consumption can therefore be
allocated to three functional domains: sensing, communication, and data processing, each
of which requires optimization. In the context of communications, a node plays the dual
role of data collection and processing and acts as a data relay point. Therefore it needs
rerouting or retransmission and requires additional power. It is necessary to design a
novel power aware routing scheme in wireless sensor network. Due to energy constraints,
a sensor node can communicate directly with other sensors within a limited distance. In
order to enable communication between sensors within the communication range, they
form a multi-hop communication network. It is thus difficult to use the traditional power
aware routing schemes for WSN applications and it is necessary to propose a simple,
robust and scalable power aware routing mechanism to provide strong security over the
communications performed in WSNs.

Power-aware routing is a key element for sensor networks. In this section,
four main challenges are described in designing routing protocols for WSN: scalability,
heterogeneity, robustness and energy efficiency. Heterogeneity problem of WSNs is
discussed by Xiao Chen et al (2013). Sensor networks can be classified into
homogeneous sensor networks and heterogeneous sensor networks (Ilyas and Mahgoub
2005). In a homogeneous network, the sensor nodes have identical capacities and
functionality with respect to the various aspects of sensing, communication, and resource
constraints. A heterogeneous WSN is one where the constituent motes are not all of the
same hardware design, and may not execute the same code, or perform the same
functions. In particular, various sensors may not have the same battery capacity. Since
the dominant process of consuming energy in a mote is communication (Polastre et al
2005), the upper bound in the lifetime of sensor networks is constrained by the
communication costs and battery capacity.
Therefore, maximising the lifetime of a heterogeneous WSN requires the network routing protocol to take into account of the heterogeneity of motes. On the other hand, WSN routing protocols are designed to ensure that devices coordinate with each other to exploit redundancy. Redundancy of data can occur when multiple sensors generate the same data within the vicinity of a phenomenon (Al-Karaki & Kamal 2004).

1.3.1 Robustness

Robustness of the network resources require tolerance of sensor nodes that may fail, lose battery power or be temporarily unable to communicate due to environmental factors.

1.3.2 Scalability

A sensor network may have thousands or hundreds of thousands of nodes which spread over a wide geographical area (Akkaya & Younis 2005), unlike a typical ad-hoc network which has no more than a few hundred nodes. Therefore, routing must be designed to scale and support several thousands of sensor nodes in the sensor field. Hierarchy (Pan et al 2005; Pan et al 2003; Ye et al 2002), clustering (Gupta & Younis 2005; Younis & Fahmy 2004; Heinzelman et al 2002) and location-awareness (Xu et al 2001) techniques have been proposed to cope with scalability in large sensor networks.

1.3.3 Resources constrained at each sensor node

Sensor nodes are designed with mostly simple devices of low cost according to the economy of scale. In contrast, a typical computer serves a wired internet or an ad-hoc network with unconstrained energy availability, high Central Process Unit capacity and several Giga Bytes of memory capacity. Economic factors state that sensor networks must cover a wide spatial area with the lowest cost sensing devices. As a result, sensors tend to have limited battery energy, low performance processor and constrained memory. Therefore, energy consumption is a key concern in WSNs.
1.3.4 Energy-efficiency

Energy is a precious resource in wireless sensor networks. When sensors are battery-powered, sensor networks are expected to have lifetimes for several years. It is thus a crucial requirement to conserve and save the battery power in wireless devices. There are two factors which hinder the possibility to recharge the power supplies of WSN nodes.

A large number of nodes: It is difficult to recharge nodes where thousands of nodes are deployed in a WSN.

Complexity of the application environment: It may be dangerous and time-consuming to replace failed sensors due to battery energy depletion.

Hence it is necessary to study about the various energy-efficient routing algorithms. An important issue to be focused is the energy aware routing in WSNs. Therefore, the main goal is the design of routing methods for maximizing energy efficiency.

1.4 ROUTING CHALLENGES IN WIRELESS SENSOR NETWORKS

The applications of WSNs are usually based on highly dynamic environment requiring the network to change over time to face permanent or transient node faults, failures, and environmental changes such as landslides due to growing vegetation. Moreover, we can experience power run out with a subsequent disconnection from the network. Energy harvesting mechanisms proposed by (Ottman et al 2006; Paradiso et al 2005; Rahimi et al 2003; Alippi et al 2008) induce change in the network topology with an unpredictable dynamism.

In current deployments, since a fully reliable communication (Ferrari 2006; Kim 2008) protocol is not addressed due to the power consumption overhead, the acquired data are sent with a best effort modality. Development of smart routing
algorithms must assure effective communication in large-scale WSNs, with an ability of adaptation is the key issue along with the power-aware feature.

WSNs have several restrictions such as limited energy supply, computing power, and bandwidth in wireless links that connect sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. Many factors influence the design of routing protocols in WSNs. For example, network deployment, network dynamic, data delivery model and data aggregation are major WSNs system design issues and the factors that influence. The routing designs are based on energy consumption, scalability and Quality of Service (QoS). Depending on the application and the size of the network, different architectures and design goal-constraints have been considered for sensor networks. It is clear that the performance of a routing protocol is closely related to the architectural model.

The most important factors that influence the selection of a routing protocol are:

- **Energy Balanced Network**: The main target of the energy efficient routing protocol should be based on load balancing that the sensors consume. This means that the routing protocols need to minimize the energy consumption of the network by selecting not only the shortest routes but also the routes that will lead to the extension of network lifetime.

- **Network Dynamics**: The main components of a sensor network are the sensor nodes, sink and monitored events. In most of the network architectures, sensor nodes are assumed to be stationary. On the other hand, supporting the mobility of sinks or cluster-heads is sometimes necessary. Routing messages sent or received from nodes are more challenging since route stability is an important optimization factor along with
energy, bandwidth etc. The sensed event can be either dynamic or static and depends on the application. Thus in a target detection application, the event is dynamic, but for example, forest monitoring for early fire prevention is a static event.

- **Node Deployment:** Node deployment may be either deterministic or self-organizing and affects the performance of the routing protocol. In deterministic situations, the sensors are placed manually and all the data are routed through pre-defined paths. In self-organizing systems, the sensor nodes are scattered randomly and creates an infrastructure in an ad hoc manner.

- **Energy Considerations:** The set-up of a route is greatly influenced by energy consideration. Since the transmission power of a wireless radio depends on distance which is squared or of a higher order in the presence of obstacles. Though multi-hop routing consumes less energy than direct communication, it may add significant overhead for topology management and medium access control. In contrast, direct routing performs well enough if all the nodes are very close to the sink.

- **Data Delivery Models:** The data delivery model to the sink, depends on the application of the sensor network which can be continuous, event-driven, query-driven and hybrid. In the continuous delivery model, each sensor sends data periodically whereas in event-driven and query-driven models, the transmission of data is triggered when an event occurs or a query is generated by the sink. Moreover, there are some networks that apply a hybrid model using a combination of continuous, event-driven and query driven data delivery. The routing protocol is based on the data delivery model, especially with regard to the minimization of energy consumption and route stability.

- **Node Capabilities:** In a sensor network, different functionalities can be associated with the sensor nodes. In many networks, a node can be dedicated to a specific function such as relaying, sensing and aggregation. This is because when all the three
functionalities are combined to work on a node at the same time, it may drain the energy of that node rapidly.

- **Data Aggregation/Fusion**: The sensor nodes might generate similar packets from multiple nodes that can be aggregated so that the number of transmissions would be reduced. Data aggregation is the combination of data from different sources. This can be fulfilled by using functions such as suppression, min, max and average. However, there is still a lot of work that has to be done, not only in the area of energy efficiency but also, in other areas. Some factors that should be examined when developing a routing protocol may be the following:

- **Nodes Mobility**: The nodes in the WSNs were assumed to be static. In the previous years, there was an increased interest in applications that support the mobility of the users. An example of this is the medical care applications where the mobile sensors are attached to the patients and need to send continuous data from the patient to the doctor. There is a lot of scope for future research in this area.

- **Performance Evaluation on Real Environment**: Most of the WSN protocols have been evaluated through simulations. However, it is important to evaluate the performance of these protocols in a real environment with a lot of users.

- **Real-Time Application and QoS**: There is an ongoing need to develop real-time application that will offer high level QoS to the end users. Thus, it is important for the scientists to make a lot of efforts to develop routing protocols that will offer QoS to real-time applications.

- **Integration of Fixed with Mobile Networks**: Most of the applications like health care monitoring require the data collected from the sensor nodes to be transmitted to a server, so that the doctor may access the data and make diagnosis or send medication
to the patients. In this case the routing requirements of each environment are different and so, further research is necessary for handling this sort of situations.

- **QoS routing protocols:** The QoS is important in the delivery of data in critical applications such as healthcare. Thus, the development of routing protocols consider both energy efficiency and accurate delivery of data.

### 1.5 OBJECTIVES OF THE THESIS

The objective of the thesis is to design and evaluate the following new mechanisms for supporting power aware routing schemes in WSNs in terms of Geographic relay region based routing, Power aware data diffusion scheme using discrete RTS/CTS function, Individual node delay based efficient power aware routing and Request-Response based power aware routing.

1. To design a geographic relay region based power aware routing scheme in wireless sensor networks.
2. To design a power aware data diffusion scheme using discrete RTS/CTS function for wireless sensor networks
3. To design an individual node delay based efficient power aware routing protocol for wireless heterogeneous sensor networks
4. To develop a Request – Response based power aware routing protocol for wireless heterogeneous sensor networks.

The brief introduction about each of the above is as follows.

**Geographic relay region based power aware routing scheme in Wireless Sensor Networks:** The proposed Geographic Relay Region based Power Aware Routing (GRRR) provide an energy efficient, loop-free, stateless, sensor-to-sink power aware routing without the help of prior neighborhood information. In this routing scheme, each node first announces its next-hop optimum relay position on the straight
line toward the sink and each node computes its quality value based on the residual power and distance between the optimum relay regions. Forwarder node is elected by the source based on quality value which is communicated using the Request-To-Send/Clear-To-Send (RTS/CTS) handshaking mechanism. The proposed GRRR establishes the conditions for guaranteed delivery in sensor-to-sink routing, assuming no packet loss and no failures in greedy forwarding. Our routing protocol works in two modes such as greedy mode and angular relay mode. In greedy mode, RTS/CTS handshaking mechanism is used to identify the forwarder for further forwarding the packet. In this way, each packet is expected to deliver to a node adjacent to the relay region and has maximum battery power. If there is no node in the relay region, then this protocol moves into an angular relay mode in order to recover from local minimum.

The performance of GRRR is evaluated through simulation by comparing with the existing clustering protocols Beacon-Less Routing Algorithm (BLR) and Geographic Power Efficient Routing in sensor networks (GPER) algorithm. GRRR takes the advantage of both geographic routing and power aware routing to provide energy efficient, loop-free, stateless sensor-to-sink routing in dynamic scenarios. Simulation results show that GRRR outperforms well in most scenarios and consumes less power than the related schemes based on neighborhood information in highly dynamic circumstances.

**Power Aware Data Diffusion Scheme using Discrete RTS/CTS scheme:**

The proposed mechanism named Power Aware Data Diffusion Scheme (PADDS) is based on a discrete geographic function. The proposed scheme consists of two modes such as power aware forwarding mode and power aware recovery mode. In power aware forwarding mode, priority is given only to a node which is located inside the optimal hop circle. If there is no node available in the optimal hop circle or ready to respond within a
time boundary, then our protocol moves to the power aware recovery mode to recover the local minimum. The source node first broadcasts its Request-To-Send message along with its optimal hop circle in a straight line toward the sink. Meanwhile the receiver node broadcasts its Clear-To-Send message based on its energy value to the sink. The proposed PADDS establishes the conditions for guaranteed delivery for sensor-to-sink routing.

The performance of PADDS is evaluated through simulation by comparing with virtual energy-based encryption and keying scheme, dynamic en-route filtering scheme. It has been observed that PADDS achieves maximum packet delivery ratio within a minimum number of hops. It provides an energy efficient, stateless, sensor-to-sink routing without the help of neighborhood information. Thus it widens itself to lossy sensor networks to provide a stable and efficient routing in the presence of unreliable communication links.

**Individual Node Delay Based Efficient Power Aware Routing Protocol:**
IDEPARP uses both symmetric and asymmetric links to forward data from the source to the sink. The source node broadcasts its location information to all the neighbor nodes and each neighbor node calculates a delay slot based on the information obtained from the source to forward its power value to it. The node that has a minimum delay slot forwards the power earlier than the other nodes during contention phase and the delay slot is used to suppress the selection of unsuitable low-power nodes at that time. The proposed IDEPARP addresses the problem of providing energy-efficient power aware routing scheme for WHSNs in which each node has an asymmetric link. Without prior knowledge of neighbors, this method creates an efficient data path by delivering each packet to the sink.

It has two phases such as source broadcast phase and analyzing reply messages phase. In source broadcast phase, the source node broadcasts the source ID and
its location information. The node which receives a broadcast message calculates the delay slot. In reply message phase, each source node uses a location message to detect its best-hop node. This location message leads a way to calculate the delay slot value in receiver node level. Then, the receiver node produces its reply message based on the calculated delay slot. A reply message contains the receiver ID and its power. If another neighbor node receives a reply message of a receiver node, it either forwards the message again by appending its node ID or truncates the message by re-producing a new reply message. New reply message contains the new receiver ID and its power. In this way, the reply message generated by one or more nodes reaches the source if an asymmetric link exists between them.

The performance of IDEPARP is evaluated through simulation by comparing with related energy efficient routing schemes. By extensive simulations, the proposed IDEPARP shows that it significantly outperforms than existing schemes in WHSNs. It has been observed that IDEPARP achieves maximum delivery ratio. Further, it ensures power aware routing to prolong the network lifetime.

**Request-Response based Power Aware Routing Protocol:** This proposed protocol Request-Response based Power Aware Routing Protocol for Wireless Heterogeneous Sensor Networks (RRPARP) is designed for a heterogeneous sensor network. RRPARP provides a loop free and stateless routing without using prior neighborhood information. It utilizes both symmetric and asymmetric links to forward a data from source to sink. This method explores the neighbor node relations and chooses the best-hop based on the node power. It eliminates the low-powered nodes to become hop-nodes in the contention process. The proposed RRPARP consists of two phases such as the handshake phase and selection phase. The handshake phase identifies the power
of a hop-node and a reverse path for the nodes which has an asymmetric link. The selection phase identifies the best-hop node based on node residual power.

The performance of RRPARP is evaluated through simulation by compared with existing schemes including probabilistic routing protocol with assured delivery rate in wireless heterogeneous sensor networks (ProHet) and SELRP. The proposed RRPARP uses both symmetric and asymmetric links for achieving better performance with respect to energy efficiency and packet delivery ratio compare to other two related schemes. It has been observed that the proposed RRPARP enhances the energy efficiency to increase the network lifetime.

1.6 ORGANIZATION OF THE THESIS

The thesis is organized in seven chapters

Chapter 1 gives a brief introduction about the energy efficiency issues related to maximizing network life time in WSNs. The need for power aware routing requirement in WSN has been discussed and the existing routing mechanisms and problems that occur when applying traditional routing mechanisms for WSN have been explained. The main objective of the thesis is elucidated well. The focused objectives are designed and evaluated as an enhancing energy efficiency and prolongs the network lifetime in Wireless Sensor Networks using novel power aware routing schemes.

Chapter 2 presents a literature review to provide the necessary background for understanding the general challenges faced while maximizing the network life time in WSNs. This chapter presents an overview of the latest literatures related to power aware routing. Various energy efficient routing schemes and literatures related to increase the network life time of WSN have been reviewed. Power aware routing mechanisms for WSNs were studied and analyzed. The challenges of energy efficient
routing in WSNs were surveyed and the problems related to maximizing network life time were made clear.

**Chapter 3** is about the design of a Geographic Relay Region based Power Aware Routing scheme to minimize energy consumption and prolong the network lifetime. It explains about how to improve network life time by using Geographic Relay Region based Power Aware Routing scheme. This scheme is energy efficient in terms of efficient routing which is performed for improving the network life time of WSNs. The outcomes acquired from this work are: Packet delivery ratio is very high and energy consumption is very low.

**Chapter 4** is about the design of a Power Aware Data Diffusion Scheme using Discrete RTS/CTS function for WSNs for increasing network life time. This chapter explains about Power Aware Data Diffusion Scheme to provide an energy efficient, stateless, sensor-to-sink routing without the help of neighborhood information. The outcomes obtained from this work are: Congestion and flooding are controlled by delay based RTS/CTS scheme, packet delivery ratio is very high and energy consumption is very low.

**Chapter 5** explains about the design of an Individual Node Delay Based Efficient Power Aware Routing Protocol for Wireless Heterogeneous Sensor Networks to minimize power consumption and prolong the network lifetime. I reply messages phase. The outcomes obtained from this work are: minimize the power consumption, obtain good packet delivery ratio and prolong the network lifetime.

**Chapter 6** is about the development of Request-Response based Power Aware Routing Protocol for Wireless Heterogeneous Sensor Networks. This chapter explains how efficiently the symmetric and asymmetric links are used to forward data from the source to the sink. It also explains the neighbor node relations and chooses a
best-hop based on node power. It eliminates the low-powered nodes to become hop-nodes in the contention to enhance energy efficiency. The following outcomes have been derived in this work: less power consumption, reduce congestion and minimize the packet drop ratio with maximum network lifetime.

Chapter 7 summarizes the outcomes of this research work and outlines the possible direction for future research. The first work concludes that minimizing the energy consumption and prolonging the network lifetime is achieved through Geographic Relay Region based Power Aware Routing. In the second study, Power Aware Data Diffusion Scheme achieves less power consumption and packet drop ratio. The Third study, Request-Response based Power Aware Routing Protocol for Wireless Heterogeneous Sensor Networks utilizes both symmetric and asymmetric links to forward data to minimize the power consumption. The fourth study, Individual Node Delay Based Efficient Power Aware Routing Protocol for Wireless Heterogeneous Sensor Networks shows an improvement in network life time of WHSNs by less power consumption.