CHAPTER 1

INTRODUCTION

Wireless Sensor Networks (WSNs) are becoming more popular as Wireless Communication (WC) advances. These networks consist of tiny sensor nodes capable of observing the surroundings, calculating, and communicating wirelessly with the base station and other nearby nodes at low cost. The sensors, randomly distributed over a large surface area, collect data via a sensing unit, process it, and send it to sinks. Nodes in sensor networks consist of three subsystems, sensing, processing, and communication, which perform the assigned tasks.

Major goals of WSN include:

- Monitor the specified area
- Measure the necessary parameters
- Document the events that occur

The features of WSN include low cost, limited energy resources, narrow radio range, self-organization, and concurrent processing. Since energy exhausts during transmission, the network cannot operate even if a single sensor node dies. Energy usage and network longevity are inversely correlated, and striking a balance between them is challenging for WSNs. This problem can be solved by using the proper clustering and routing strategies. Sensor nodes are grouped into clusters with CHs to minimize long-distance communication to the base station, optimize resource usage, and enable higher service quality. To achieve effective communication over short distances, routing is required between the base station and sensor nodes. To overcome these obstacles, research is still in progress.

In this research, a balance between network lifetime and energy consumption is achieved by choosing a proper optimization technique. Chapter 1 describes in detail the block diagram, applications of WSN, as well as clustering and routing techniques, problem definitions, and an overview of the thesis.

1.1 BLOCK DIAGRAM OF WSN

Figure 1.1 illustrates the block diagram of WSN. It consists of four elements namely:

- Sensing unit
- Processing unit
- Communication unit
- Power generation unit

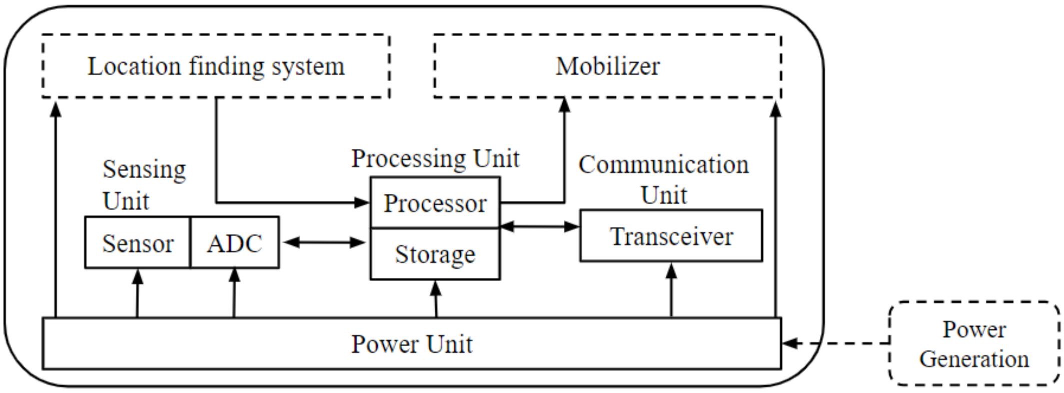

Figure 1.1 Block Diagram of WSN

1.1.1 Sensing Unit

The Sensing Unit (SU) comprises sensors, including cameras, pressure sensors, temperature sensors, and an Analog to Digital Converter (ADC). These sensor nodes collect data about the operational environment. The ADC converts the analog signals from these sensors into a digital format so they can be transmitted to other nodes and base stations for further analysis.

1.1.2 Processing Unit

Signals are fed to the processing unit after being converted to digital. The processing unit consists of a processor and memory to control the sensor unit. Intermittent sensor readings, packets from other nodes, and other data must be stored in Random Access Memory (RAM). RAM is quick, but it loses its contents when the power supply is lost. It is possible to store programs only in Read Only Memory

(ROM), Electrically Erasable Programmable Read Only Memory (EEPROM), or Flash Memory.

When RAM is insufficient or requires its power source to be temporarily shut off, the flash memory serves as a temporary storage for data. However, flash memory requires higher energy for its operation.

1.1.3 Communication Unit

The communication unit exchanges the data between two nodes. The primary function is to convert bit streams to radio waves. The transceivers are used to perform both transmission and reception. The transceiver has four operational states, namely,

Transmit: The transceiver's active transmitter emits energy into the environment.

Receive: The receiver portion is operational.

Idle: In this condition, the transceiver is prepared to receive data but is not getting any.

Sleep: In this state, some significant part of the transistor is switched off.

1.1.4 Power Generation Unit

The power unit is essential for WSN, providing the necessary power to all other units.

1.2 CLASSIFICATION OF WSN

Irrespective of applications, WSN is classified as follows:

- **Static and Mobile WSN:** The sensor nodes are fixed in most applications without any movement and are known as static networks. Whereas applications like biological systems require mobile sensor nodes, and these networks are termed mobile networks**.**
- **Deterministic and Nondeterministic WSN:** If the position of the sensor node is calculated and fixed, then it is termed a deterministic network. Factors like harsh environments and hostile operating conditions make it difficult to

calculate the distance and fix the sensors; such networks are called non-deterministic networks.

- **Single base station and Multi base station WSN:** If a WSN consists of only one base station closer to the sensor node region to collect the data, it is termed a single base station WSN. Whereas a multi-base station WSN comprises more than one base station, and the sensor node transfers data to the nearest base station.
- **Static base station and Mobile base station WSN:** Similar to sensor nodes, the base station can also be either static or mobile. The static base station has a fixed position close to the sensing region whereas the mobile base station moves around the sensing region and collects data from the nodes.
- **Single hop and Multi hop WSN:** The sensor nodes in a single-hop WSN connect directly to the base station. Cluster heads are used in multi-hop WSN for data relaying for energy consumption.
- **Self-re-configurable and Non-self-configurable WSN:** In self-re-configurable WSN, sensor nodes are capable of organizing, maintaining the connection, and working with the other nodes to accomplish the task. In a non-self-configurable network, nodes cannot organize themselves and depend on a control unit for gathering information.
- **Homogenous and Heterogeneous WSN:** In homogenous WSN, all sensor nodes have similar energy consumption, computational power, and storage capabilities. In heterogeneous WSNs, some sensor nodes have higher computational power and energy requirements than others.

1.3 CHALLENGES OF WSN

The design challenges of WSN are listed as follows:

- **Limited energy and power:** Sensors in WSNs are mostly battery-powered with limited energy storage, which makes it challenging to keep the network operational for longer periods without frequently replacing the batteries.
- **Limited bandwidth:** The limitation of bandwidth directly affects the exchange of messages among sensor nodes, and this avoids synchronization**.**
- **Fault tolerance:** The sensor nodes will become unreliable when deployed in a faulty or harsh environment.
- **Scalability:** A scalable system is one whose performance increases in direct proportion to the amount of additional hardware.
- **Interference:** WSNs are primarily deployed in areas where interference from other wireless devices is present. As a result, it could be challenging to ensure reliable communication between the sensor nodes.
- **Security:** Since WSN is prone to attacks, the security of the network and data is a major challenge.
- **Quality of Service:** In real-time applications, the data must be transmitted within the allocated time to avoid loss.

1.4 RESEARCH ISSUES IN WSN

A major challenge in WSN is the energy consumption and battery life of the sensor nodes. In addition, there are some more serious issues, such as security issues caused by a lack of privacy requirements.

- **Node deployment:** In WSN, deploying sensor nodes is also one of the critical challenge. The deployment of the nodes will be handled properly. Remote areas and some vital areas require more sensors to collect the data, which is sometimes not useful.
- **Selection of relay node:** A sensor transmits the data that it acquired to the destination. Relay nodes can be used to determine the quickest path for data transfer to the destination. Several strategies must be used to choose the relay node. The relay node selection process is laborious and time-consuming.

- **Selection of Cluster Head (CH):**Choosing a CH is difficult due to the presence of grouped node deployment in some networks. Cluster nodes, cluster node size, and CH need to be chosen to transmit the data to the base station.
- **Energy consumption:** Wireless Sensor Networks are battery-operated, so efficient usage of battery power is crucial since it will disrupt communication. Therefore, battery power must be conserved for a long time.
- **Security Issues:**Secured data transmission is essential in battlefield and medical applications;therefore, an efficient protocol needs to be developed.
- **Path loss:** Path loss is a critical concern. This issue arises when choosing many paths to send the data most effectively. A single path only will experience path loss in antenna.
- **Delay:** Time is a critical aspect of data transmission and communication. Message delivery could have failed because of the delay.

1.5 CLUSTERING

The method of clustering involves selecting a CH for each cluster and organizing nodes for each cluster. Data is gathered by CHs from every node and sent to the base station. One of the key techniques for extending the lifetime of a network and lowering energy usage is clustering.

1.5.1 Purpose of Clustering

Cluster formation has some advantages, such as non-overlapping with multi-cluster creation and resource reuse to increase system capabilities. CHs improve routing process performance and serve as the essential framework for inter-cluster routing. Managing node mobility to improve energy efficiency, which tends to increase network utility, is the focus of clustering.

1.6 ROUTING

The process of choosing an appropriate path for data transfer via a router from a source to a destination is known as routing. Choosing the correct route can be challenging because it relies on the type of network, the features of the channel, and performance measures. In a WSN, sensor node data is transmitted to a base station that links two or more networks, where it is gathered and examined, and appropriate action is taken.

1.7 MAJOR SOURCES OF ENERGY USAGE IN WSN

Managing energy, a limited resource, is essential to extend the life of sensor nodes. Energy use is advantageous for data transmission and reception, information processing, and information sharing with neighbours. Collisions, idle listening, and the possibility of many nodes gathering the same data are the reasons behind unnecessary energy consumption. When collision-causing packets need to be removed and retransmitted, the amount of energy used increases. Sending communications before the destination is ready is the primary cause of energy waste.

1.7.1 Energy Management Techniques

Communication is the main source of energy consumption. A node needs to broadcast data to listen, which consumes a lot of energy. Techniques for energy management include turning off different nodes when not in use, increasing computing, and reducing communication. The trade-off between latency and energy efficiency is a major concern.

1.7.2 Data Reduction Techniques

The transmission cost is higher compared to sensing and processing; hence, the number of times the data is transmitted between the nodes must be reduced. The amount of redundancy is reduced by using data aggregation methods. Power consumption is less for the data aggregation method than for data transmission and receiving. Before the data is sent to the base station, the LEACH protocol, which is cluster-based, minimizes the volume of data that is gathered by the sensors. Eventually, the sensor nodes share the energy load.

1.7.3 Algorithms for Choosing a Cluster

There are certain methods designed to save energy by allowing a node to join a cluster that is appropriate for it. The CH gathers the data and transfers it throughout the network. A node can transition autonomously from an active state to a sleep state. Throughout the network, nodes oversee the sensing of specific areas and act as relay nodes to send data to the sinks over a few hops. A node that detects an event remains active and communicates with other nodes that are within a hop's reach. The node transmits until the neighbours have received the data. Once the neighbours receive the message, the node will go to active and sleep mode based on the schedule. The process continues until the data reaches the sink. One significant issue is the latency caused by messages attempting to reach a dormant node. The random distribution of nodes, sensing range, and sleep duration of nodes influences latency. Greater latency occurs when the node is distant from the sink.

1.7.4 Event Based Communication

In event-based communication, nodes subscribe only to the events they are interested in. Every node will be scheduled for data transmission and reception, and the power is turned off when nodes are not in use. An event scheduler is available to allocate a time slot for each event.

1.7.5 Reducing the Power Consumption

Energy consumption is less when the sensor covers less area. Reduction in the sensor's coverage area and the application will determine the frequency of sensing activity, which will reduce the network's energy consumption. The number of sensors required for an application is to be increased for area coverage, which would increase the life of a particular node of WSN.

1.7.6. Reducing the Lossy Link

Several routing algorithms attempt to direct packets to the sink near the source. It is efficient since it requires fewer hops to deliver the packet. An issue develops when those nodes experience a significant quantity of data loss. Also, energy loss occurs due to unreliable links. Numerous studies illustrate data forwarding in which packets reach their destination without loss. If the distance between two nodes is high, the unreliable weak link causes data loss that results in retransmission. Conversely, when the distance between two nodes is short, it leads to increased energy consumption due to the need for more transmission packets to reach the destination.

In some studies, the following strategies are utilized to optimize energy use:

- Distance between the CH and mobile sinks is reduced.
- The number of active nodes is maximized
- The number of dead nodes is minimized.
- Energy input is retained.
- Distance between the two nodes is minimized.

1.8 OPTIMIZATION

Optimization involves maximizing or minimizing the objective function to find solutions for complex problems that are not solvable using deterministic approaches within a given timeframe. Optimization is also known as meta-heuristic optimization since it addresses optimization problems with meta-heuristic techniques. Some algorithms are suitable for local search, while others are suitable for global search. Complex problems such as clustering, routing, security, localization of nodes, and node maintenance can be achieved using optimization techniques.

Optimization challenges in WSNs can be categorized as single-goal or multi-objective optimization problems. Single-objective optimization focuses on minimizing or maximizing one objective while considering numerous constraints, whereas multi-objective optimization involves simultaneously optimizing many objectives. Several real-world challenges entail numerous objectives that need to be optimized simultaneously.

There are two forms of meta-heuristics: single solution-based and population-based. Single solution-oriented meta-heuristic focus on local search methods such as simulated annealing and tabu search. In contrast, population-based meta-heuristics involve local searches and are categorized into evolutionary algorithms and swarm intelligence. Evolutionary algorithms consist of Genetic Algorithm (GA) and Differential Evolution (DE). Swarm intelligence encompasses algorithms such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and Bacterial Foraging Optimization (BFO).

A few of the nature inspired optimization techniques used in WSN are explained as follows:

1.8.1 Particle Swarm Optimization (PSO)

PSO promotes the social behaviour of birds. Each bird within the solution space is referred to as a particle. The fitness objective function determines birds' fitness. The fitness function is based on the bird's velocity and its distance from the prey. During multiple iterations, the fitness value of a group of birds is modified to the one closest to the aim. The bird with the highest level of fitness is referred to as the g-best, whereas the best fitness of each bird is known as the p-best. PSO provides superior Quality of Service (QoS) for addressing routing issues in WSN.

1.8.2 Bacterial Foraging Optimization (BFO)

BFO is based on the foraging behaviour of Escherichia Coli. It exhibits rapid convergence and employs a global search strategy. Bacteria search for nutrients to optimize their energy levels. Bacteria communicate by signal transmission. The three phases of BFO are chemotactic, reproductive, and elimination-dispersal. After each cycle, the bacteria relocate to a new site, and the cost function is computed. When a bacterium encounters a favourable circumstance, it moves in a certain direction, and when it encounters a destructive one, it moves in the other direction.

1.8.3 Chicken Swarm Optimization (CSO)

CSO stands for the foraging behaviour of chickens. There are different groups within the chicken population. There is a dominant rooster, hens, and chicks in each group. The rooster has the highest fitness value among the chickens. The rooster leads the remaining. The chick has the lowest fitness value. Hens select their group autonomously in a random fashion. Each member of the group has a distinct job when seeking food. The rooster is responsible for safeguarding others in the group and has a high priority in accessing food. Hens follow the rooster during food exploration and steal others' food. Chicks follow their mother (hens). This algorithm is useful for load balancing criteria.

1.8.4 Squirrel Search Algorithm (SSA)

Seasonal variations influence SSA in its behaviour. During the summer, they are active, searching for food by leaping between trees and storing food for the winter when they are sedentary. The amount of food consumed is directly related to its energy content. The primary goal is storing food for future use. The fitness value of tree species determines food characteristics. SSA is utilized in routing to select the CH.

1.8.5 Fish Swarm Algorithm (FSA)

FSA imitates the behaviour of fish. The location of the food space is regarded as the solution space. Fish exhibit collective behaviour to evade threats. Each fish locates food and shares information with the group. The objective function is to maximize food density. By assessing fitness values, FSA can be used in routing to assist a mobile node in locating the closest base station.

1.8.6 Need For Optimization

Optimization in routing aims to enhance network performance and save costs. Network optimization is necessary to achieve specific objectives, such as reducing energy usage and maximizing network lifespan. WSN faces issues in routing related to network lifetime, security, energy consumption, and node deployment.

1.9 PROBLEM FORMULATION

The primary challenges identified behind implementing suitable cluster-based routing protocol are as follows:

- Each node may be prone to unanticipated failure.
- High-speed energy exhaustion occurs in sensor nodes, which are responsible for data communication, gathering, and aggregation.
- Based on the application, nodes must be capable of moving anywhere in the sensor field.
- WSN should have the capability to work in dynamic topology.
- Communication failure.

- Working of sensor nodes in a cooperative manner between different networked sensors.
- Maximum performance with less energy.

1.10 OBJECTIVES OF THE RESEARCH

The major objectives of the research are as follows:

- To improve network lifespan
- To reduce high speed energy exhaustion
- To improve latency and QoS
- To avoid data loss

1.11 CONTRIBUTION OF THE THESIS

As WSNs gained more attention in real-world applications as well as between researchers, the energy optimization of sensor nodes is more important to increase the lifetime of WSNs. This research aims to improve the lifetime of WSN by adopting energy efficient clustering and routing techniques. Along with that, secured WSN is very important. Hence, secured data transmission is adopted over the clustered network. This research work is divided into three energy optimization categories: Clustering, Routing, and Security.

1.11.1 Clustering:

Clustering is the most important task for the WSN in achieving efficient energy optimization. Grouping sensor nodes and selecting the proper CH are part of the clustering process for homogeneous and heterogeneous WSNs. The communication between CH and member nodes reduces the communication distance, which, in turn, reduces energy consumption. Even though many clustering algorithms are proposed by many researchers, an evolutionary optimization algorithm is proposed in this research work, where clustering is carried out using a hybrid technique that combines Genetic Algorithm and Algorithm for Cluster Establishment, and the results are compared with the LEACH algorithm.

1.11.2 Routing: Routing is another important technique through which energy minimization would be carried out. Routing is the act of determining the most efficient path. In most of the algorithms, the routing path is found, which could give the shortest path whether the data is ready to transmit or not. In the proposed work, the routing is found based on On Demand and nodal behaviour in which the node's behavior would fall into four different categories Reliable (R), Un-Reliable (U), Malicious (M), and Selfish (S). The shortest path is determined after determining the node behaviour, and the outcomes are evaluated against other established algorithms. Performance parameters are assessed based on Quality-of-Service metrics.

1.11.3 Security: A Secured Wireless Sensor Network is another required factor for secured data transmission, which needs node authentication, data confidentiality, protection against compromise, and resilience against traffic analysis. A secure routing system based on Multi Criteria Based Secured Routing Protocol (MSRP) is developed to enhance energy savings while maintaining network security. The multiple criteria included in this work are the number of neighbours, residual energy, link quality, and communication cost. Adopting multiple criteria will quickly identify the malicious nodes present in the network. The proposed algorithms initially identify and separate the malicious nodes, and then the processing between nodes is carried out. The performance parameters are compared with other existing algorithms.

1.12 THESIS ORGANIZATION

The thesis contents are organised as follows:

Chapter 1 gives an introduction, classification, challenges, and research issues of WSN and discusses clustering, routing, energy management, and optimization techniques.

Chapter 2 provides a literature review of clustering, routing, security, and energy management in WSN.

Chapter 3 discusses clustering its types and characteristics. The evolutionary hybrid optimization algorithm used to form clustering and CH selection is explained in detail. The performance of the proposed algorithm is compared with the other existing algorithms.

Chapter 4 details the routing and its challenges and explains about the algorithm used. The parameters are evaluated and the performance of the algorithm is compared with other existing algorithms.

Chapter 5 discusses security, and its challenges, explains the importance of secured clustered based routing, and discusses the algorithm used. The performance of the algorithm is compared with the other existing algorithms.

Chapter 6 concludes the thesis with a summary of the findings and discusses the directions for future work.