CHAPTER 1
INTRODUCTION

This chapter presents the preliminary information of research that deals with communication protocol for Wireless Sensor Network (WSN) with retention of energy efficiency. Chapter focuses on the background of the work, which is essential to understand the core information included in routing protocols of WSN. Work also discusses the problem statement followed by brief discussion of research objectives. Research methodology is briefly elaborated for having a quick snapshot of implementation techniques used for the proposed work. Finally, entire research organization is discussed at the end of the chapter.

1.1 INTRODUCTION

There are places on earth where it is never possible for human to move and collect information therefore WSN is one such technology that assists to bridge this gap. Usually, a WSN is also termed as a set of specific sensors that are distributed widely over the area that requires remote surveillance [1, 2]. In order to understand the domain of WSN, it is essential to first understand fundamentals of a sensor node. It is a type of device, powered from electrical and electronic characteristics, that is responsible for sensing some of significant physical attributes such as smoke, moisture, thermal, pressure, motion, temperature, humidity etc. [3].

Sensor nodes are scattered on the area where the information is required to be gathered. Hence, normally, such sensor nodes are dropped from the aeroplane [4]. This form of distribution of sensor nodes on the monitoring area is called as random distribution, where the position of sensors are quite unknown or unpredictable for the user before deployment [5]. Random deployment of sensors is preferable only for a large geographical area, where it is not possible for human to go and plant sensors. A uniform distribution of sensors is just the opposite of random deployment, where the sensor
location is well known to the user. It is generally used in small area for surveillance. Referring to Figure 1.1, it can be seen that a sensor node is designed using various forms of internal components examples transceiver, microcontroller, external memory, Analogue-to-Digital Converter (ADC), and power source [6].

![Figure 1.1: Hardware Components of Sensor Nodes](image)

Various types of sensors are as follows:

- **Pressure Sensor**: These sensors are used for capturing data related to pressure for example vacuum, fiber optics etc.
- **Temperature Sensor**: These types of sensors are used for capturing thermal data e.g. temperature data of thermocouples, integrated circuits, thermistors etc.
- **Level Sensor**: It is used to capture the differential data when the horizontal or vertical levels are subjected to any change.
- **Proximity Sensor**: It is a form of motion sensors which capture data related to any object coming closer to them.
- **Biosensor**: Such sensors are connected to body of living organism to capture vital stats.
- **Miscellaneous Sensor**: speed sensor, smoke sensor, humidity sensor etc.
1.1.1 Applications of WSN

The applications of the WSN are as follows:

- **Environmental Monitoring**: Sensors can be used in the surrounding to capture the forest fire, data of rainfall, precipitation, pollution, landslide, natural calamities, level of pollution etc.
- **Process Management**: Various forms of process in factories or industries for example chemical plant, nuclear plant, roadways, airport etc can be evaluated using sensor nodes.
- **Industrial Monitoring**: Sensors are also used for capturing the information about data logging, structural health monitoring, evaluating the health of complex machineries system.
- **Healthcare Monitoring**: Sensor nodes can also be used to capture vital statistics as well as certain clinical information to understand specific medical condition of a patient.

1.1.2 Essential Characteristics of WSN

Some of essential characteristics of WSN are as follows:

- A sensor node is characterized by less memory, minimal computational capability
- The deployment of sensors happens only once and nodes are usually stationary. Few nodes have mobility but it is not consistent.
- The nature of WSN is quite centric to data which means that any queries to the sensor network will be processed by sensors without any feasibility of unique addressing as nodes lack global identifier.
- The deployment of sensor nodes are usually carried out by single owner as they are normally application specific.
- The rate of data transfer is quite minimal in WSN and is quite statistical in nature.
- In conventional theory, the quantities of sensor nodes are considered to be quite large and should have the capability of scaling up to higher degree of network.
1.1.3 Design Issues in WSN

The communication performance of sensor network solely depends on the quality of the wireless transmission mode. Design issues in WSN are as follows:

- WSN has less supportability for multihop networking which results in minimization of transmission link range.
- Battery of sensor consistently dissipates energy thereby lowering the network lifetime and degrading the higher duty cycle operation.
- There is a less availability of routing protocol that supports energy efficiency and efficient data transmission during peak traffic condition.
- Inefficient clustering mechanism will lead to selection of imprecise cluster head leading to unnecessary energy depletion.

1.2 ENERGY PROBLEMS IN WSN

A WSN is a collection of various sensors that are small and inexpensive interconnected in an Ad-hoc manner [7]. Sensors are electronic devices that can sense the physical attributes example motion, pressure, temperature, smoke, humidity, etc. Very often, such devices are represented as nodes. Wireless sensor nodes are battery driven devices, which are capable of transmitting data to each other [8].

![Typical WSN Architecture](image)

*Figure 1.2: Typical WSN Architecture*
Architecture of a sensor node includes three basic components which are used for sensing various environmental attributes with respect to a process of sampling signals. Processing subsystem for aggregated data and storage components as well as a wireless communication unit for transmitting and receiving signals [9]. Each and every sensor node consists of a battery source with a limited power capacity. As sensor nodes are deployed over a hostile region, it will not be possible to recharge the batteries if batteries get exhausted [10]. Prolonging the life time of a sensor network has become more challenging now a day’s [11]. Figure 1.2 shows a typical WSN architecture which includes geographically distributed different sets of sensor nodes. Where each and every sensor node has the capability of running various Application Programming Interfaces (API) with the help of one operating system [12].

Existing research trends highlight that sensor nodes placed in a particular deployment area form a cluster. The cluster head in a cluster which consists of more powerful and computationally efficient resources [13]. Every cluster head maintains and collects aggregated data from its respective sensor nodes where a data acquisition process is performed for sampling of a received signal and resulting analog sample values are converted into digital numeric values for the ease of computation and pre-processing. Sensor nodes sense various kinds of environmental attributes using its sensing unit and transmit the information to its corresponding cluster head [14]. The entire cluster heads gather the collected information and retransmit it to a sink node which is also an electronic device used for processing of huge amount of collected data and sending it to the monitor station via a gateway node [15]. All sensor nodes use an analog to digital converter for converting conditioned sensor signals to digital values [16].

Energy consumption issues impose a great deal of challenges in the field of WSN as sensor nodes are deployed over a hostile region and there is no external wired source that can recharge sensor node batteries [17]. Scarcity of efficient power consumption has to be managed wisely in order to extend battery as well as network lifetime [18]. As the WSN network architecture has been designed to be implemented in various military
applications which consume more power for data communication between cluster heads which have very limited power capacity [19].

It can be seen that there are two other factors which affect badly, quality of services for large networks and wireless link qualities respectively. A huge distance between two sensor nodes and a poor link quality between nodes increase the data transmission power consumption within a particular WSN [20]. Link quality depends on different factors such as several physical barriers and climatic conditions. In order to maintain the link capacity for efficient data packet transmission several factors such as link quality and transmission power can be adjusted for data delivery success [21]. Earlier literature highlights that while designing a sensor node the computation energy and data transmission power has to be considered, as transceiver plays a very significant role in the conservation of overall power.

Transceiver consumes battery power by different type of stages such as

- Signal Transmission
- Signal Receiving
- Idle/Inactive mode
- Sleeping Mode/ (Off)

The above mentioned different types of stages of transceiver dissipate different amount of power during data transmission [22]. Many of the existing work show that transmission consumes more energy than data acquisition of a particular node. The configuration of a transceiver can be developed in a way that the enable and disable mode of these four different stages can be adjusted as per requirements of routing because in most cases it happens like a transceiver is in an idle mode which means it is not sending or receiving signal and puts itself in a power saving mode. Figure 1.3 highlights an overview of power management and energy harvesting of sensor node architecture.
Figure 1.3: Power Management of a Sensor Node

The concept of LEACH protocol has been introduced for low cost and low energy wireless data transmission over a sensor network [23]. In many applications it can be seen that various sensor nodes sense many physical parameters of the environment as bits and transmit these bits to a central node which is denoted by cluster head. The cluster heads also have some specified time limit for processing of those bits. If some delay in transmission happens, those bits become wastage for that cluster head. Hence specific and efficient end to end delivery of data bits and bits per energy consumption has to be addressed properly as the sensor device has very limited power and computational capacity. So, bits should be transferred to the specific node within the specific interval of time else more energy will be consumed for transmission and bits will remain unprocessed. Various sensor node hardware designs control end to end delivery of data packets in order to meet the bit transfer deadline.

All network layer protocol stacks also should be well synchronized for saving energy. In order to optimize the energy consumption in an overall WSN, various resources which are associated with data packet transmission in a WSN has to be managed very efficiently
as energy is a very scarce resource for sensor networking systems [24]. It is really essential to extend the WSN life time in order to complete a particular mission.

There are two types of resources which can be responsible for energy depletion. These are both useful and wasteful resources. Useful energy depletion happens due to the transmission and receiving of electrical signals, converting and sampling of the received signal into data, processing of query requests and forwarding queries and data to its respective neighbor nodes. Wasteful energy depletion can be happened due to two reasons. First, idle listening which is listening to an idle channel or links and expecting possible traffic. Second, energy depletion is collision between various nodes, when a receiver node receives more than one data packet at a particular moment of time then it is considered as collision of data packets even if they collide with each other partially. All data packets which have failed to process properly at the receiving end due to collision have to be thrown away. Thus, retransmission of these data packets will consume a huge amount of time and energy [25].

There is another reason of unnecessary energy consumption which is overhearing where a node receive a data packet which has been assigned for another destination node where wrong route towards a wrong destination node consumes a huge amount of energy. The control packet overhead also can cause energy waste as a minimum number of control packets should be utilized for a successful data transmission over a WSN. Over emitting of data packets is also a reason of energy waste where transmission of data packets happen without receiving any acknowledgement control signal from the destination node. The mentioned facts highlights that an energy efficient routing protocol must be designed to mitigate various energy consumption issues of WSNs [26].

1.3 HARDWARE COMPONENTS

WSNs consist of hundreds or thousands battery driven electronic devices which are termed as nodes [27]. A sensor node is sometimes also termed as node in short. A sensor node is composed of various electronic subsystems which can sense numerous
environmental parameters such as pressure, humidity, sound, vibration and changes to the health of person like blood pressure, stress and heartbeat as a form of digital signals and process them in order to take necessary actions. A sensor node also consists of a sensing unit which also includes an analog to digital converter (A/D converter), this subsystem is used for converting the sensed analog signal into a digital signal where some discrete data values are created using an efficient data acquisition technique for the ease of further processing [28]. One more sub system is composed of an RT-OS where various Application Programming Interfaces (APIs) are managed by the preinstalled Tiny-OS which is a real time operating system installed in every sensor nodes, a microcontroller and a memory buffer which performs some internal operations of data acquisition in sensor nodes [29]. One power unit which is nothing but a battery source is used for power generation and power supply to various components. Transceiver is also used for transmitting and receiving signal components.

**Figure 1.4: Typical Structure of a Sensor Node**

Figure 1.4 shows a typical structure of sensor node architecture. A radio transmitter is also can be used for creating an Ad-hoc network. Transceiver subsystem receives and generates control signals for transmission of data packets over a WSN. RT-OS, Transceiver Unit and A/D converter are altogether sometimes called as Mote. A mote and a sensing unit together form a sensor node. It can be seen that different sensors are installed in one sensor node for multipurpose task managements. A mote is sometimes also called as smart dust. A sensor node is considered as a basic unit of an overall WSN [30]. Nodes, which are deployed in a WSN, have various energy issues and a very limited
Various hardware design oriented issues can be found in a sensor node which is quite different from other applications. Various hardware design issues found in a sensor node are listed below.

- **Radio Range:** The radio range should be high in case of any sensor node deployment. It should be within 1 to 5 kilometers. It is very difficult to ensure the efficient network connectivity and data collection in the presence of radio range communication. Sometimes it can also happen that an environment which is being monitored by a sensor node has not activated with a proper communication systems [32]. It is also discovered that many sensor nodes located can remain disconnected with the network for many days and bring out higher consumption of energy or it may also go out of a particular radio range after establishing the network connectivity [33].

- **Use of Memory Chips like flash memory:** Flash memories are suggested to be used in a sensor node as characteristics of flash memory includes nonvolatile, inexpensive and volatile natures respectively [34].

- **Energy/Power Consumption:** Energy depletion of a sensor node should be optimized and sensor nodes should be very energy efficient as their limited power capacity decides their lifetime [35]. For the conservation of energy the node should stop the radio power supply while it is not in use. Battery types have to be selected efficiently as it can cause various design issues within a sensor node. Battery protection services such as controlling overcharge and discharge issues should be activated in a sensor node in order to avoid unnecessary power consumption [36].

As a sensor network is composed by a huge number of nodes, it is preferred that the cost of the sensor node should be cheap. Various sensor node platforms such as Mica, Mica2, MicaZ, Telos, BT Node, Imotes and MIT μ-AMPS (μ-Adaptive Multi-domain Power-aware Sensors) have been developed and brought out various above mentioned
designed issues [37]. Among them Berkeley’s Motes which uses concept of crossbow technologies has become very popular. This circuitry is used in many sensor devices of many organizations. The embedded design of Berkeley Mote system includes an embedded micro controller, a low power radio and a flash memory where power supply is done by two AA batteries. MICA and MICA2 are the most powerful and efficient hardware families of Berkeley Motes. The MICA2 platform has been designed with various components such as an Atmel ATmega128L and has a CC1000 transceiver. A 51-pin extension can be used as connector which is accessible to interface sensors. Microcontroller chips which are embedded in a sensor node can be utilized for processing of medium access and baseband. An event driven real time operating system which is known as Tiny-OS has been installed in a sensor node in order to perform some specific tasks such as process and resource with respect to the specific needs of sensor nodes. Figure 1.5 highlights an overview of Mica2 sensor node.

Figure 1.5: The Mica2 Sensor Node

1.4 OPERATING SYSTEMS

An operating system which is to be installed in a sensor node should offer a good platform which can manage all concurrent processes and memory with respect to an efficient computational complexity in an adverse environment also. There are various issues associated with an operating system design of a sensor network which is highlighted below.
A sensor node can be utilized in the processing of extracted data from a local environment where as a data acquisition mechanism is also performed for sampling of signals and it also manipulates the sensed data as per requirements of an application. Process management and task scheduling algorithms should be very much efficient as various activities of sensor network perform a transmission, routing and processing of data in a real time environment. Real time request/response activities also require efficient process management systems in a WSN.

The design constraints of sensor node architecture represents that operating systems which are installed in a sensor node should be platform independent and compatible to some specific applications. The configuration of a sensor node also should be activated with a multi-hop routing and accustomed with various dynamic networking topologies. As a sensor node is a battery driven device the operating system should be designed in a way so that it can optimize the battery power.

Operating system which has been installed in a sensor node should compose of many features which can optimize the energy consumption of a battery. Sensor device batteries cannot be recharged when it is required as it is deployed in an unassisted and hostile environment; also it has some issues due to small size and low cost requirements. There should be some enforcement which can be applied in every usage of resources by various applications installed in that operating system. A priority based task scheduling algorithm should be utilized where higher priority based events can get superiority.

Application software developers also should focus on defining efficient logical algorithms instead of concentrating on low level hardware issues such as scheduling, preempting and networking. Operating systems should have an understandable programming environment so that developers can fix the bugs easily.
Many operating systems which have been developed for sensor networks such as Tiny-OS, Mantis Operating System and Nano-Qplus do not bring out the above mentioned designed oriented challenges. Tiny-OS is considered as open source real time software which has become very popular in many industries as well as many research and development organizations, where it has been adapted and configured with sensor network devices. Technical documentation of Tiny-OS architecture shows that it has developed with respect to a component based architecture which enables a rapid development in optimization of code size as per the requirement of various memory constraints of sensor node.

1.5 Energy issues in WSN

The communication system of the sensor network is governed by routing protocols in sensor network. There are three types of routing protocols in sensor network i.e. data centric, hierarchical, and location-based as shown in Figure 1.6, out of which hierarchical routing protocols are used only in energy efficiency. General information of routing can be seen in the work of Mundada [38].

![Figure 1.6: Classification of Routing Protocols in WSN](image-url)
• **Battery Power**

It is noticed that excessive battery power consumption may affect the life span of a WSN and its respective applications. Most of sensor nodes are deployed in a region for a long-term purpose but the limited power resources only can supply the required power mostly for months or years. It can be observed that power issues are not a factor in various conventional systems but in case of sensor node architecture it has to be counted as a essential resource like processor and memory. Data packets transmission and communication consume a huge power loss as compared to sensing and computational processes. Various mathematical modeling show that the cost associated with energy for 1 bit data packet transmission over a radio frequency channel is almost similar to energy consumed by processing thousands of instructions with respect to a processor of a sensor node [39].

Reading and writing of data from memory also can cause significant energy consumption. Runtime environment which includes compiler in order to load and unload various program modules into program memory also increases the power consumption overhead. It is an essential accountability of an operating system to manage all types of applications for reducing the consumption of power in order to increase the network lifetime of WSN. Many power saving mechanisms are introduced which ensure power saving within terms of various periodic sleeping nodes. In order to conserve energy three sleep modes can be activated within a sensor node they are idle mode, Power Down mode and Power Saver mode respectively. In the idle mode processor alone stops working where power down mode interrupts every processing task and forces them to stop except watch dog timer as control and interrupt signals are necessary to bring back a node into a wake up state. The power saver mode is almost same as the power down mode only exception is, it keeps the timer running. The following Table 1.1 highlights various wireless standards along with their transmission data rate and the distance of radio range.
### Table 1.1: Various Wireless Standards

<table>
<thead>
<tr>
<th>Data rate</th>
<th>Standard</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>39kbs</td>
<td>CC1000</td>
<td>300m</td>
</tr>
<tr>
<td>256kbps</td>
<td>802.15.4 (PAN)</td>
<td>100m</td>
</tr>
<tr>
<td>Up to 3 Mbps</td>
<td>Bluetooth</td>
<td>1m to 100m</td>
</tr>
<tr>
<td>54Mbps</td>
<td>802.11 (Wi-Fi)</td>
<td>45m to 90m</td>
</tr>
</tbody>
</table>

- **Processing Power**

  Processing power of sensor nodes is merely a few MIPS (Millions of Instructions per Second) [40]. The operating system should allocate various computation intensive operations and processes efficiently, otherwise higher priority based tasks will remain unprocessed/delayed/ravenous and it will consume more energy unnecessarily. There are various computation models which follow the concept of event driven mathematical modeling. It also takes much processing time and prevents other higher priority based tasks from being processed. It also delays job schedules irrespective of their priority scheduling thus operating system and its components should be designed properly in order to optimize the energy consumption.

- **Bandwidth**

  In a WSN communication, sensor nodes use various Radio Frequency (RF) channels for communicating with each other [41]. A survey of recent emerging trends shows that ZigBee is an efficient typical protocol which can be utilized for defining a communication protocol stack on physical and data link layers of IEEE 802.15.4 [42] Personal Area Network (PAN). In PAN the data rate which has been defined is 256kbps. In case of Bluetooth communication it supports data rate up to 3Mbps. CC1000 is considered as an efficient standard of network communication which is being used in the
area of WSNs [43]. The data transmission rate associated with this standard is almost 39kbps.

Wi-Fi technology which is IEEE 802.11 standard is rarely used in the field of WSNs where the data transmission rate is almost 54Mbps. The current analysis towards research trends shows that PAN consumes low power as compared to Wi-Fi technology. So the WSN uses the concept of PAN. The operations take place in different modes for optimizing the power consumption issues.

If Bluetooth RF transceiver is used in the field of WSN then it will consume more power for switching between intermediate nodes. The experimental analysis shows that 8MHz clock speed processor, 10k of RAM and 128k of flash memory sensor nodes is available currently for deployment. Less bandwidth should be consumed as it is proportional with energy consumption of WSNs as well as a node should last at least 945 days after deployment with two AA batteries [44].

- **Multitasking**

  Wireless sensor nodes could be utilized for more than one task basically it performs multitasking as an example sensor nodes sense and gathers various environmental attributes, perform data acquisition, aggregation with respect to various filtering conditions. Encryption and decryption also performed before transmitting the data towards a sink/gateway node or some other corresponding nodes of a particular sensor network [45].

  Following are various tasks performed by a sensor node at given interval.
  
  1. Sensing of data packets
  2. Collection of data packets from other corresponding sensor nodes
  3. Aggregation of the data which can be based on certain conditions provided
  4. Encryption/decryption of the data before processing/transmitting.
  5. Forwarding the data over a secure route to the destination or sink node.
A sensor node may be useful for doing many operations at a time which have been listed above but it can affect energy sources of a sensor node and cause a huge amount of energy depletion [46]. Some operations are concurrent processes which should be handled properly by a processor and operating a sensor node in use. If some delay oriented constraints arise then it will degrade performance of overall systems as important tasks or some of operations will be on a queue waiting long for its execution. Increment of the waiting time of a process will increase the consumption of more energy. Many tasks scheduling algorithms are found insufficient for optimizing energy issues in the field of WSN [47].

- **Load Balancing**
  
  Load balancing is a mechanism for indistinguishable allotment of various loads associated with a WSN to avoid the network overhead or congestion [48]. Various load balancing techniques have been designed for creating an energy efficient route in between source and destination node in order to enhance the network lifetime [49]. Though various load balancing techniques can achieve highest throughput and minimize the response time but some of techniques consume a huge amount of power while distributing the workload among sensor devices. Sometimes many drawbacks can be found in many load balancing strategies which can reduce the transmission cost but enhance the routing overhead. Some of the existing studies only discussed about various load balancing strategies and their application over a WSN for enhancing network life time and throughput but those strategies does not talk about how to minimize energy consumption issues happening due to routing overhead [50].

**1.6 Power Consumption Models in WSN**

There are various energy consumption models which have designed for monitoring the amount of power depletion caused by a sensor network. Different types of energy consumption models chosen from various existing studies are highlighted below [51].
• **The Classical Energy Consumption Model**

A classical energy consumption model has been introduced which can be configured with a sensor and it also can monitor how much energy can be consumed by a data communication subsystem of a sensor node [52]. Table 1.2 represents various existing radio models and the amount of their respective energy consumption in a WSN.

**Table 1.2: Radio Characteristics, Classical model**

<table>
<thead>
<tr>
<th>Radio Mode</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Electronics (E\textsubscript{TX-elec})</td>
<td>50nJ/Bit</td>
</tr>
<tr>
<td>Receiver Electronics (E\textsubscript{RX-elec})</td>
<td></td>
</tr>
<tr>
<td>(E\textsubscript{TX-elec} = E\textsubscript{RX-elec} = E\textsubscript{elec})</td>
<td></td>
</tr>
<tr>
<td>Transmit amplifier (E\textsubscript{amp})</td>
<td>100pJ/bit/m\textsuperscript{2}</td>
</tr>
<tr>
<td>Idle (E\textsubscript{idle})</td>
<td>40nJ/bit</td>
</tr>
<tr>
<td>Sleep</td>
<td>0</td>
</tr>
</tbody>
</table>

• **μAMPS Specific Model**

A specific model for energy consumption monitoring and reducing has been designed which can be configured with a specific platform of the μAMPS WSN [53]. Table 1.3 highlights the above mentioned model characteristics with respect to various parameters.

**Table 1.3 Sensor States for μAMPS Model**

<table>
<thead>
<tr>
<th>State</th>
<th>Sensor, A/D</th>
<th>SA-1110</th>
<th>Radio</th>
<th>Pk (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Sense</td>
<td>Active</td>
<td>Tx/Rx</td>
<td>1040</td>
</tr>
<tr>
<td>Ready</td>
<td>Sense</td>
<td>Idle</td>
<td>Rx</td>
<td>400</td>
</tr>
<tr>
<td>Monitor</td>
<td>Sense</td>
<td>Sleep</td>
<td>Rx</td>
<td>270</td>
</tr>
<tr>
<td>Observe</td>
<td>Sense</td>
<td>Sleep</td>
<td>Off</td>
<td>200</td>
</tr>
<tr>
<td>Deep Sleep</td>
<td>Off</td>
<td>Sleep</td>
<td>Off</td>
<td>10</td>
</tr>
</tbody>
</table>

The platform has a Strong ARM SA 1110 microprocessor which also includes a clock speed from 59 MHz to 206 MHz. Model monitors the amount of energy consumed by the
microcontroller, energy lost due to leakage and the average consumption of the radio. As many authors have explained about many aspects towards current consumption and time, assuming that Mica2 is powered by a 3V source, one can calculate the total power in transmitting and receiving one bit, as:

\[
\text{Power} = \text{Current Flow} \times \text{Voltage} \times \text{Time}
\]

Where current is in amperes, voltage is measured in volts and time is in seconds

\[
\text{Power Tx} = 20 \times 10^{-3} \text{A} \times 3 \text{ Volts} \times 416 \times 10^{-6} \text{ sec} / 8 \text{ bits} = 3.12 \mu\text{J/bit}
\]

\[
\text{Power Rx} = 15 \times 10^{-3} \text{A} \times 3 \text{ Volts} \times 416 \times 10^{-6} \text{ sec} / 8 \text{ bits} = 2.34 \mu\text{J/bit}
\]

- **Mica2 Specific Model with Actual Measurements**

A current consumption model based on various parameters on the Mica2 platform has been introduced in the work of [54]. A summary of the model has been represented in Table 1.4.

**Table 1.4: Current Consumption with Actual Measurements**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Current</th>
<th>Mode</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>8.0mA</td>
<td>Rx</td>
<td>7.0mA</td>
</tr>
<tr>
<td>Idle</td>
<td>3.2mA</td>
<td>Tx (-20dBm)</td>
<td>3.7mA</td>
</tr>
<tr>
<td>ADC Noise</td>
<td>1.0mA</td>
<td>Tx (-19dBm)</td>
<td>5.2mA</td>
</tr>
<tr>
<td>Power-down</td>
<td>103μA</td>
<td>Tx (-15dBm)</td>
<td>5.4mA</td>
</tr>
<tr>
<td>Power-Save</td>
<td>110 μA</td>
<td>Tx (-dBm)</td>
<td>6.5mA</td>
</tr>
<tr>
<td>Standby</td>
<td>216 μA</td>
<td>Tx (-dBm)</td>
<td>7.1mA</td>
</tr>
<tr>
<td>Extended Standby</td>
<td>223 μA</td>
<td>Tx (dBm)</td>
<td>8.5mA</td>
</tr>
<tr>
<td>Internal Oscillator</td>
<td>0.93mA</td>
<td>Tx (+dBm)</td>
<td>11.6mA</td>
</tr>
<tr>
<td>LED’s</td>
<td>2.2mA</td>
<td>Tx (+dBm)</td>
<td>13.8mA</td>
</tr>
<tr>
<td>Sensor Board</td>
<td>0.7mA</td>
<td>Tx (+dBm)</td>
<td>17.4mA</td>
</tr>
<tr>
<td>Read</td>
<td>6.2Ma</td>
<td>Tx (+10dBm)</td>
<td>21.5mA</td>
</tr>
<tr>
<td>Read Time</td>
<td>565</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write</td>
<td>18.4mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write Time</td>
<td>12.9ms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.7 PROBLEM DESCRIPTION AND STATEMENT

Various problems that were identified in the proposed thesis are as follows:

- **Vague Knowledge about Power Requirements**

  Problems associated with the energy issue in WSN are quite difficult to visualize as well as to investigate. Normally, a sensing device is constructed with various forms of hardware components and RF antenna which has different sorts of power requirements. Although, it is known that WSN has limited battery life, it is not exactly known as to how much energy is required by each circuitry components in sensor nodes. This situation makes the investigation quite difficult to ascertain how much of the power could be actually balanced during data dissemination process. Although existing research work speaks about significant ways of reducing power consumption, the question still lies unanswered that if the conserved power is actually enough for running the sensor node and for how much time or cycle of data dissemination process.

- **Inadequate Routing Operation**

  Normally, the process of routing data takes place in WSN only during the data aggregation process. In general cases, the routing process is also closely associated with clustering techniques in sensor network. In majority of existing studies, approaches are more or less don’t support multi-hop where dynamic decision is required to be considered for selection of an appropriate node to precede the data dissemination process. Moreover, designing of inappropriate decision results in selection of an inefficient node which not only shut down the communication of data from itself owing to energy depletion but also seriously disrupts connectivity that it makes with other nodes. Hence, joint supportability of multihop routing and energy optimization is quite difficult to accomplish.
Moreover, theoretical occurrences of energy efficient routing protocols are quite less in WSN and even they could not balance between energy efficiency with quality of service requirements in sensor networks. For an effective routing, it is highly essential that it should be scalable, energy efficient, and exhibit similar performance on multiple forms of traffic loads in sensor network. Such forms of routing protocols are actually very few to find.

- **Ineffective Visualization of Load Balancing**

  A load balancing technique is essentially designed in order to reduce the processing task by ensuring maximum number of node participation in data dissemination process. With increasing rounds of data dissemination process, energy constantly depletes, resulting in much increase in processing capability for remaining alive nodes. However, such situation infact leads to faster node death. Hence, there is a need of a load balancing technique that becomes stronger with increasing simulation rounds.

Thus, after above clauses of problem description, the problem statement of proposed work is as follows it is computationally challenging task to carry out optimization of the performance of the WSN for jointly ensuring energy efficiency, load balancing and routing technique.

1.8 RESEARCH OBJECTIVES

Proposed system aims to design a framework that can ensure the best energy efficient communication protocol for catering up demands of the traffic in WSN. Following are research objectives:

1. To present a sustainable framework that can carry out novel optimization technique of communication strategy in order to leverage network lifetime.
2. To develop a fresh topology in WSN that can perform an effective load balancing over large scale environment of sensor network.

3. To design and implement an innovative routing agent-based model for carrying out dynamic reconfiguration for improving communication and energy efficiency.

1.9 RESEARCH METHODOLOGY

Proposed work considers the mixed mode research methodology. Work essentially considers adopting analytical and mathematical modeling approach mainly as the standard of research methodology. This section will also discuss about the motivation factor behind adoption of this mechanism of research methodology.

It is observed that all issue surfaces are mainly due to routing operation. Therefore, proposed system requires a technique where the routing protocol could be designed mathematically and then validated from the simulation work. Strategies adopted in the proposed work are to understand the problem of energy efficiency in routing sensor network, to develop a new model mathematically that can mitigate the adverse effect of reduced energy lifetime and to validate the available technique with the most standard energy efficient communication protocol in sensor network. The schematic diagram of the proposed work is as shown in Figure 1.7. The proposed work is essentially carried out in multiple stages with particular adoption of research methodology. Discussions of research methodology adopted in each stage are as follows:

1. Secondary Research for Preliminary Investigation

The proposed work has initially adopted a secondary research technique for carrying out preliminary stages of data collection. A significant amount of literature inclined towards energy issues, routing issues, load balancing issues and traffic management are collected and studied. All the existing work has been effectively studied to understand the impact of the existing techniques on energy
efficiency and also to visualize the existing problems of routing protocols pertaining to energy efficiency and load balancing.

2. Analytical Research for Core Studies

An analytical research approach adopted in proposed work combines both empirical approach as well as mathematical modeling approach in order to accomplish the work objectives. The design and adoption of analytical research methodology was carried out in following stages of proposed work
Figure 1.7: Schema of Adopted Research Methodology
• **Developing Simulation Test-Bed**

This stage of the work is more emphasized on design of architecture and validating it in the simulation test-bed. The proposed work uses MATLAB as simulation tool and Origin Pro as the data analysis tool. The core backbone part of the work is energy factor, routing factor and load balancing factor. Where energy factor is most dominant aspect of the thesis. Hence, work considers adoption of standard radio-energy model in order to apply the energy efficient routing and validate its effectiveness.

The simulation work is carried out in normal machine with Windows operating system. Common research variables used in the analytical work are number of sensor nodes, transmission range, initial energy and dimension of simulation area etc. Development of this simulation test-bed assists in further work and implementation of algorithms mapping with work objectives.

• **Optimization using Probability**

Proposed work adopts potential features of probability theory in order to optimize the lifetime of the sensor at multiple levels of clustering. The development of the proposed system is assisted by the design of two core modules where the first module is responsible for confining the decision to local level while the second module is responsible for confining the decision to global level. The decision essentially is related to the selection of the best strategy or solution of routing that can ensure energy efficiency by choosing an appropriate cluster head. This system is based on dual level of sequential decision making allows the system to have better probability of energy retention while performing routing in WSN. This approach also assists in carrying out intra-clustering as well as inter-clustering in WSN. The analytical modelling has also resulted in evolution of some new parameters example core locus point, residual energy, and near locus point.
• **Load Balancing with Globular Topology**

This part of the work has adopted analytical scheme for the purpose of addressing of load balancing issues in WSN. The latest scheme has introduced a new routing process that ensures the optimal data transmission in large density network. Core modules involved in the design stage are updating of task allocation, analytical design of globular topology and querying task allocation. The research methodology is more dominantly analytical as well as mathematical. The prime intention is to ensure both load balancing as well as energy efficiency while performing routing using an innovative globular topology.

• **Designing Dynamic Reconfiguration**

This stage of the work mainly seeks to reconfigure the routing agents dynamically in order to protect nodes from further energy depletion. System introduces a routing agent that will be responsible for allocating the cluster head as well as to compute effectiveness in their adopted decision. The analytical modeling is performed using graph theory and best version of radio energy modeling. Backbone of this work phase is essentially mathematics where the validation is carried out using performance comparative analysis with most standard energy efficient routing protocols in sensor network.

**1.10 THESIS ORGANIZATION**

First chapter discusses about the preliminary information, background and essential characteristics of WSN along with discussion of research objectives. The existing literature that addresses problems of energy optimization, topological based energy efficient techniques and existing techniques of load balancing. It also discusses the significant research gap as an outcome in second chapter.

Third chapter presents a novel technique that target to accomplish energy efficiency using the modern clustering mechanism. This section also briefs the research methodology, algorithm implementation, and result discussion. A new
topology that is responsible for optimizing both routing and load balancing simultaneously. Fourth chapter discusses the research methodology, algorithm implementation and result discussion.

Fifth chapter elucidates the technique of dynamic reconfiguration of latest routing agents in order to retain maximum lifetime of the sensor network. Combined outcome of the work and results are discussed in sixth chapter.

Seventh chapter concludes the summary of thesis with a special focus on core findings of the research contribution and future work.