CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO WIRELESS SENSOR NETWORKS

Recent advances in integrated, low-power, wireless communication devices and sensors have enabled the development of low-cost, low-power, multifunctional sensor nodes. These sensor nodes are small in size and can communicate untethered in short distances. This has leveraged the idea of Wireless Sensor Networks (WSNs). Basically, WSN is a self-organizing network that consists of a large number of sensor nodes densely deployed in the area of interest which work together to perform some application-specific task.

The main task of a WSN is to gather information on events of interest, possibly perform aggregation or other processing and channel this information to a sink node. Each sensor node in a sensor network is capable of sensing environmental condition within their range and is typically equipped with a radio transceiver, a small micro controller and an energy source, usually a battery. Individual nodes in the sensor field are powered by a battery and consume energy for various purposes such as sensing, on-board signal processing and transmitting. Energy required for transmission is significantly higher than for other purposes and is a function of the distance between sender and receiver. In general, sensor nodes are stationary and unattended. It is not easy and in most cases impractical to replace or recharge the battery in hazardous environments. Once the battery runs out, the sensor
node becomes inoperable, increasing the coverage hole and decreasing the connectivity of the whole network, on which the sensor network’s performance depends highly. Therefore, efficient use of the sensor node battery’s energy is an important aspect of sensor networks (Akyildiz et al 2002). The lifetime of a WSN is determined by the time duration until the first node runs out of energy leading to disconnected network.

1.1.1 Typical Sensor Network Scenario

A typical sensor network scenario consists of a large number of sensor nodes that are densely deployed in the network area, as shown in Figure 1.1. A sensor node senses an event of interest from the monitored area and channels this information to a sink node or base station. Data are routed back to the sink by a multihop infrastructureless architecture through intermediate sensor nodes. The sink acts as a gateway that communicates with the internet or satellite.

![Figure 1.1 A Typical Sensor Network scenario](image-url)


1.1.2 Components of a Sensor Node

A sensor node consists of four important components, i.e., sensing component, communication component, processing component, and power supply component (Akyildiz et al 2002). In some special applications, the sensor node may also have additional parts, such as location detection and node mobility controller, as shown in Figure 1.2. The sensing unit usually consists of two components, i.e. sensor and Analog to Digital Converter (ADC). The sensor captures the interested events, which are then converted from analog signal into digital signal using ADC. The processing unit consists of a microprocessor or microcontroller unit and memory. The processing unit does all the computation and management work. The microprocessor is responsible for the control of the sensor and execution of communication protocols. The memory is used to hold the application and temporarily buffer a small amount of user data. The communication unit has a transceiver that transmits and receives data messages. It consists of a short-range radio which is used to communicate with the neighboring nodes and the outside world.

![Figure 1.2 Components of a sensor node](image-url)

Figure 1.2 Components of a sensor node
The transceiver can operate under the Transmit, Receive, Idle and Sleep modes. Each sensor node has a power supply component, usually a small battery which powers the sensing unit, on-board signal processing unit and communication (transmitting and receiving a data) unit.

1.1.3 Layered Architecture of WSNs

The sensor network protocol stack is shown in Figure 1.3. Such a model partitions WSN into five layers from bottom to top, consisting of physical layer, data link layer, network layer, transport layer and application layer. There are three planes namely power management plane, mobility management plane and task-management plane. The Physical Layer is responsible for Frequency selection, Carrier frequency generation, Signal detection, Modulation etc. It takes care of the basic data transmission across some medium.

Figure 1.3 Sensor Network protocol stack
The Data Link Layer is involved in multiplexing of data streams, data frame detection, medium access control and Error control. Medium Access Control (MAC) ensures fair and efficient sharing of communication resources between sensor nodes. Since the environment is noisy and sensor nodes can be mobile, the MAC protocol must be power-aware and able to minimize collision with neighbor’s broadcasts. Network Layer is responsible for finding the available routing paths for data. Transport Layer takes care of end-to-end reliability, congestion and multihop re-transmissions. Finally, Application Layer provides specific protocols and applications to the user.

In addition, this model also includes three planes spanning all layers namely power management, mobility management and task management. These planes indicate that the relevant functions must be achieved in all layers rather than any single layer. Power Management Plane manages the power usage in sensor nodes. For example, the sensor node may turn off its receiver after receiving a message from one of its neighbors. This is to avoid duplicated message transmissions. Also, when the power level of the sensor node is low, the sensor node informs the power security by broadcasting status to neighbors and avoids participating in routing. The remaining power is reserved for sensing.

The mobility management plane detects and registers the movement of sensor nodes, so a route back to the user is always maintained and the sensor nodes can keep track of their neighbor sensor nodes. By knowing the neighbor sensor nodes, it can balance their power and task usage. The task management plane balances and schedules the sensing tasks given to a specific region. Not all sensor nodes in that region are required to perform the sensing task at the same time. As a result, some sensor nodes perform the task more than others depending on their power level. These management planes
are needed so that sensor nodes can work together in a power efficient way, route data in a mobile sensor network and share resources between sensor nodes.

### 1.1.4 Characteristic Features of WSNs

Some of the typical characteristics of WSNs are that they are

- Resource-constrained (computational and storage capacity)
- Operated using limited power (non-renewable battery power)
- Able to withstand harsh environmental conditions
- Able to cope with node failures
- Able to manage mobility of nodes
- Subject to communication failures
- Able to cope with unattended operation
- Scalable to node capacity, limited bandwidth of gateway node
- Able to deal with dense deployment
- Self-organizational ad hoc network topology
- Homogeneous and each node are assigned a unique Identifier (ID)
- Able to use power control to vary the amount of transmission power according to the distance to the desired recipient
1.1.5 Advantages of WSNs

In wired networks, bundles of lead wires and fiber-optic “tails” are subject to breakage and connector failures. Long wire bundles represent a significant installation and long term maintenance cost, limiting the number of sensors that may be deployed, and therefore reducing the overall quality of the data reported. Also, wiring is expensive and constitute maintenance problem. The wires prevent entities from being mobile and thus prevent sensors or actuators from being close to the phenomenon. WSN eliminate these costs, easing installation and eliminating connectors. The ideal wireless sensor is networked and scalable, consumes very little power, is smart and software programmable, is capable of fast data acquisition, is reliable and accurate over the long term, costs little to purchase and install and requires no real maintenance.

1.1.6 Applications of WSNs

With the advancement in the related technologies, it is possible to deploy deeply embedded WSN for various types of applications, such as surveillance detection, wildlife tracking, virus monitoring, military usages, industrial control and monitoring, home automation, environmental sensing and health monitoring etc. as discussed in Akyildiz et al (2002). Few parameters measured are temperature, humidity, visual and infrared light (from simple luminance to cameras), acoustics, vibration (e.g. for detecting seismic disturbances), pressure, chemical sensors (for gases of different types or to judge soil composition), mechanical stress and magnetic sensors (to detect passing vehicles). Some of the real time applications where WSN could be used are listed below.
- Disaster relief applications (Forest fire/wild fire)
- Environmental control & biodiversity mapping (animals, ocean ground floor)
- Intelligent buildings (temperature, airflow, humidity control for inhalation and reduce energy consumption, safety of buildings after earthquake)
- Facility management: keyless entry application, detection of intruders or vehicles
- Machine surveillance and preventive maintenance
- Precision agriculture (humidity/soil composition sensors)
- Medicine and health care
- Logistics (tracking of objects, inventory)
- Telematics (monitor traffic conditions and avoid traffic jams and danger/warning)

1.2 DIFFERENCES BETWEEN MOBILE ADHOC NETWORKS AND WSNs

On the basis of these application examples and main challenges, the closeness of Mobile Ad Hoc Networks (MANETs) and WSNs becomes apparent (Karl & Willig 2005). Nonetheless, there are some principal differences between the two concepts, warranting a distinction between them. Some of them are listed in Table 1.1.
Table 1.1 Differences between MANETs and WSNs

<table>
<thead>
<tr>
<th>Characteristic features</th>
<th>MANETs</th>
<th>WSNs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications and equipment’s</td>
<td>Terminals are powerful (PDA/Laptop) with large battery</td>
<td>Each node has limited computational power and storage capacity. They operate on non-renewable power sources and employ a short-range transceiver to send and receive messages.</td>
</tr>
<tr>
<td>Application Specific</td>
<td>Network density variation is less</td>
<td>Sensor nodes are generally densely deployed in the area of interest.</td>
</tr>
<tr>
<td>Environment Interaction</td>
<td>Traffic characteristics are well understood</td>
<td>Since they interact with environment, their traffic characteristics are varying (sometimes high/low)</td>
</tr>
<tr>
<td>Scalability</td>
<td>Less scale and identifiers exist for each node</td>
<td>Scale to large numbers (thousands/tens of thousand) hence needs scalable solution to work without any unique identifier</td>
</tr>
<tr>
<td>Energy</td>
<td>Scarce</td>
<td>Very much scarce</td>
</tr>
<tr>
<td>Self-configurability</td>
<td>Self-configured into connected networks</td>
<td>Same as in MANET with difference in traffic and energy</td>
</tr>
<tr>
<td>Dependability and QoS</td>
<td>Each node should be reliable</td>
<td>Because of presence of large nodes reliability is lesser</td>
</tr>
<tr>
<td>Routing</td>
<td>Address centric</td>
<td>Data centric</td>
</tr>
<tr>
<td>Simplicity &amp; Resource scarceness</td>
<td>Uses heavy weight routing protocols</td>
<td>OS and networking software kept very simple due to energy scarce</td>
</tr>
<tr>
<td>Mobility</td>
<td>Movement of nodes have to be handled</td>
<td>Protocols need to take mobility of the phenomenon (like intruder or movement of sink)</td>
</tr>
</tbody>
</table>
1.3 SOME EXAMPLES OF SENSOR NODES

There are quite a number of nodes available for use in WSN research and development (Karl & Willig 2005). Again, depending on the intended application scenarios, they have to fulfill quite different requirements regarding battery life, mechanical robustness of the node’s housing, size, and so on. Few examples are listed below.

1.3.1 The “Mica Mote” Family

Starting in late 1990s, an entire family of nodes has evolved out of research projects at the University of California at Berkeley, partially with the collaboration of Intel, over the years. They are commonly known as the Mica motes, with different versions (Mica, Mica 2, Mica 2 Dot). They are commercially available via the company Crossbow in different versions and different kits. TinyOS is the usually used operating system for these nodes. An early example for the schematics of such a node is shown in Figure 1.4.

![Figure 1.4 Mica 2 node](Courtesy: www.tinyos.net)
All these boards feature a microcontroller belonging to the Atmel family, a simple radio modem (usually a TR 1000 from RFM), and various connections to the outside. In addition, it is possible to connect additional “sensor boards” with, for example, barometric or humidity sensors, to the node as such, enabling a wider range of applications and experiments. Also, specialized enclosures have been built for use in rough environments, for example, for monitoring bird habitats (Mainwaring et al 2002). The MEDUSA-II nodes (Raghunathan et al 2002) share the basic components and are quite similar in design.

1.3.2 EYES Nodes

The nodes developed by Infineon in the context of the European Union – sponsored project “Energy efficient Sensor Networks” (EYES) are another example of a typical sensor node (Figure 1.5). It is equipped with a Texas Instrument MSP 430 microcontroller, an Infineon radio modem TDA 5250, along with a SAW filter and transmission power control; the radio modem also reports the measured signal strength to the controller. The node has a USB interface to a PC and the possibility to add additional sensors/actuators. It has integrated temperature and light sensors and full TinyOS software support.

![Figure 1.5 EYES sensor node](Courtesy: www.ubimon.doc.ic.ac.uk)
1.3.3 BTnode

The BTnode is an autonomous wireless communication and computing platform based on a Bluetooth radio and a microcontroller. It serves as a demonstration platform for research in mobile and ad hoc connected networks (MANETs) and distributed sensor networks. The BTnode has been jointly developed at ETH Zurich by the Computer Engineering and Networks Laboratory (TIK) and the Research Group for Distributed Systems. Currently, the BTnode is primarily used in two major research projects: NCCR MICS and Smart-Its. BTnode rev3 is shown in Figure 1.6

![BTnode Image](http://www-micrel.deis.unibo.it)

**Figure 1.6 BTnode**

(Courtesy: www-micrel.deis.unibo.it)

Some of the features of BTnode are listed below.

- Microcontroller: Atmel ATmega 128L (8 MHz @ 8 MIPS)
- Memories: 64+180 Kbyte RAM, 128 Kbyte FLASH ROM, 4 Kbyte EEPROM
- Bluetooth subsystem: Zeevo ZV4002, supporting AFH/SFH
• Scatternets with max. 4 Piconets/7 Slaves, BT v1.2 compatible

• Low-power radio: Chipcon CC1000 operating in ISM band 433-915 MHz

1.3.4 Scatterweb

The Scatterweb platform was developed at the Computer Systems & Telematics group at the Freie University at Berlin. This is an entire family of nodes, starting from a relatively standard sensor node (based on MSP 430 microcontroller) and ranging up to embedded web servers, which comes equipped with a wide range of interconnection possibilities – apart from Bluetooth and low-power radio mode, connections for I2C or CAN are available. Scatterweb embedded server is shown in Figure 1.7.

![Figure 1.7 A Scatterweb embedded web server](Courtesy: www.mi.fu-berlin.de)

The microcontroller-based Embedded Web Server provides a lot of input and outputs for sensors and other devices. They provide the heart of the off-board communication and steering. Furthermore, the Embedded Web Server provides standard connection to other devices like a serial connector,
the CAN-Bus system or the JTAG interface. They can be used to debug this
device or steer other devices.

1.4 LOCALIZATION

Localization technique is proposed to obtain reduced estimation
error. To begin with, the problem statement is first defined on “Localization”
in WSN. Localization is a fundamental service for many applications of
WSN. Localization refers to the ability of determining the position (relative or
absolute) of a sensor node, with an acceptable accuracy. In a WSN,
localization is a very important task and is relevant to many applications
(target tracking, intruder detection, environmental monitoring, etc.), which
depend on knowing the location of nodes.

The location information of nodes (Krishnamachari 2005) in the
network is fundamental for a number of reasons:

- **To provide location stamps** for individual sensor
  measurements that is being gathered.

- **To locate and track point objects** in the environment.

- **To monitor the spatial evolution** of a diffuse phenomenon
  over time, such as an expanding chemical plume. For instance,
  this information is necessary for in-network processing
  algorithms that determine and track the changing boundaries
  of such a phenomenon.

- **To determine the quality of coverage** if node locations are
  known, the network can keep track of the extent of spatial
  coverage provided by active sensors at any time.
To achieve load balancing in topology control mechanisms if nodes are densely deployed, geographic information of nodes can be used to selectively shut down some percentage of nodes in each geographic area to conserve energy and rotate these over time to achieve load balancing.

To form clusters location information can be used to define a partition of the network into separate clusters for hierarchical routing and collaborative processing.

To facilitate routing of information through the network. There are a number of geographic routing algorithms that utilize location information instead of node addresses to provide efficient routing.

To perform efficient spatial querying a sink or gateway node can issue queries for information about specific locations or geographic regions. Location information can be used to scope the query propagation instead of flooding the whole network, which would be waste of energy.

1.5 FACTORS FOR CLASSIFYING LOCALIZATION SCHEME

Pandey & Agrawal (2006) have explored the key factors for classifying localization schemes, shown in Figure 1.8.
Figure 1.8 Factors Classifying Localization
1.5.1 Area of Deployment

The area of deployment is predominantly different due to the differences in network topology, number of users and available resources for wireless networks. Depending on the deployment area and types of network, the localization scheme is classified into wide area localization, local area localization and ad hoc localization.

- **Wide Area Localization (WAL):** This is characterized by predominantly outdoor deployment, expensive long-range Localization Base Station (LBS) and no power constraint at the LBS. Usually Global Positioning System (GPS) is used to localize the nodes for WAL.

- **Local Area Localization (LAL):** This is characterized by predominantly indoor implementation throughout an enterprise or commercial establishment and lower area of coverage as compared to a wide area network.

- **Ad hoc Localization (AHL):** Ad hoc/sensor networks are power constrained and may be heterogeneous in nature. The algorithmic requirements of AHL are low power consumption, lower computation and communication costs. In WSN, usually node locations are determined relative to location of reference nodes called “anchor nodes”. The anchor nodes may be mobile (Corke et al 2003), (Sichitiu & Ramadurai 2004) or stationary (He et al 2003), (Lazos & Poovendran 2004). For AHL, sensor nodes such as (Crossbow Technology Inc., 1999, Smart Dust, 2005) or tags such as (Hightower et al 2001), (Hightower et al 2000) correspond to the Localization Node (LN) while the anchor node corresponds to the LBS.
1.5.2 The Physical Layer

The Physical layer specifications considered are operating frequency, bandwidth, modulation technique, transmission power level and antenna diversity. The frequency spectrum, over which the localization scheme is deployed, directly influences its performance. Various localization techniques are based on different physical spectrum such as Infrared (IR) (Want et al 1992), Ultrasound (US) (Priyantha et al 2000), (Ward et al 1997), (Savvides et al 2001), (Dutta & Bergbrieter 2003), (Whitehouse 2002) and Radio Frequency (RF) (Guard 1996), (Bahl & Padmanabhan 2000), (Caffrey & Stber 1998).

- **Infrared (IR):** Active Badge (Want et al 1992), one of the earliest localization schemes, used IR. In this case, LN would be an IR badge that would periodically transmit unique ID. IR is limited to line of sight transmission; each room has an IR receiver which would relay the received IDs to a central server. The server then maps LN’s location to the corresponding room. The localization schemes based on IR usually have lower accuracy and are affected by sunlight. Also, it is not scalable for large deployment areas. Hence, IR is rarely used for localization.

- **Ultrasound (US):** US are used for localization and these signals can propagate through the walls and Time of Arrival (ToA) can be accurately measured using existing inexpensive devices. ToA provides more robust location estimate as compared to Signal Strength measurements and is generally adopted for US. In Cricket (Priyantha et al 2000), LN uses ToA of US signals from various LBS to estimate its location.
As RF travels much faster than US, an RF signal is used by LBS to indicate the start of US transmission in Cricket. An LN measures the time difference between the reception of RF and US signals from LBS. This difference is the ToA for US signals from LBS to LN. Using the LBS location information (broadcasted in the initial RF transmission), LN estimates its location using US ToA from different LBSs.

- **Radio Frequency (RF):** RF is commonly used by most communication networks. As integrated location estimation systems are less expensive than their dedicated counterparts, localization based on this underlying RF technology of communication network, lowers deployment cost. The RF localization uses Received Signal Strength (RSS) measurements (e.g., RADAR; Bahl & Padmanabhan 2000) or ToA (e.g., GPS). RF makes use of the RSS (Mao et al 2007) to measure distance between nodes. RF signals are deeply affected by the environment either due to the presence of obstacles or to the multipath phenomenon. Also, the heterogeneity of the channel depends on the propagation model, cannot be ignored. The propagation model used is Two-ray ground reflection model (Rappaport 2001) considers both the direct path and a ground reflection path. It is shown that this model gives more accurate prediction at a long distance than the free space model. The received power $P_r$ at distance $d$ is predicted by

$$p_r(d) = P_t G_t G_r h_t^2 h_r^2 / d^4 L$$  \hspace{1cm} (1.1)
where $P_t$ is the transmitted signal power and $G_t$ and $G_r$ are the gains of the transmitter and receiver, respectively. $L$ is the system loss and $h_r$ and $h_t$ are the height of the transmitter and receiver, respectively.

### 1.5.3 Parameters

Various localization schemes use different parameters such as Received Signal Strength (RSS), Time of Arrival (ToA), Connectivity and Angle of Arrival (AoA).

- **Received Signal Strength (RSS):** RSS is measured by monitoring the received signals from a wireless interface. RSS is preferred for low-cost simple localization. Theoretically, the RSS is inversely proportional (Rappaport 2001) to squared distance and known radio propagation model can be used to convert the RSS into distance. The main advantage is its low cost, because most receivers are capable of estimating the RSS.

- **Time of Arrival (ToA) / Time Difference of Arrival (TDoA):** The distance between two nodes is directly proportional to the time the signal takes to propagate from one point to another is ToA. TDoA is based on the difference in the times at which a single signal from a single node arrives at three or more nodes or the difference in the times at which multiple signals from a single node arrive at another node.

- **Connectivity:** Connectivity indicates that LN is within the transmission range of LBS. The location of the LN may be estimated based on its connectivity to LBSs by finding the region where the transmission ranges of these LBSs overlap.
This method incurs minimal processing/communication overhead but results in lower localization accuracy compared to that of other schemes. It is proposed for ad hoc/sensor networks where light weight, energy-efficient protocols are used for localization (Shang et al 2003), (Doherty & El Ghaoui 2001).

- **Angle of Arrival (AoA):** The estimation of the AoA is done by using directive antennas or an array of receiver, usually three or more that are uniformly separated. Based on the arrival times of the signal at each of the receivers, it becomes possible to estimate the AoA of this signal.

### 1.5.4 Localizing Entity

The location estimation process can be carried out by the client device (LN) or by the network (comprising the several LBS).

- **Client:** For the client-based localization, the client (LN) itself determines its location by monitoring signals from different LBSs. In this case, the LBS act as a beaconing device which may send out time-stamped packets along with its location. The LN measures the parameter of localization (such as SS) for the messages transmitted from different LBSs. It then determines its location by using these measurements and the knowledge of all LBSs locations (available at LN). This scheme is highly desirable where user privacy is an important consideration as the network has no knowledge of the user location.
Network: For network-based localization, the network would determine LN’s location by measuring the parameter of localization for the signals from LN at several LBSs. The location of LN can be determined based on the measured values and the location of the LBS known by the network. This scheme is desirable where the security of localization is an important consideration.

1.5.5 Location Lookup Table (LLT)

The physical parameter values are mapped onto the various locations within the deployment site prior to the actual localization process. The resultant map is stored in a lookup table, LLT. The LLT would contain the statistics (such as mean, median, standard deviation) of the parameter at various locations. Each location may be represented as a row in the LLT.

- Measurement-based LLT: LLT may be constructed and updated in different ways. The most common way to construct an LLT is to measure the parameter at various locations within the deployment site. The parameter values at the remaining locations are interpolated from these measured values. Such map is built in many indoor localization schemes where RSS is the parameter of localization.

- Agent-based LLT: LLT is built using agents without extensive manual measurements. The agents are deployed at various locations and LLT is generated from the readings of these agents. This avoids the laborious task of manual measurement. The agents may be low-cost devices (Krishnan et al 2004) or trusted users within the network (Pandey et al 2005) or desktops with wireless interfaces (Bahl et al 2005).
This scheme is favorable for high initial-cost deployments requiring low maintenance cost such as in enterprise networks.

- **Model-based LLT**: The LLT may also be generated by limited or no actual measurements of the parameter. An analytical/empirical model defining parameter variation with distance may be used to estimate the parameter values at any location. Due to the resource constraint nature of sensor network and dynamic environment of the deployment site, the LLT in AHL are usually based on simple models with predefined parameters.

### 1.5.6 Estimation Technique

The localization scheme may be deployed after generating an LLT. The location of LN is then estimated based on the current measured values of the parameter and the LLT. Using an estimation technique, the physical location in LLT having parameter values “closest” to the current measured values is chosen as the current location of LN. The estimation technique is classified into Deterministic and Probabilistic estimation.

- **Deterministic Estimation**: For deterministic estimation, statistical parameters such as mean (Bahl & Padmanabhan 2000) or median (Li et al 2005) are used for robust estimation. The most commonly used techniques are Multilateration, Trilateration and Least Square Estimation (LSE).

- **Probabilistic Estimation**: LN’s location can thus be estimated based on the distribution of parameters at different locations. In such cases, probabilistic estimation such as
Bayesian estimation techniques is commonly used. The probability distribution function (pdf) of RSS at each of these locations can be chosen as a nonparametric distribution based on the histogram or it may be approximated to a normal distribution (Haeberlen et al 2004).

In this thesis, the factors classifying localization schemes are highlighted in Figure 1.8, which adheres to wide area localization for the area of deployment. The Physical layer specification adopts RF based on the RSS measurement parameter. The localization entity used is Network and Probabilistic estimation technique is used for the location estimation. The basic network assumptions made are that the sensor node is randomly deployed with few percentage of nodes knowing their location using GPS (anchor node), which remain static and rest of the nodes move dynamically obtaining their location through the localization process.

In most WSN nodes are stationary, so localization algorithms are designed specifically to this kind of networks. However, due to the emergence of new applications, algorithms should adapt to the existence of Mobile Nodes (MN). Mobility can help overcome several typical problems, such as: low node density, obstacles, concave topologies, etc. Pazand & McDonald (2007) have dealt about various mobility models such as Random Walk Mobility Model (RWM), Random Waypoint Mobility Model (RWP) and Reference Point Group Mobility Model (RPGM) for node movement.

In RWM, an MN moves from its current location to a new location by randomly choosing a direction and speed in which to travel. The new speed and direction are both chosen from pre-defined ranges, \([\text{speedmin}, \text{speedmax}]\) and \([0, 2\pi]\), respectively. Each movement in the RWM model occurs in either a constant time interval ‘t’ or a constant distance traveled ‘d’, at the end of which a new direction and speed are calculated. If a node which
moves according to this model reaches a simulation boundary, it “bounces” off the simulation border with an angle determined by the incoming direction. The MN then continues along this new path.

The RWP includes pause times between changes in direction and/or speed. An MN begins by staying in one location for a certain period of time (i.e., a pause time). Once this time expires, the mobile node chooses a random destination in the simulation area and a speed that is uniformly distributed between \([\text{minspeed}, \text{maxspeed}]\). The node then travels toward the newly chosen destination at the selected speed. Upon arrival, the node pauses for a specified time period before starting the process again. It is noted that the movement pattern of an MN using the RWP model is similar to the RWM model if pause time is zero.

In RPGM, the movement of the group leader determines the mobility behavior of the entire group. Each node has a speed and direction randomly deviating from that of the group leader. The movement in the group mobility is characterized as follows.

\[
|\vec{v}_{\text{member}}(t)| = |\vec{v}_{\text{leader}}(t)| + \text{random()} \times SDR \times \text{max. speed} \tag{1.2}
\]

\[
\theta_{\text{member}}(t) = \theta_{\text{leader}}(t) + \text{random()} \times ADR \times \text{max. angle} \tag{1.3}
\]

where SDR is the Speed Deviation Ratio and ADR is the Angle Deviation Ratio. SDR and ADR are used to control the deviation of the velocity of group members from that of member.
1.6 OBJECTIVES

- To localize the nodes for accuracy and low power consumption based on RSS.

- To localize cluster of nodes for accuracy and low power consumption.

- To optimize the node location using Bio-inspired algorithms.

- To obtain the improved location accuracy and low power consumption using time-dependent approach.

1.7 MOTIVATION

Based on the type of information required for localization, Range-based RSS approach is used to find the location of non-anchor nodes by calculating their distances from the designated anchor nodes with known positions. The existing problem on localization tries to address the probabilistic method based on particle filter. The particle filter requires continuous updates; increases in the network traffic and power consumption has motivated to propose Learning Movement Model for location estimation.

1.8 RESEARCH CONTRIBUTIONS

The contribution in this thesis is that it proposes new techniques and algorithms to improve the state-of-art localization systems from the point of view of location accuracy and energy consumption. The contribution is summarized as follows:
- Localization of Sensor Nodes using Hidden Markov Model.
- Cluster Localization of Sensor Nodes using Hidden Markov Model.
- Improved Location Accuracy using Bio-Inspired Optimization Algorithm.
- Localization of Sensor nodes using Hidden Semi-Markov Model.

1.9 PERFORMANCE EVALUATION

To evaluate the performance of the algorithms developed in the forthcoming chapters, the performance evaluation is defined as the percentage improvement of algorithm F over another algorithm G in terms of the performance metrics Estimation Error, Control Overhead and Average Energy dissipated and is given by Equation (1.4) as follows.

\[
\text{Percentage improvement} = \left( \frac{\text{LOC}(G) - \text{LOC}(F)}{\text{LOC}(F)} \right) \times 100
\]

(1.4)

where LOC(F) denotes the Localization using algorithm F. LOC(G) denotes the Localization using algorithm G.

1.10 ORGANISATION OF THESIS

Various strategies or techniques are proposed in this thesis to reduce the estimation error and energy consumption for localization. A brief overview of the various works is presented in this section.

Chapter 2 presents the Literature Survey of the existing schemes related to the schemes proposed.
Chapter 3 presents Localization of sensor nodes using Hidden Markov Model (HMM) to obtain reduced estimated error. The performance is compared with the Bayes Particle Filter to improve the accuracy and energy consumption of the localization process.

Chapter 4 presents Cluster Localization of sensor nodes using Hidden Markov Model. The clustering technique used is Coverage Preserving Clustering Protocol (CPCP) and is compared with the existing Low Energy Adaptive Clustering Hierarchy (LEACH) for the cluster localization.

Chapter 5 presents Improved Location accuracy using Bio-Inspired optimization algorithm. Various types of Bio-inspired optimization algorithm are explored to find an optimum location for increasing the location accuracy. Finding the optimum location using hybrid optimization technique improves the accuracy and speed of the localization process.

Chapter 6 presents a time-dependent approach using Hidden Semi-Markov Model (HSMM) to obtain estimation error for sensor node localization and is the extension of the work done in Chapter 3.

Chapter 7 discusses the performance improvement of the various proposed works. Overall summary and suggestions for future scope and improvement is also presented.