CHAPTER 1

INTRODUCTION

The beauty of technology lies in to revolutionize the way we live, work, and interact with the environment around us. Wireless communication is one such technology, which is undergoing rapid advancements with the phenomenal rise of Wireless Sensor Networks (WSNs). WSNs are comprise of randomly distributed, self-configured and autonomous Sensor Nodes (SNs), which are deployed to collect specific event data. WSNs are typically having minimum or no fixed infrastructure as they share common features of wireless ad-hoc networks like the ability to adopt dynamic networks and topologies along with the capability of self-organization without any manual intervention. These features indorse WSNs for such applications where there is no existing network setup or setting up a fixed infrastructure network is considered infeasible. This flexibility of WSNs leads to variety of applications such as habitat monitoring, enemy surveillance, object tracking, structural health monitoring or smart farming to name a few. Even though WSNs has immense potential and promising future, there are big challenges too which need great attention as well. Some well-known challenges include node connectivity, link quality, localization, scalability, security, and energy-efficiency. Out of these, energy-efficiency for WSNs remain a topnotch challenge for researchers around the world as it affects
overall performance of the network despite best design and deployment strategies. In this proposed work, efforts are made to address this foremost concern through energy-efficient routing techniques for WSNs.

1.1 Wireless Sensor Networks (WSNs)

WSNs are capable of collecting, processing, and communicating event data at specific area of deployment with the help of self-configured, autonomous SNs, equipped with limited power and storage capabilities. A group of SNs in a WSN, can collaboratively perform data processing activities to obtain meaningful information from a remote geographical area. A SN sense data through Analogue to Digital Converter (ADC) and process it further for transmission to a central server, known as Base Station (BS) or Sink, where data can be processed for variety of applications (Al-Karaki, 2004). During transmission every node acts as a repeater for passing information of other SNs to the BS. SNs may differ in their functionalities as simple sensors only monitor and transmit data for a physical phenomenon where ever deployed, on the other hand complex SNs may process and aggregate data for better performance of WSNs. SNs also differ in their communication range as more powerful nodes can directly transmit data to BS bypassing all intermediate nodes. The choice of SNs depend on the complexity of application and area of deployment.

The most critical part of the SN is its power supply, which caters to the energy requirements of sensors, processors and transceiver however, its limited battery life can led to premature exhaust of the network due to excessive usage (Akkaya Kemal, 2005). As manual recharging of batteries is not possible in complex deployments, efficient use of the energy becomes a tough challenge in applications where prolong network life is required (Gaura, 2010). Further, some nodes may be installed with Global Positioning System (GPS) receivers for location awareness however, such WSNs often consume lot of energy which is non-viable for low-cost and low-power SNs. A typical WSN scenario is shown in Fig. 1.1, where SNs
1.1 Wireless Sensor Networks (WSNs) are clubbed in small groups known as clusters and each cluster has a leader node called Cluster Head (CH).

All SNs transmit their event data to their respective CH, which forwards it to BS through single or multi-hop wireless communication. Additionally, there are mainly two types of WSNs viz. structured and unstructured (Jennifer Yick, 2008).

An unstructured WSN will contain randomly distributed SNs which are placed in ad-hoc manner on a specific field of operation, e.g., hilly areas, deserts or sea etc. Since there are large number of nodes spread in the field, network maintenance in an unstructured WSN is very difficult. On the contrary, in a structured WSN, all or some of the SNs are deployed in a pre-planned order, hence node management and network maintenance becomes easy.
1.2 Sensor node architecture

SNs are integral part of a WSN, which are responsible for sensing, processing, and transmission of data events. The quality, type, and frequency of the collected data are highly influenced by the physical characteristic of the sensor therefore, the designing of a SN is a critical step. Each SN consists of sensing, processing, transmitting, and power components as shown in Fig. 1.2.

The processor component is the central element of the SN and the type of a processor determines the trade-off between energy consumption and performance. Some type of available processors types are micro-controllers, application-specific integrated circuits, digital signal processors and programmable gateways. The Analog-to-Digital Converter (ADC) converts continuous analog signal of a SN into a digital signal. The digitized and processed data is then transmitted to the BS through CHs, using multi-hop communication.

1.3 Communication standards in WSNs

IEEE 802.11 set of standards are most widely accepted wireless standards for mobile communication, which employs number of frequency channels like, the 2.4-GHz channel is adopted by IEEE 802.11b and IEEE 802.11g protocols, while the
IEEE 802.11a make use of the 5-GHz frequency channel. WSNs also incorporated IEEE 802.11 standards in early communication and can still be used in current networks when bandwidth requirements are very high as in case of multimedia sensors. However, the energy overhead and communication trade-off of IEEE 802.11 based networks makes this protocol undesirable for low-power WSNs. This has led to the development of IEEE 802.15.4 protocol which cater to the needs of low power devices and low data rate channels thus specifically designed for short range communications of low-power SNs. Now a days, this standard is accepted for most of the academic and commercial projects of WSNs.

1.4 Applications of WSNs

Many applications of WSNs has touched day to day activities of humans, some of them are highly advance, while majority of them are very common. The multifariousness of applications in this field is noteworthy and few of them are discussed here as (Jennifer Yick, 2008):

1. **Health Care Management**: One of the foremost application of WSNs include health care applications which include monitoring patients with diseases like parkinson, epilepsy, patient rehabilitation as well as handling critical illness. Some health care applications cannot function as self-supportive systems instead, they require a wide-variety of complex health support and rescue tools. The researchers around the world are particularly active in developing next generation ready to wear wireless sensors which can seamlessly monitor heart beat, pulse rate, oxygen inflow, blood circulation, respiratory rate, and muscle movements to name a few.

2. **Precision Agriculture**: One another area where WSNs drive attention is precision agriculture, which is a type of farming practice that make farmers to produce more expeditiously through economical use of technological resources. This include variety of measurers, such as micro level monitoring
of soil, crop diversification, climate movements in a farm field etc. and prepare a Decision Support System (DSS) to make precise decisions. Some of precision agriculture tools are:

(a) **Yield monitors:** WSNs that use humidity sensors, temperature sensors, and a GPS devise to monitor crop yield at different intervals of time. SNs capture weight or volume of grain, separator movement, ground health, soil moisture, and corp height.

(b) **Yield quality:** SNs having number of GPS devices fitted with yield monitors to calculate spatial coordinates for the corp yield.

(c) **Fertilizer management:** SNs manages the flow and quantity of liquid and gaseous fertilizer on corps.

(d) **Weed checking:** SNs can help farmer to check weeds along with seeding, spraying, or field searching.

(e) **Alternate spraying:** SNs will detect weed positions, and implement instant control mechanisms by altering the amount of herbicide applied.

3. **Traffic Control:** Now a days, volume of SNs are deployed in traffic management worldwide which include video capturing SNs, sonar or radar based SNs, magneto-meters, micro-loop probe sensors, pneumatic road tube sensors, piezoelectric wires and pneumatic treadle sensors. Video and sonar-based SNs need to be fixed on high poles, whereas magneto-meters and pneumatic treadles can be installed on the existing transportation base. WSNs are used to fully automate congestion recognition in which, self-configured camera-based devices are used to count and categorise vehicles. SNs keep an eye on the license numbers of all vehicles and relate their driving history as a proof of establishing congestion causes but at the time of fog, smog, dust, snow, or rain, roadside cameras became treacherous.

4. **Active Volcano Monitoring:** Monitoring of active volcanoes is another application for WSNs. Researchers use seismic and acoustic sensors to collect
1.5 Design challenges and constraints in WSNs

and study the behaviour of active volcanoes by analysing seismic and infrasonic signals. A considerable number of small, inexpensive, and autonomous SNs can be deployed to cover a large geographical field, in contrast to the expensive and bulky devices presently used. Moreover, the deployment of WSNs is quick and economical which do not require regular maintenance routines.

5. Military Operations: WSNs can be an integral part of military control and communication command which include computing, intelligence gathering, surveillance activities, reconnaissance, and targeting applications. The deployment of SNs near the international borders to observe and monitor enemy movements is one of the major applications where WSNs are very effective and safe. WSNs require almost no or minimal manual configurations therefore, highly suitable for such applications.

6. Habitant Monitoring: To preserve wild life, tracking of rare species is a tough task, which can be carried out with the help of WSNs. Habitants suitability monitoring is easily possible for growth of the species under supervision in forestry area.

7. Environment Checkups: WSNs are being deployed to monitor environmental change due to increasing pollution level or green house effect in adverse conditions /areas where stay of human beings is extremely difficult.

8. Structural Health Monitoring: It is one of the latest application area of WSNs, where monitoring of structural health of new/old buildings and big structures are being done using SNs.

1.5 Design challenges and constraints in WSNs

WSNs has many common attributes with other wireless networks, but it face variety of challenges and lot of constraints which influence the architecture of
protocols that differ from their counterparts in other wireless systems. Here, some of the most vital design challenges and constraints of WSNs are presented:

1. **Energy-efficiency:** The most crucial aspect in WSNs is the limited power supply of SNs, which affect the overall life of the network as SNs operate with limited battery power. Typically, SNs are backed by external power batteries, which can be either replaced with new one or recharged manually, when exhausted. As in most of the scenarios, manual intervention is not possible after deployment of SNs, neither option is appropriate. Ultimately, they need to be simply discarded once their energy source is depleted. Thus, energy management is very vital for efficient and prolong working of the WSN. Therefore, energy-efficiency become the first and foremost design challenge for a WSN, which adversely affects the overall performance of the network. Moreover, mechanism adopted at the physical layer of a SN can influence the energy consumption of the entire device and also the designing of upper-level protocols. Designing of energy-efficient routing protocols are one of the effective solution for better energy management in WSNs.

2. **Ad-hoc Deployment:** Majority of WSNs applications do not require predetermined infrastructure support and prior location awareness of individual SNs. This is primarily very significant for networks which are deployed in far remote or unapproachable geographical areas where manual interaction is almost impossible. Therefore, the SNs must automatically perform a variety of set-up and pre-configuration steps, including prerequisite communication with neighboring SNs, finding their location, and initialization of other vital parameters which are necessary to operationalise the entire network.

3. **Self-management:** After deployment all WSNs, must function without any external interference therefore, network management and topology control must be carried out in self-configuration manner. Such networks need to supervise its surroundings, be adaptive to frequent changes in the physical environment, and must collaborate with other neighboring devices as well. Moreover, in WSNs the quality of self-healing allows SNs to detect, recognize,
and respond to link failures while self-optimization helps to analyse and optimize the use of their own network resources efficiently. Therefore, in energy-constrained WSNs all such characteristics must be incorporated in such a way that it cannot lead to unreasonable energy expenses.

4. **Hardware Issues:** Due to limited computational capabilities and small memory space, SNs are not capable to process large amount of data at a time, which add to low efficiency of the network. In WSNs, communication delay can also be high due to sharing of limited communication channels by all SNs within each other’s transmission range. Hardware needs also influence the designing and implementation of routing protocols used for network operations. Further, data aggregation algorithms require high computational and memory therefore, software design and solution must be implemented to operate efficiently on resource-restricted hardware of WSNs.

5. **Security:** Many applications in WSNs collect vital and sensitive data. This inaccessible and unattended task of SNs will enhance their vulnerability to malicious invasion and attacks. Moreover, due to wireless communication it become too easy for an intruder to penetrate into sensor data. A Denial-of-Service (DoS) or Distributed Denial-of-Service (DDoS) attack, is one of the most crucial security threats, whose aim is to interrupt the operations of a WSN by sending malicious data to legitimate destination. The concerns of these attacks can be very serious and depend on the type and potential of application. While there are many mechanisms to prevent or reduce the impact of such attacks, many of them require advance processing and adequate memory which is often an unaffordable thing for WSNs.

6. **Scalability:** Some of the applications in WSNs require deployment of hundreds or thousands of SNs to be spread over a wide geographical area, which require efficient mechanisms to be employed for smooth operation of the network for long duration. It require sophisticated hardware and complex algorithms that can work in diverse environments. Moreover, the routing
protocols designed and implemented for WSNs should be able to manage these largely deployed SNs efficiently.

7. Quality of Service: Real time WSNs application require delivery of data events within a certain period of time from the moment it is captured at any location of deployment, otherwise the data may become unusable. Accuracy and integrity of the data are other quality of service parameters that cannot be ignored in some real time applications.

8. Production Costs: As WSNs contain hundred or thousands of SNs, the operational cost of a single node unit is very vital to accumulate the overall cost of the network. If the overall cost of the network deployment become expensive then some application specific WSNs will not be cost justified. As a result, the design and operational cost of each SN has to be kept low. Furthermore, a SN may also carry some extra components like a GPS devise for location awareness, or a mobilizer depending on the need of the application of WSNs. These all components will add extra cost to the sensor devices, therefore, the overall cost of a SN is a another very crucial issue against its set of functionalities.

1.6 Energy consumption in WSNs

There are numerous reasons for dissipation of energy in a WSN, which need to be investigated for better understanding of the problem domain.

1. Data processing, transmitting and receiving: SNs dissipate major part of their available energy in data processing, transmitting and receiving activities. This energy is very much essential for correct working of the WSN and its consumption depend on the relevance and complexity of the application for which a SN is being deployed.

2. Idle listening: As a SN may not be aware exactly when it will receive a data event, it must continuously listen to its surroundings therefore, it
remains in the idle state for long time even in the absence of the event, thus consumes energy. It is observed that energy consumed in the idle state is approximately close to the power consumed in receiving state.

3. **Over listening:** When a SN broadcast one data packet to next hop, all nearby neighbors of the source receive this packet even if it is intended to only one of them. Thus over listening is the cause of energy dissipation when a SN is just an one-hop neighbor of the sender and is not the final destination.

4. **Interference:** Due to interference of channels, considerable amount of energy is dissipated which do not count for any meaningful purpose and is just a overhead to the network and affects its operational efficiency.

5. **Collision:** In case of medium access control protocols used in WSNs, if a collision occurs among data events generated by SNs, the energy consumed during transmission and for the reception of colliding frames is completely wasted.

The above mentioned reasons point toward the energy constrained nature of WSNs and requires the use of energy-efficient mechanisms to minimize the energy wastage in all these affairs to prolong network lifetime. In the next section, some potential techniques are discussed for minimizing energy consumption and improving network lifetime of WSNs.

### 1.7 Energy management techniques for WSNs

Due to energy constrained nature of WSNs, it is very significant to use energy efficiently. Many researches address this issue by proposing various energy-efficient mechanisms, some of them are discussed below:

1. **Energy-efficient routing:** Designing energy-efficient routing protocols are one of the foremost energy management techniques adopted by researches
as top priority solutions for energy constrained WSNs. Its goal is to minimize the energy consumed by the end-to-end transmission of a data packet without compromising its accuracy, through optimal routing schemes for WSNs. But there exist some unavoidable challenges too, as most of the routing mechanisms require each SN to communicate data among its neighbors. The amount of data to be communicated will differ depending on the routing approach and application needs. In such conditions, SNs consume energy in communicating data through the wireless channel, which increases the communication overhead of the network. Thus, to enhance the energy-efficiency of the routing protocols, local data exchange among SNs should be minimized without affecting the routing goals. Secondly, in WSNs it is assumed that computation cost is much lower than communication cost in terms of energy consumption. Therefore, the biggest challenge is to integrate computation cost with routing schemes to improve energy-efficiency of the network.

2. **Node activity scheduling:** Other energy management technique for WSNs is the idea of scheduling SNs activity by alternating its states between sleeping mode and active mode to minimize energy consumption while ensuring the network and application functionalities. By scheduling the SN states, lot of energy can be saved during its idle listening period. Unfortunately, as manual intervention is not possible after deployment of SNs, node scheduling require self-organise mechanisms and efficient routing strategies.

3. **Reducing voluminous data:** By reducing the volume of data transferred between SNs, lot of energy can be saved, which include aggregating data at CHs and optimizing the broadcasting of messages throughout the network. Aggregation plays a significant role by eliminating the redundant data in the network, thus reduces energy consumption in WSNs. Appropriate data aggregation algorithms need to be developed for efficient data integration without the loss of information.
4. **Minimizing interference and congestion in the network:** Channel interference and data congestion also pose a big challenge to energy starved WSNs, thus effective mechanisms needs to be developed to minimise channel interference with better traffic management schemes.

### 1.8 Motivation of work

With the above discussions, energy-efficiency has been seen as one the key issue in WSNs, which may influence the overall performance of the network, therefore, to design an energy-efficient routing protocol is a prime concern for WSNs. A robust energy-efficient routing protocol can prolong the network life by employing energy aware routing algorithms and appropriate energy saving techniques. Further, energy-efficient routing is considered to be a NP-hard optimization problem and nature inspired Computational Intelligence (CI) based metaheuristic need to be explored for effective solutions. Having characteristics like adaptation, high computational speed, versatility, self learning and self organization, CI based metaheuristic are most sought and found suitable for dynamic WSNs. Nature inspired Swarm Intelligence (SI) is one branch of CI which is most explored and employed for number of multi-modal optimization problems in various domains. Many researchers has already presented SI based optimization solutions for localization, node deployment, data aggregation and even for energy-efficient routing in WSNs.

As every work need further improvement with better replacement, this motivates the idea to present an energy-efficient routing protocol based on nature inspired metaheuristic for WSNs. In general, through this work an attempt has been made to minimize the energy consumption of WSNs to improve the network lifetime by proposing an energy-efficient routing protocol based on nature inspired metaheuristic.
1.9 Objectives of the work

The objectives of the proposed work are as follows:

1. To review various existing routing mechanisms and classify existing routing protocols for WSNs.

2. To propose an energy-efficient routing protocol for WSNs based on nature inspired metaheuristic.

3. To implement the proposed routing protocol, LEACH, MRP, ERP and PSO for WSNs.

4. To compare and analyse the performance of proposed routing protocol with LEACH, MRP, ERP and PSO based on Energy consumption, Throughput, Average latency rate, Packet delivery ratio, Packet loss ratio, Energy-efficiency and Network lifetime.

1.10 Organization of the thesis

Rest of the dissertation is structured into following chapters:

1. **Chapter 2:** presents a brief overview of the various routing mechanisms and classification of existing routing protocols, highlighting their key features and limitations. This study helps to understand the basics of routing mechanisms in WSNs and provide an opportunity to experience the behaviour of well known existing routing protocols.

2. **Chapter 3:** presents a nature inspired improved Artificial Bee Colony (iABC) metaheuristic which uses Students-t distribution, a compact probability density function (cPDF) from the family of Estimation of Distribution Algorithms (EDAs). This cPDF is employed first time in population based
metaheuristic for better sampling and requires only one control parameter to be stored on memory thus consumes minimum energy. Further, an improved solution search equation named $ABC/rand-to-opt/1$ is proposed, which educes an optimal solution from the current best solutions thus improve convergence rate of the proposed metaheuristic.

3. **Chapter 4**: presents BeeSwarm, an energy-efficient hierarchical routing protocol, based on proposed nature inspired $iABC$ metaheuristic for WSNs. The proposed routing protocol is based on three phases namely 1). BeeCluster- set-up phase, 2). BeeSearch- route discovery phase and finally 3). BeeCarrier- data transmission phase. Further, the detail working structure of this proposed protocol is discussed in this chapter.

4. **Chapter 5**: presents extensive evaluation of the proposed protocol along with other set of existing routing protocol based on various performance metric. This evaluation helps to understand various aspects of the proposed protocol in comparison to its existing peers.

5. **Chapter 6**: finally concludes this dissertation work and provides directions for further research.