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Average Load Distance (ALD) radio communication model for wireless sensor networks

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Average Load Distance (ALD) Radio Communication Model for Wireless Sensor Networks

by

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ABSTRACT

The lifetime of network is one of the most critical issues that have to be considered in the application of wireless sensor networks. The network nodes are battery powered and remain operational as long as they can transmit the sensed data to the processing (sink) node. The main energy consumption of sensor node can be attributed to the task of data transmission to sink node or cluster head. Hence, conserving energy in transmitting data shall maximize functional life of the wireless networks. In this paper we proposed a computationally efficient Average Load Distance (ALD) communication model for forwarding data from sensor to the cluster head. Experiment results indicate that the proposed model can be up to 88% more efficient over direct mode of communication, in respect of per-round maximum energy consumption. An application study shows that ALD can save up to 89% of wireless sensor networks operational cost when compared to direct mode transmission.

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LIST OF ABBREVIATIONS

ADC: Analog to Digital Converter

AFN: Aggregation and Forward Node

ALD: Average Load Distance

APM: Acoustic Plate Mode

APTEEN: Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network

ASIC: Application-Specific Integrated Circuit

BS: Base Station

CDMA: Coded Division Multiple Access

COTS : Commercially off-the-self

CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance

DARPA : Defense Advanced Research Projects Agency

DSSS: Direct Sequence Spread Spectrum

EBC: Energy Balanced Chain

FHSS: Frequency Hopping Spread Spectrum

FPW: Flexural Plate Wave

GPS: Global Positioning System

IEEE: Institute of Electrical and Electronics Engineers

ISM: Industrial Scientific and Medical

LAN: Local Area Networks

LEACH: Low Energy Adaptive Clustering Hierarchy

MAC: Medium Access Control

MEMS: Micro- Electromechanical System

MINLP: Mixed Integer Non-linear Problem

NCAP: Network Capable Application Process

NIST: National Institute of Standards and Technology

PAN: Personal Area Networks

PEGASIS: Power-Efficient Gathering in Sensor Information System

RN: Relay Node

SAW: Surface Acoustic Wave

SCADDS: Scalable Coordination Architectures for Deeply Distributed Systems

SNR: Signal to Nose Ratio

SPIN: Sensor Protocols for Information via Negotiation

SPINDS: Smart Pairing and Intelligent Disc Search

SPRING : Sensor Placement and Role Assignment for energy-efficient Information Gathering

STIM: Smart Transducer Interface Module

TEDS: Transducer Electronic Data Sheet

TEEN: Threshold-sensitive Energy Efficient sensor Network

TSM: Thickness Shear Mode

UC: University of California

USC/IS : University of Southern California's Information Sciences Institute

WINS NG : Wireless Integrated Network Sensor – Next Generation

WLAN: Wireless Local Area Networks

WPAN: Wireless Personal Area Networks

WSN : Wireless Sensor Network

ZC: ZigBee Coordinator

ZDO: ZigBee Device Object

ZED: ZigBee End Device

CHAPTER 1
INTRODUCTION

General overview

Wireless sensor networks (WSNs) are composed of large number of tiny and relatively inexpensive equipment, called sensor nodes. These nodes are linked wirelessly to perform the tasks of monitoring, controlling and providing the user with necessary information about events of interest. This is a new paradigm in wireless technology, and drawing significant attention from diverse areas of engineering. WSNs are a new application of ad-hoc wireless networks for high-quality monitoring of large geographical areas. This kind of network is required, where a communication infra-structure do not exist and the environment is hostile and dangerous while it is necessary to monitor the activities of the area to timely prepare for (or react to) possible events [22]. Wireless sensor network differs from traditional wireless ad-hoc networks [5]. In a traditional ad-hoc network, global identification schemes for the nodes are usually implemented. The sensor network involves deployment of a large number of small sensor nodes over an area to be monitored. This makes it impractical to build global addressing scheme for such huge volume of sensor nodes [33]. It implied that the classical IP-based protocol is not appropriate for sensor networks.

In a typical sensor network, sensors are some nodes with a desired sensing functionality in the close vicinity or inside the phenomenon to be measured or monitored. Generally there are two ways to deploy such networks: a) deterministic and b) stochastic fashion. The nodes of WSNs are usually battery powered and due to the size and cost constraints the built-in energy capacity of the sensor node is limited. A typical sensor network is shown in Figure1.1 (redrawn from [18]). Physical representation of such a network is shown in Figure 1.2 (redrawn form [23])

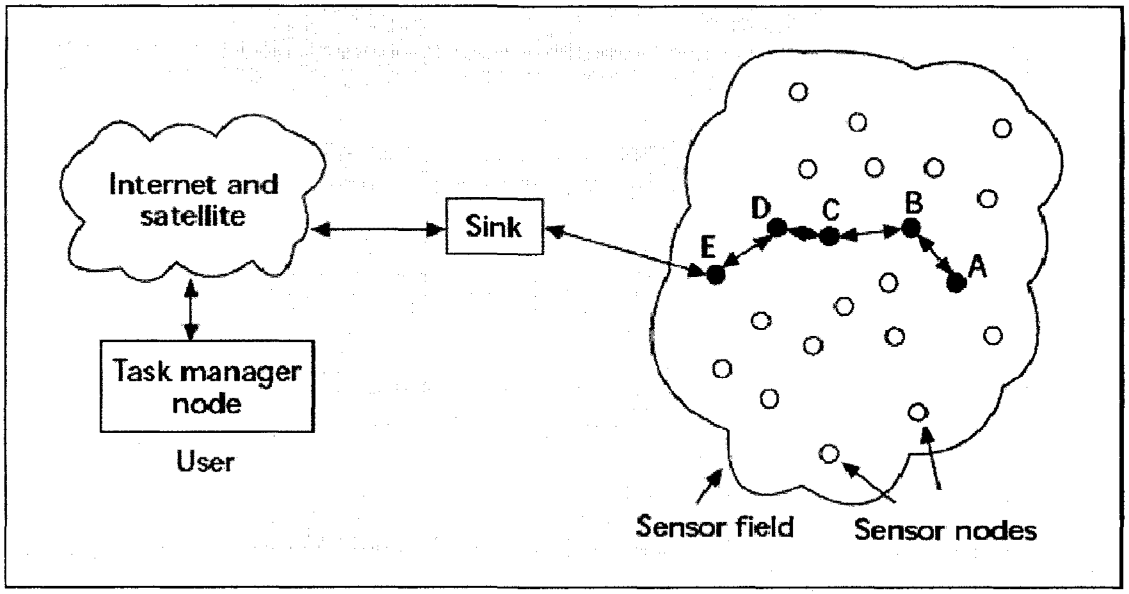


Figure 1.1: Typical Sensor Network

Sensor networks aim to provide an efficient and effective bridge between physical and computational world [20]. Distributed sensor networks, designed to monitor and/or control the surrounding environmental phenomena, have the potential to revolutionize many applications [25]. This kind of networks may be able to monitor a wide variety of ambient conditions that include temperature, humidity, vehicular movement, lightning condition, pressure, soil makeup, noise levels, the presence or absence of certain kinds of objects, mechanical stress levels on to which they are attached objects, and the current characteristics such as speed, direction and size of an object [1].

Some of the commercial applications of WSNs are: monitoring material fatigue, managing inventory, monitoring product quality, constructing smart office spaces, environmental control in office buildings, robot control and guidance in automatic manufacturing environments, factory process control and automation, monitoring disaster area, smart structures with sensor nodes embedded inside, machine diagnosis, radiation level monitoring of nuclear plant factory instrumentation, detecting and monitoring car thefts, vehicle tracking and detection [1, 2].

Sensor nodes can also be used for continuous sensing, event detection and identification, location sensing, and local control of actuators. The concept of micro-sensing and wireless connection of these nodes looks promising for many new application areas.

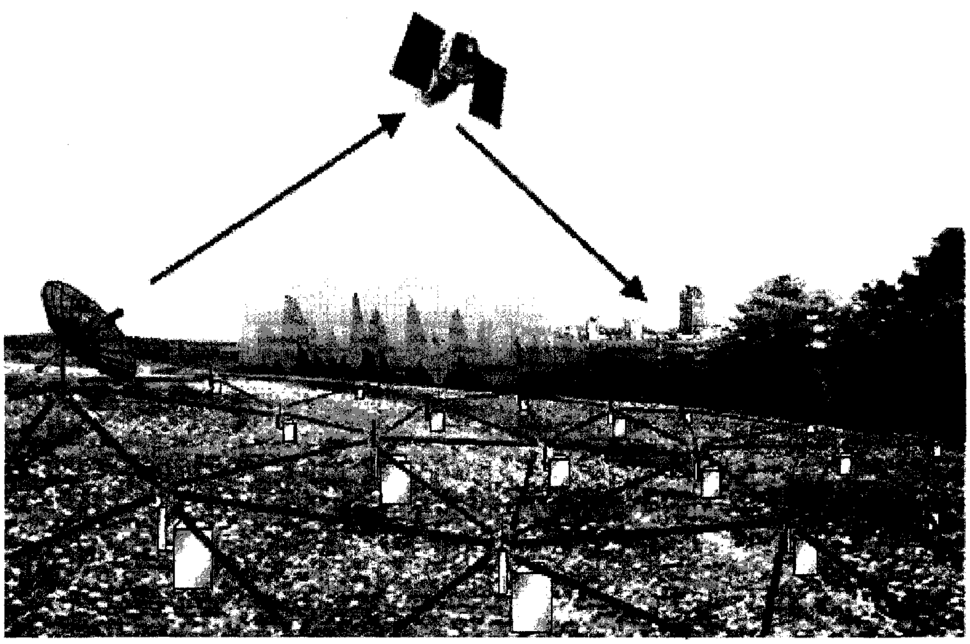


Figure 1.2: Physical representation of Wireless sensor network

The sensor nodes in a sensor network are usually resource-constrained, which means they have limited energy, limited processing and memory capabilities. These nodes are expected to operate in an unattended manner with the help of lightweight batteries, which are not feasible to be replaced or recharged. Therefore, the life of a sensor network is usually defined by the time interval between which a certain amount of critical nodes runs out of their battery power. A great deal of research has focused on the energy conservation in sensor networks so that the lifetime of a network is maximized. The main power consumptions in a sensor node is for the data forwarding tasks, which increases with the increment of (a) the amount of data to be transmitted and (b) the distance between the transmitter and the receiver.

1.2 Performance Metrics

To design good wireless sensor network, it is important to consider the following parameters –

Energy Efficiency/system life time: - The protocols of sensor network must be energy efficient, because the nodes of the network are battery operated. It may be inconvenient or impossible to recharge the node batteries to prolong the life time of networks. The system life time can be measured by the application directed metrics, such as when the network fails to provide the application with desired information about the monitored environment.

Latency: - Data from sensor networks are typically time sensitive. In general, an observer is interested in knowing the events within given time delay. The sensitivity of delay depends on the application.

Accuracy: - The primary objective of the observer and/or end user is to obtain accurate information. The tolerances of the required accuracy can vary from application to application. There is a trade-off between accuracy, latency and energy efficiency. The deployed network should able to be adjusted with different conditions to achieve the desired accuracy and delay with minimum energy expenditure.

Fault tolerance: - The fault tolerance is the ability to sustain sensor network functionality without any interruption due to sensor node failure [18]. A sensor fails when its energy exhausted or due to its surrounding physical conditions. As it is difficult to replace the faulty node, the network must be designed so that any non-catastrophic failures are hidden from the application.

Scalability: - Scalability is also a critical factor need to consider in design of wireless sensor networks. Depending on the application, the number of sensor nodes deployed may be in the order of hundreds or thousands or even more. The protocols need to be scalable to handle a large number or densely deployed nodes so that the increase in the number of nodes does not affect the dependability of the networks.

1.3 Sensor Nodes

A sensor node is the basic element of WSNs. It is also known as smart dust. Recent technological advances in the field of micro-electromechanical systems (MEMS) and in wireless communications have fostered the development of technically and economically feasible tiny multi-functional sensor nodes.

The core of the sensor node is small, low-cost and low power computer. Computer monitors one or more sensors of acoustic, seismic, image, magnetic, temperature, light, position, acceleration, stress, weight, pressure, humidity and other functionality of interest. The computer connects to the outside world with a radio link. Figure 1.3 [49] has shown the interaction of computer with the sensor and radio. All these components including its run-off battery are packaged in a smallest possible container.

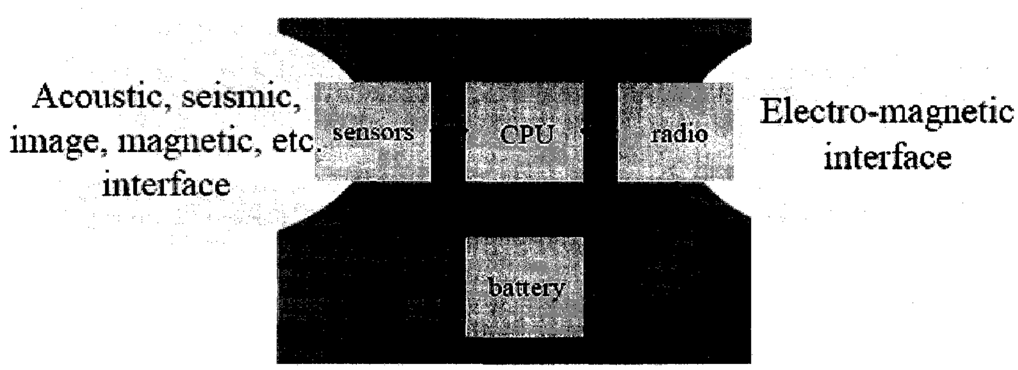


Figure 1.3: Interaction of mote computer

At present considerable research programs are progressing on development of sensor nodes. Some available products are: UC Berkeley motes, Sensoria WINS NG nodes, MIT μAMPS -1 and II node, and PC –v104 based nodes [32].

The motes come in two form factors: - a rectangular of size 2.5 $\times$1.25 $\times$ 0.25 inches (5.7 $\times$ 3.18 $\times$ 0.64 cm); and circular of size 1.0 $\times$ 0.25 in (2.5 $\times$ 0.64 centimeters). The MICA mote uses Atmel Atmega 128L processor running at 4MHz. The radio range of mote is several hundred feet and can transmit 40,000 bits/sec. When transmitting, mote consumes 25 milliamps, and during receiving it consumes 10 milliamps [34]. The software of mote built on TinyOS operating system [34]. TinyOS is a small, open source, component-based operating system developed at UC Berkeley [39]. A dot mote is shown in Figure 1.4 (redrawn from [19]). The newest Spec mote is shown in Figure 1.5 (redrawn form [68]). The design goal of smart dust is to build a self contained, millimeter-scale sensing, and communication platform for a massive distributed sensor network [32].

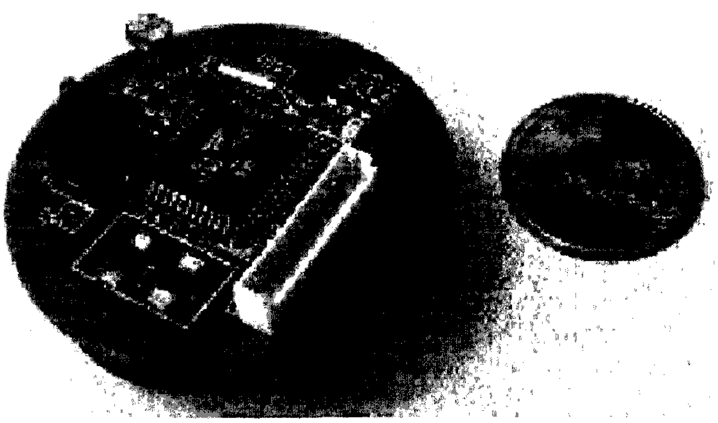
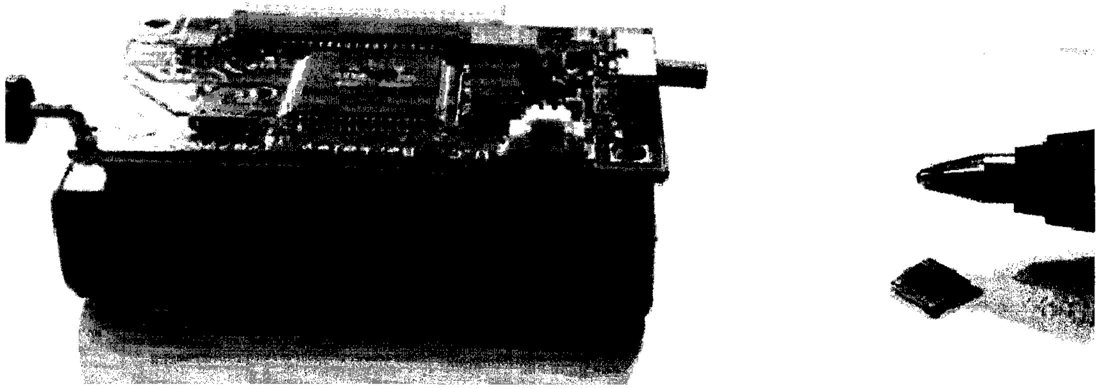


Figure 1.4: Dot type Berkeley Mote alongside a U.S Penny



(a) *(b)*

(a) Broad view of "Spec" sitting on top of the previous generation of UC Berkeley Motes, the Mica node. "Spec" is the tiny little square on top of the raised bit in the middle. (b) "Spec" pictured beside the tip of a ballpoint pen

Figure 1.5: Spec type UCBerkeley Mote

Tmote sky is the next generation mote platform with extremely low power, high data rate. It is designed with dual goal of fault tolerance and development ease. Tmote sky uses 250 kbps 2.4 GHz IEEE 802.15.4 Chipcon Radio. It has 8MHZ TI MSP430 microcontroller with 10kB RAM. The humidity and temperature sensor are integrated with Tmote sky [40].

Sensoria Corporation developed WINS NG 2.0 platform for the DARPA/ITO Sensor Information Technology (SensIT) program. WINS NG (Wireless Integrated Network Sensors – Next Generation) [35, 36] is a Linux-based embedded computing platform with several interfaces to externally connect sensors, wireless extension cards and serial port devices if needed. Figure 1.6 (redrawn from [32, 36]) shows a WINS NG sensor node. The platform of this node is designed for modular operation, which facilitate independent operation of each block to maximize the utility and energy efficiency. The node use Hitachi SH-4 , 32 bit RISC processor. It is designed for 4 analog input channels and 15 configurable digital input/output lines.

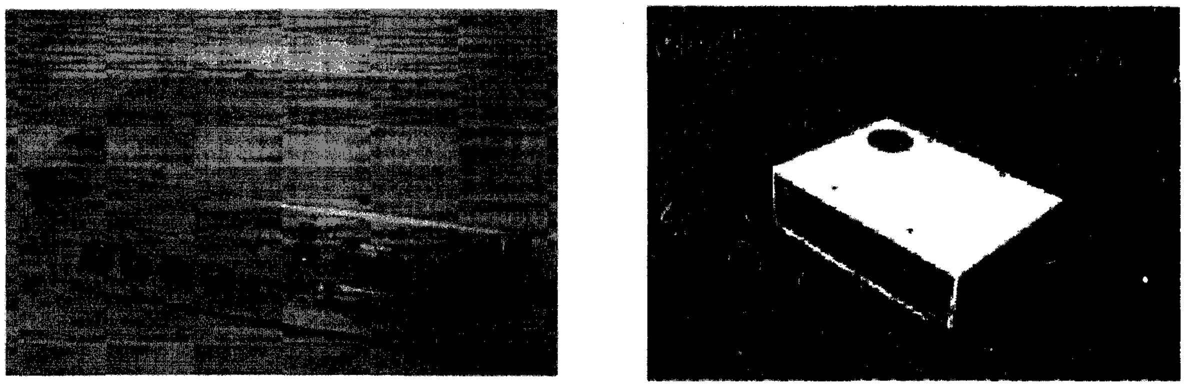
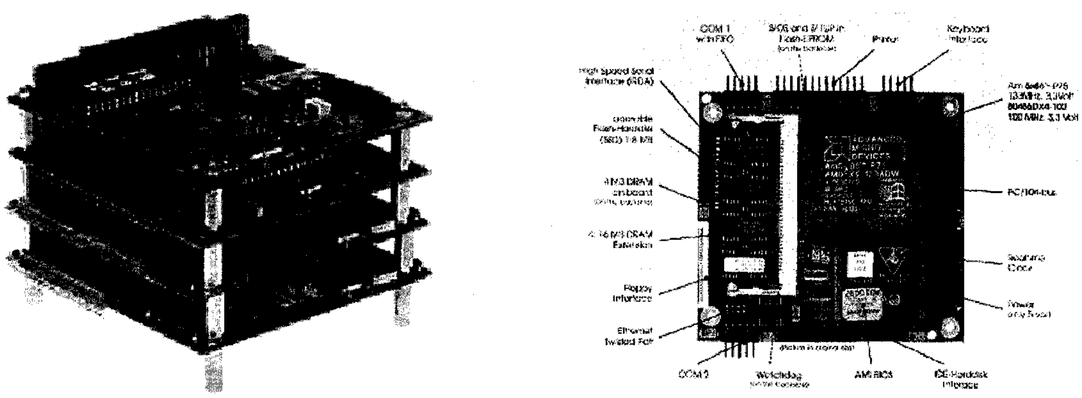


Figure 1.6: WINS NG 2.0 sensor node

PC–104 based node is an industry standard of PC-compatible modules that can be staked. The PC-104 is very similar to PC but has different form factor, about 4" X 4". PC-104 nodes are designed for minimal power consumption, small foot-print, modularity, expandability, and ruggedness. These types of systems are often found in factories, laboratories, and machinery to provide programmable control of a complex system [38]. The nodes can be custom-built with chosen processor, memory configuration, and hard disk.



(a) (b)

(a) PC – 104 based sensor node. (b) Typical PC-104 module

Figure 1.7: PC-104 Node and Module

Figure 1.7 (redrawn form [32]) shows a PC-104 based sensor node. The Scalable Coordination Architectures for Deeply Distributed Systems (SCADDS) research project at University of Southern California's Information Sciences Institute (USC/IS), sponsored by Defense Advanced Research Projects Agency (DARPA) under the Sensor Information Technology (SenIT) program, has used 30 nodes of PC -104 based products [37].

MIT -μAMPS (μ-Adaptive Multi-domain Power-aware Sensors) project goal is to develop a framework for implementing adaptive energy aware distributed microsensors. In the first step of project they developed hardware that satisfy the goal of energy efficiency and flexibility. They have created μAMPS version-1 node using commercially off-the-self (COTS) components. In the next step they have undertaken the design of μAMPS version-2 node. This node will have two dedicated Application-specific Integrated Circuits (ASICs), one for the digital signal processing and one for the analog/RF part of radio. To achieve the targeted energy efficiency and recofigurability they continuing their on novel system architectures and design technique. Figure 1.8 (redrawn form [39]) has shown MIT -μAMPS node versions and time lines.

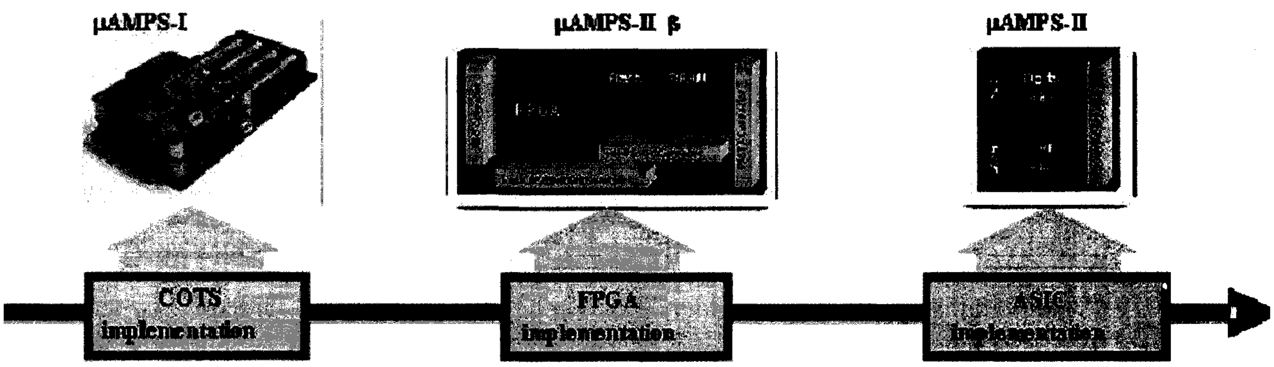


Figure 1.8: MIT- μAMPS node versions and time lines

In general, a sensor node has six components: processor, storage unit, radio, sensors, actuators, and power supply subsystems [20]. The basic structure of a sensor node is shown in Figure 1.9 (redrawn form [18]).

The *sensing unit* composed of various sensors and analog to digital converters (ADC). In the simplest sensor design, the purpose of a sensor is neither computing, nor communicating, but rather to sense phenomena. However, the current trend is to build the smart sensors by adding significant processing and computing abilities [20]. The sensor transducer is the front-end component of the sensor node, which is used to transform one from of energy into an other, mainly into an electrical signal. Type of sensors may include, for example, microphone, geophone, accelerometer, magnetometer, passive infrared detector, etc. The sensory transduction may be carried out using physical principles, some of which are described in Section 1.5.

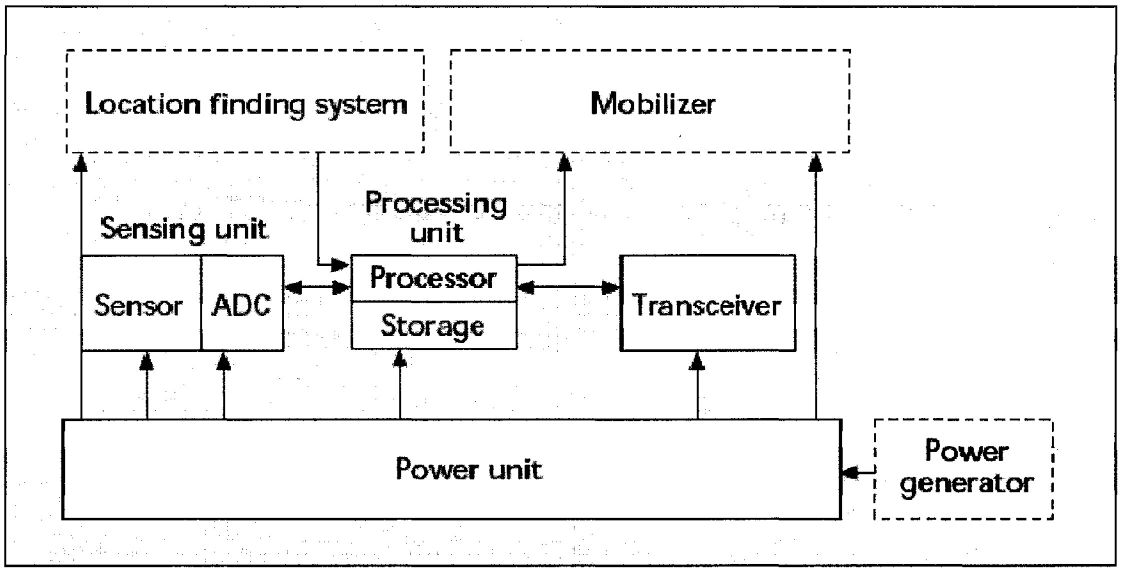


Figure 1.9: Sensor node architecture

The *Processing unit* composed a of processor and storage component. The processor is responsible for the control of the sensors and execution of the communication algorithms. For example UC Berkeley's motes uses Atmel Atmega 128L processor running at 4MHZ and Sensoria corporation's sensor node uses Hitachi SH-4 , 32 bit RISC @167 MHz processor. The scheduling of processor switches between various operation mode in order to manage the power efficiently. This shuttling between various operation mode involves drainage of battery power, which needs to be addressed to prolong overall life time of battery.

Radio unit performs the task of communication across the nodes. It consumes significant amount of energy during communication. This necessitates the use of low power RF (radio frequency) radios that are capable of delivering a fair bandwidth. It can operate in the following modes: transmit, receive, idle and sleep. The RF communication involves modulation, bandpass, filtering and demodulation circuits. The sensor node for under water uses acoustic frequencies of the special propagation environment. Propagation of electromagnetic waves for under water RF communication is not possible over long distances. Therefore, underwater sensor nodes have to rely on the physical means, such as acoustic signals, to transmit information [41].

Power unit normally consists of batteries that supply power to node. It is difficult to replace the node's battery once run off. Some time node may have power generation unit, for example solar cell, something exotic like vibration power [34] to keep running the node. It is one of the node's units which determines the life time of the sensor nodes.

Location finding system provides the location information of the node. It is an attractive feature of the node that can provide information about its location. The value of the information provided by the sensor node would increase when location data of the sensor is also available to the user. Self-localization method allows the node to determine their geographic position on their own. The localization information is gathered by the node during network initialization phase. The location information is very essential for target tracking, habitat monitoring and location-aware query process. The Sensoria node has a built-in GPS for finding their position.

Mobilizer is needed for the sensor network where sensor nodes are to be dynamic; means it is required to move from one place to another. It is an optional feature [32].

1.4 Protocol Stack

The protocol stack used in the node of sensor network shown in Figure 1.10, is redrawn from [1]. The protocol stack consists of : application layer; transport layer; network layer; data link layer; physical layer; power management plane; mobility plane; and task management plane [1]. This protocol stack combines power and routing awareness, integrates data with the networking protocol, communicates power efficiently through wireless medium, and promotes the cooperative efforts of the sensor nodes.

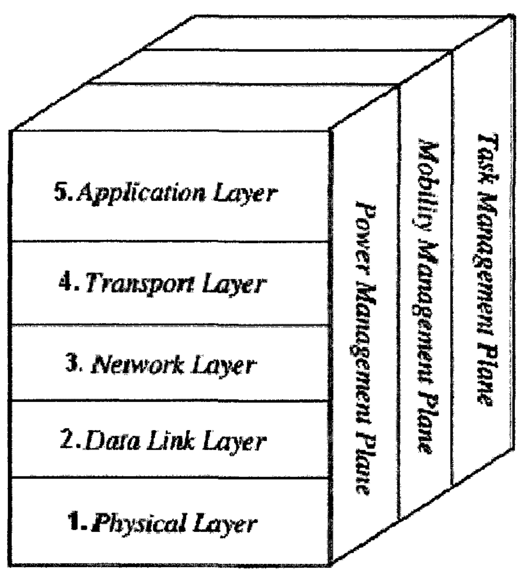


Figure 1.10: Protocol Stack in sensor networks

The application layer is responsible for supporting network application. Based on the task of sensing, different types of application software can be built and used on the application [1]. The transport layer provides the service of transporting application-layer message if the sensor network's application demands it.

The network layer is responsible for routing the data supplied by the transport layer. The link layer is responsible for multiplexing the data streams, data frame detection, medium access and error control [18]. Since the wireless sensor field environment is noisy and occasionally sensor node is mobile, the link layer protocol must be power aware and able to minimize collision broadcast of data. The physical layer addresses the issues of modulation, transmission, demodulation and receiving techniques. In addition to above layers, as shown in Figure 1.10, the Power management plane, the Mobility plane, and the Task management plane monitor the power, movement and task distribution among the sensor nodes respectively. The power management plane manages how a sensor should use its power. Such management may turn off the node receiver after receiving data in order to avoid duplicate data. Also when the residual power of a node is in minimum level then the low powered sensor node broadcasts its neighbors about its low power status and abstains from participating in routing message. The mobility management plane detects and registers the movement of the sensor nodes in order to ensure the route back to the user. The mobility manage plane also lets the sensor node to be aware of the status of its neighbors nodes so that nodes can balance their power and tasks. The task management plane balances and schedules the sensing tasks given to a specific region. The three management planes facilitate sensor nodes to work together in a power efficient manner and share the resources between the sensor nodes. In the absence of these planes, each sensor node has to work individually. From the view point of whole sensor network, these management planes make collaboration among the sensor nodes to extend the life time of the network.

1.5 Sensing principles

Sensor is a transducer device which converts energy from one domain to another. In general it converts sensed data into a useful signal that can be directly measured and processed. The signal conditioning and digital signal processing is carried out by electronic circuits. The output currents or voltages of this circuit are use for sensor networks. Figure 1.10, redrawn from [47], shows the block diagram of sensor transducer.

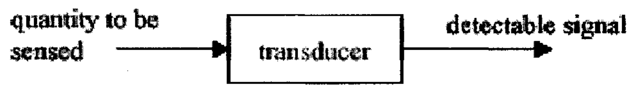


Figure 1.11: Sensory Transducer

Different type of physical principles are used in sensory transduction. Following are review of some principles used for sensory transductions [47]:

Mechanical Sensor: - Sensor that relies on physical contact

The Piezoresistive Effect converts an applied strain to change in resistance. Such change in resistance uses electronic circuits such as Wheatstone Bridge. The relationship between the parameters is $\Delta R / R = S\varepsilon$, where R is the resistance, ε is the strain, and S is the gauge factor which depends on quantities such as the resistivity and the Poisson' ratio of the material.

The Piezoelectric effect converts an applied stress on certain crystal or ceramic materials into a voltage. A piezoelectric sensor uses the piezoelectric effect to measure the pressure, acceleration or forces by converting them into electric signal. sBrium Titanate, Lead Zirconate Titanate (PZT), and single-crystal quartz are example of piezoelectric materials. The relation between the change in force F and the change in voltage V is given by $\Delta V = k\Delta F$, where k is proportional to the material charge sensitivity coefficients and thickness, and inversely proportional to the crystal area and material relative permittivity.

Tunneling sensing: Tunneling is a quantum-mechanical state of transitioning through classically-forbidden energy state. The sensing principle depends on the exponential relationship between the tunneling current I and the tip/surface separation z given by relationship $I = I_a e^{-kz}$, where k depends on the tunnel barrier height. Tunneling is an extremely accurate method of sensing nanometer-scale displacements, but highly nonlinear nature requires the use of feedback control to make it useful.

Capacitive Sensors: a typical capacitive sensor has one fixed plate and one movable plate. When a force is applied to the movable plate, the change in capacitance C is given by the relation $\Delta C = \varepsilon A / \Delta d$ where, Δd is the resulting displacement, A is the area and ε is the dielectric constant. Using variety of electrical circuits the changes in capacitance can be detected and converted to a voltage or current change for further processing.

Magnetic and Electromagnetic Sensor: - This kind of sensor does not require direct physical contact and are useful for detecting proximity effects.

The Hall Effect refers to the potential difference, called Hall voltage, on opposite sides of a thin sheet of conducting or semiconducting material in the form of a 'Hall bar'. It relies on the fact that Lorentz forces deflects flowing charge carriers in a direction perpendicluar to both their direction of flow an ap applied magnetic field. The Hall voltage induce in the plate of thickness T is given by $V_H = RI_xB_z / T$, *where R* is the Hall coefficient, I_x is the current in the bar flowing in direction x, and B_z is the magnetic flux density in the z diriction. Figure 1. 12, redrwan form [47] , shows the Hall Effect.

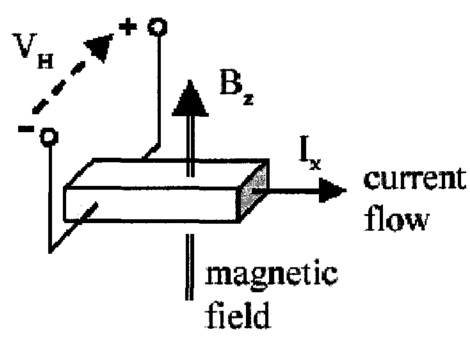


Figure 1.12: Hall Effect

Magnetic Field Sensor can be used to detect the remote presence of metallic objects.

Eddy-Current Sensors use magnetic probe coils to detect defects in metallic structures such as pipes.

Thermal Sensors : a family of sensors used to measure temperature or heat flux.

Thermo-Mechanical Transduction is used for temperature sensing and regulation in homes and automobiles. When there is a change in temperature, all materials exhibit thermal expansion relationship, $\Delta L / L = \alpha \Delta T$, where T is change in temperature, L is the length and α is the coefficient of linear expansion. Figure 1.13 (redrawn form [47]) shows the transformation into electrical signal with a strip of two joined materials of different thermal expansion, caused by change in temperature.

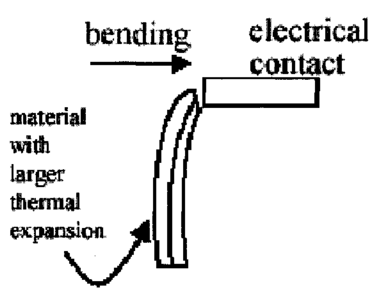


Figure 1.13: Thermal bimorph

Thermo-resistive Effects are based on the change in resistance, R in materials due to changes in temperature. In many material the relationship to moderate changes in resistance is given by $\Delta R / R = \alpha_R \Delta T$, where α_R is the temperature coefficient of resistance.

Thermocouples: It is based on the principle that a current flows through a circuit when a circuit consists of two different materials joined together at each end, with one junction hotter than the other. The properties due to which current flows in such a circuit is called thermoelectric Seeback effect. The Seeback voltage generated in a circuit is given by relation $V \approx \alpha(T_1 - T_2) + \lambda(T_1^2 - T_2^2)$ where, T_1, T_2 are the temperature at the two junctions. Semiconductor thermocouples generally have higher sensitivities than other metal thermocouples. Typically thermocouples have outputs on the order of 50 $\mu V / {}^0 C$ and some are effective for temperature ranges of -270 ^{0}C to 2700 ^{0}C.

Resonant Temperature Sensors It is based on the principle that a change in temperature in single-crystal SiO_2 exhibits a change in resonant frequency. Since this is a frequency effect, it is more accurate than the amplitude-change effects and has extreme sensitivity and accuracy to small temperature changes.

Optical Transducer: - It is based on principle of converting light into various detectable parameters by adopting several mechanisms. For each light photon of sufficient energy, the photoelectric effect causes emission of one electron at the negative end of a pair of charged plates. The consequence of which is the cause of current flow. In photoconductive sensors, photons generate carriers that lower the resistance of the material. In Junction-based photo-sensors, photons generate electron-hole pairs in a semiconductor junction that causes current flow. Thermopiles use a thermocouple with one junction coated in a gold or bismuth black absorber, which generate heat on illumination.

Chemical and biological Transducers: - It covers wide range of devices that interact with solids, liquids, and gases of all types. Potential applications include the environmental monitoring, biochemical warfare monitoring, security area surveillance, medical diagnostics, implantable biosensors, and food monitoring.

Chemiresistors have two interdigited finger electrodes coated with specialized chemical coating that changes their resistance when exposed to certain chemical challenge agents. The electrodes may be connected directly to an FET, which amplifies the resulting signal for good noise rejection.

Metal-oxide gas sensor rely on the fact that adsorption of gases onto certain semiconductor greatly changes their resistivities. Oxides of tin, zinc, iron, zirconium etc. are useful as sensors.

Electrochemical Transducers rely on currents induced by oxidation or reduction of a chemical species at an electrode surface. These are among simplest and most useful of chemical sensors. An electron transfer reaction occurs which is described by $O + ze \Leftrightarrow R$, where O is the oxidized species, R is the reduced species, and z is the charge on the ion involved. The resultant current density is given in terms of z by the Butler-Volmer equation.

Biosensor devices have a bio-chemically active thin film deposited on a platform device that converts induced property changes (e. g. mass, resistance) into detectable electric or optical signals.

The Electromagnetic Spectrum: - It is used to fabricate wide verities of remote sensors. Generally the wavelength suitable for a particular application is selected based on the propagation distance, the level of detail and resolution required, the ability to penetrate solid materials or certain mediums, and the signal processing difficulty. Doppler techniques allow the measurement of velocities. Millimeter waves have been used for satellite remote monitoring. Infrared is used for night vision and sensing heat. IR monitoring detectors are inexpensive and reliable. Electromagnetic waves can be used to determine the distance using time-of-flight information.

Acoustic sensor uses sound as a sensing medium. The measurement of velocity is done by using the Doppler technique. Ultrasound often provides more information about mechanical machinery vibrations, fluid leakage, and impending equipment faults than do other techniques. Sonar uses sound to determine distance using time-of-flight information. This principle is applicable only of underwater media.

Acoustic wave sensors are used for broad range of sensing. It can be classified as surface acoustic wave (SAW), thickness-shear mode (TSM), flexural plate wave (FPW) or acoustic plate mode (APM). Figure 1.14 shows (redrawn form [47]) SAW sensor where two set of interdigitated fingers at each end of the membrane; one set to generate the surface acoustic wave and other set to detect it.

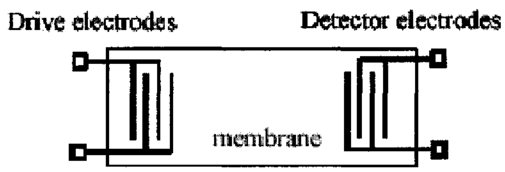


Figure 1.14: SAW sensor

Many types of sensors which are suitable for wireless network are commercially available. Table 1.1 shows the physical principles which are used for sensing various quantities [47]. MEMS sensor for most of these measurands are now available.

Measurements for wireless sensor networks		
	Parameter to be measured	**Transduction principle**
Physical properties	Pressure	Piezoresistive , capacitive
	Temperature	Thermistor, thermo-mechanical, thermocouple
	Humidity	Resistive, Capacitive
	Flow	Pressure change, thermistor
Motion Properties	Position	E-mag, GPS, contact sensor
	Velocity	Doppler, Hall effect, optoelectronic
	Angular velocity	Optical encoder
	Acceleration	Piezoresistive, Piezoelectric, optical fiber
Contact properties	Strain	Piezoresistive
	Force	Piezoelectric, Piezoresistive
	Torque	Piezoresistive, optoelectronic
	Slip	Dual torque
	Vibration	Piezoresistive, Piezoelectric, Optical fiber, Sound, Ultrasound
Presence	Tactile/Contact	Contact switch, capacitive
	Proximity	Hall effect, capacitive, magnetic, seismic, acoustic, RF
	Distance/range	E-mag,(sonar, radar, lidar), magnetic, tunneling
	Motion	E-mag, IR, acoustic, seismic (Vibration)
Biochemical	Biochemical agents	Biochemical transduction
Identification	Personal features	Vision
	Personal ID	Fingerprints, retinal scan, voice, heat plume, vision motion analysis

Table 1.1: Different physical principle for sensing

1.6 Standards

1.6.1 Wireless standards

Wireless technology standards for Local Area Network (LAN) and for Personal Area Network (PAN) are specified by the working groups of Institute of Electrical and Electronics Engineers (IEEE). The family of standards IEEE 802.11 is for Wireless LAN (WLAN) and IEEE 802.15 is for Wireless PAN (WPAN). These standards are widely used for tracking, automation and measurement applications. All these standards use Industrial Scientific and Medical frequency (ISM) radio bands, including the sub-GHz bands of 902 – 928 MHz (US), 868 - 870 MHz (Europe), 433.05 - 434.79 MHz (Us and Europe) and 314 – 316 MHz (Japan) and the worldwide acceptable 2.4 GHz bands[48]. The IEEE 802.11 family at present includes six over-the-air modulation techniques. The most abounding techniques of IEEE 802.11 family are those standards defined by IEEE 802.11b (Wi-Fi), 802.11a, 802.11g amendments to the original IEEE 802.11(Legacy) standard. The security issue of the standard was last enhanced by IEEE 802.11i. The IEEE 802.11n is another modulation technique under development which expected to be released by mid 2007. The original version of IEEE 802.11 standards was released in the 1997. In these standards, ISM band at 2.4 GHz is specified to transmit data via Infrared (IR) signals or by Frequency Hopping Spread Spectrum (FHSS) or Direct-sequence Spread Spectrum (DSSS). The original standard also defines the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol for medium access method of data link layer. This original (legacy) standard is supplemented by amendment standards released by the concerned IEEE group. A comparison of different 802.11x standards is shown in table 1.2 [51].

Standard	Release date	Operating frequency	Typical data rate	Maximum data rate
Legacy	1997	2.4 – 2.5 GHz	1 Mbit/s	2 Mbit/s
802.11a	1999	5.15-5.35/5.47-5.725 / 5.725 - 5.875 GHz	25 Mbit/s	54 Mbit/s
802.11b	1999	2.4 - 2.5GHz	6.5 Mbit/s	11 Mbit/s
802.11g	2003	2.4 – 2.5 GHz	25 Mbit/s	54 Mbit/sec
802.11 n	2007 (expected)	2.4 0r 5 GHz bands	200 Mbit/s	540 Mbit/s

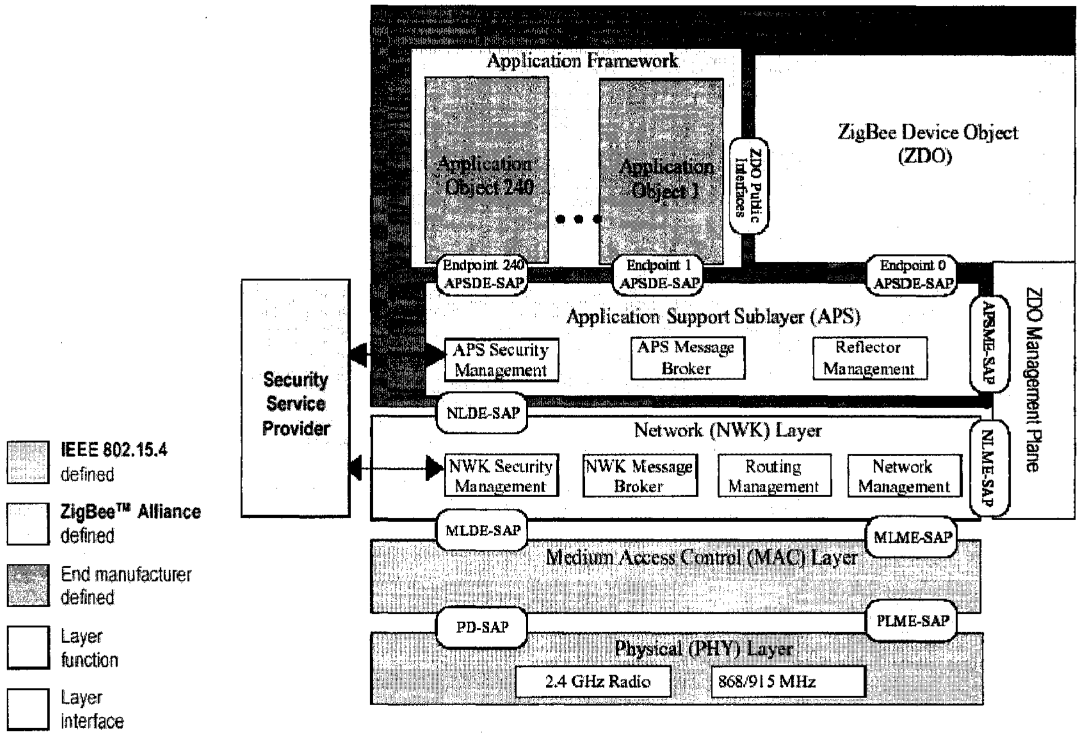
Table 1.2: Comparison of different IEEE802.11 standards

The IEEE 802.15 is standard for WPAN specified by the working group15th of IEEE 802. WPAN standard IEEE 802.15.1 also known as Bluetooth, specifies the medium access control and physical layer standards. It is released in 2002 but, an updated version has published in 2005. This radio and communication protocol primarily designed for low power consumption with short range. Based on the transceiver microchips in the device, there are three power classes: class1 – 100mW for a approximate range of 100m transmission distance; class2 – 2.5mW for a approximate transmission distance of 10m and; class3 – 1mW for a approximate transmission distance of 1m. The connection and communication in Bluetooth is established to play a master-slave role. The master can communicate with up to 7 slave device. It means this network is a group of 8 devices (1 master + 7 slaves), which is called piconet. The Bluetooth specification also allows to form a network by connecting two or more piconets together, called scatternet. In scatternet some devices plays dual role – role of master in one piconet and slave role in another piconet.

These devices yet to be in use but, expected to appear in 2007 [51]. For air interface the Bluetooth protocol operates in the license-free ISM band at 2.45 GHz. As there are many user in this band, Bluetooth divides the band into 79 channels with each channel of 1 MHz wide, in order to avoid interfering with other protocols in this frequency band [51].

IEEE 802.15.2 specifies the coexistence of WPANs with other wireless devices operating in unlicensed frequency band and IEEE 802.15.3 specifies the wireless Medium Access Control (MAC) and Physical Layer (PHY) for high rate for WPANs.

IEEE 802.15.4 defined the wireless medium access and physical layer specifications for wireless radio technology uses in PAN for low data rate, low power and short range application. The standard has first released in May 2003. It specifies two physical layers: an 868/915 MHz DSSS physical layer and 2.45 GHz DSSS physical layer. The 2.45 GHz band supports 16 channels over the air data rate of 250 Kbps, and the 868/915 MHz supports 1/10 channels over the air data rates of 20/40 Kbps [50]. Based upon the standard specified in IEEE 802.15.4, an alliance developed a set of high level communication protocol, called ZigBee. The member of this ZigBee alliance was more than 150 companies by April 2005. [51]. The ZigBee stack architecture has shown in Figure 1.15 (redrawn from [52]).



APS management entity SAP (APSME-SAP), APS data entity SAP (APSDE-SAP),

Figure 1.15: Outline ZigBee stack architecture

ZigBee protocols automatically construct a low-speed ad-hoc network of nodes. In the instance of larger networks, the network will be hierarchical architecture. It can be used for industrial monitoring and control, embedded sensing, environmental control, home automation, asset management, medical data collection, building automation, smoke and intruder warning. ZigBee is considered as the most promising for wireless sensor network due to its low power consumption and simple network configuration.

ZigBee has three different types of devices: ZigBee coordinator (ZC) , ZigBee Router(ZR) and ZigBee End Device (ZED). ZC is the most capable device and contains one ZC in each network. It forms the root of the network tree and might bridge to other networks. ZR acts as an intermediate router by passing data from other device to another.

ZED can not relay data from other device but, it contains enough functionality to talk either with ZC or ZR, the parent node [51].

When a large number of wireless sensor nodes deployed, different standard for networking can be combined to establish a network in a considerable large area. As for example ZigBee can be used for network in lower tier and 802.11b (WiFi) standard can be used for next higher tier network.

The power consumption and data rate for different wireless standard has shown in Figure 1.16 (redrawn form [66]). It is evident from Figure that IEEE 802.11 has high data rate and power consumption. These are line powered or the installed batteries are regularly charged. Thus the nodes of this network are not power constrained. As the nodes of such network have high power consumption, it is not suitable for wireless sensor networks.

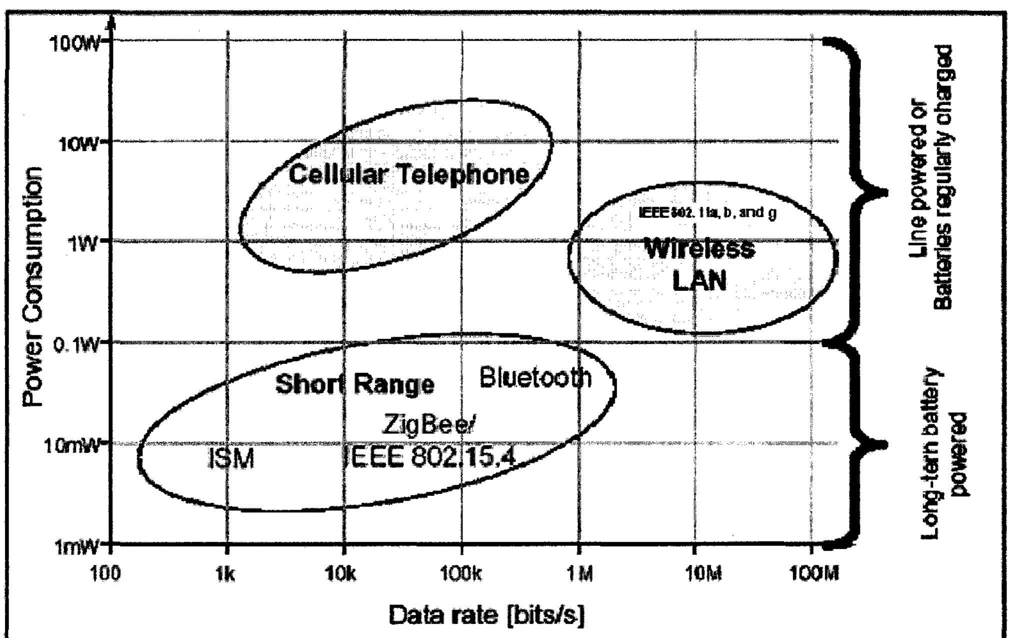


Figure 1.16: Wireless device and network standard

From Figure 1.16 above, it is found that the IEEE 802.15 is low data rate and low power consumed wireless technology, which is suitable for the wireless sensor network. This low data rate and low power wireless technology requires long-term battery energy. Figure 1.16 has also revealed that the wireless technology specified in IEEE 802.11 and for cellular telephone has higher data rate and requires high energy. This high energy consumed and data rate wireless technology is designed with power supply based on the line power or rechargeable battery.

1.6.2 Transducer Standards

Transducer is defined as the sensor or actuator which serves wide variety of real world needs. A sensor is a device which measures a physical attributes or property of an event or phenomena. The output if this device is electrical, optical or digital signal which can be transformed by other devices into information. Such information can be used either by the local intelligent device or monitoring individuals. The necessary intelligent decision is taken on the basis of monitored information and then subsequence course of action is adopted. Smart transducer is a sensor or actuator equipped with microcontrollers to provide local intelligent and network capability [50]. It would not be cost effective for transducer manufactures to make special transducers for every network in the market. The different components made by different manufacturers should be compatible. To address this issue, in 1993, a standardization effort was initiated by the National Institute of Standards and Technology (NIST). The goal was to allow the access of transducer data through a common set of interfaces whether the transducers are connected to systems or network via a wired or wireless means. The result of this initiative is the IEEE 1451 standard for smart wireless transducer.

IEEE 1451 is family of smart transducer interface standards which describes a set of open, common, network independent communication interfaces. The standard defines the specifications for connecting transducer to microprocessors, instrumentation system and control/field networks. This set of standards is to make it easier for the transducer manufacture to develop smart devices. Transducer Electronic Data Sheet (TEDS) is one of the key features specified by the IEEE 1451. The TEDS is a memory device attached to the transducer. This memory stores transducer identification, calibration, correction data, measurement range, and manufacture-related information. The standard IEEE 1451.1 defined the network independent smart transducer object model, which allows the sensor manufacture to support multiple networks and protocols. The standardized TEDS specified by IEEE 1451.2. The framework of

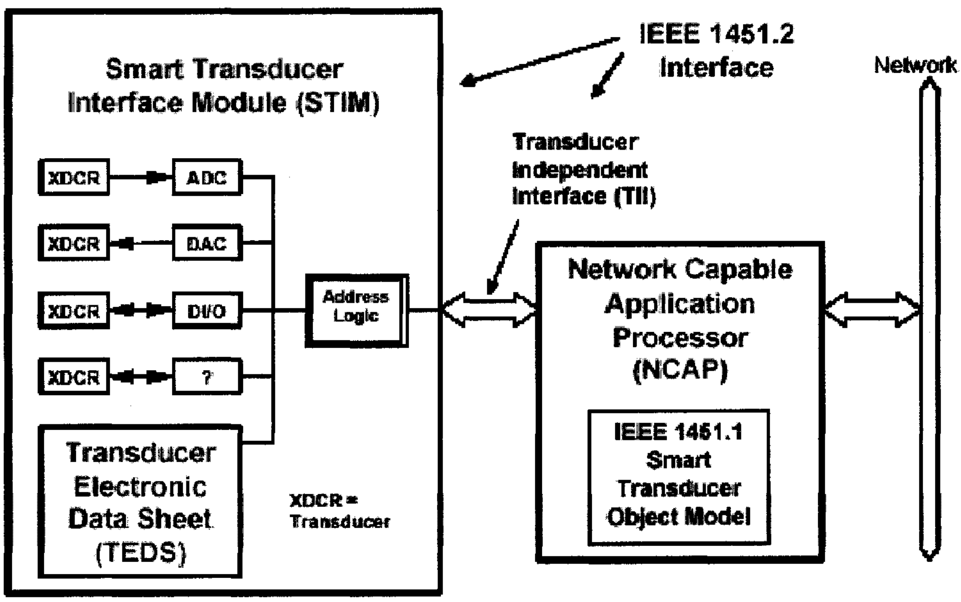


Figure 1.17: The framework of IEEE 1451.1 and IEEE 1451.2 interfaces

IEEE 1451.1 and IEEE 1451.2 interfaces has shown in Figure 1.17 (redrawn form [50]). The IEEE 1451.3 and IEEE 1451.4 standards meet the needs of the analog transducer users for high-speed applications.

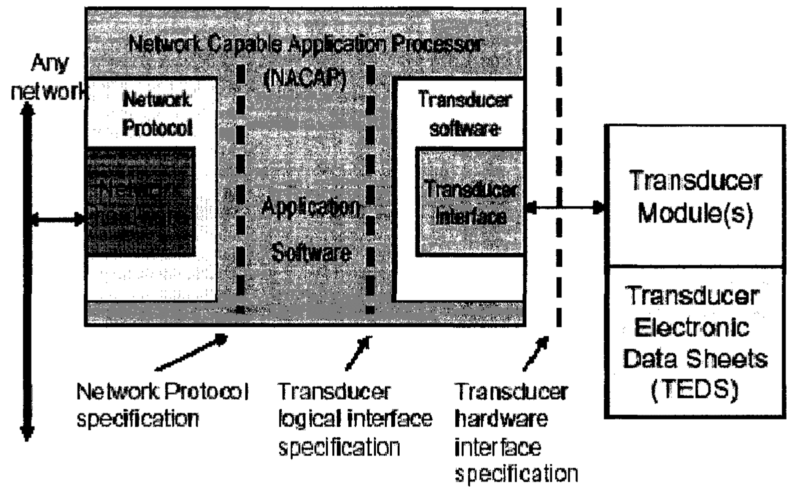


Figure 1.18: Interface of NCAP with network structure and STIM module

The architecture of a smart transducer consists of a Smart Transducer Interface Module (STIM), a Network Capable Application Process (NCAP), a Transducer Independent Interface (TII) between NCAP and STIM. There is an independent microcontroller embedded in each of STIM and NCAP module. The signal conditioning circuitry and transducer is the part of STIM module. The NCAP access the STIM transducer data through TII interface in one side and network resources on the other side. The interfacing of NCAP is shown in Figure 1.18 (redrawn from [54]). The TII interface and NCAP together facilitates the network–enable and network–independent capability of smart transducer [47, 50, 53, 54].

The wireless communication protocols for sensors are being developed by many companies. To reduce the risk for users, transducer manufacturers and system integrators an openly defined wireless transducer communication standard IEEE 1451.5 is currently being developed. This standard defines a transducer-to-NCAP interface and TEDS for wireless transducers. The interface defined in this standard will replace the TII interface with wireless links. This standard accommodated various wireless technologies including, 802.11x, 802.15.1 (Bluetooth) and 802.15.4 (ZigBee) protocol standards. The wireless structure for smart sensor network is shown in Figure 1.19 (redrawn from [67]).

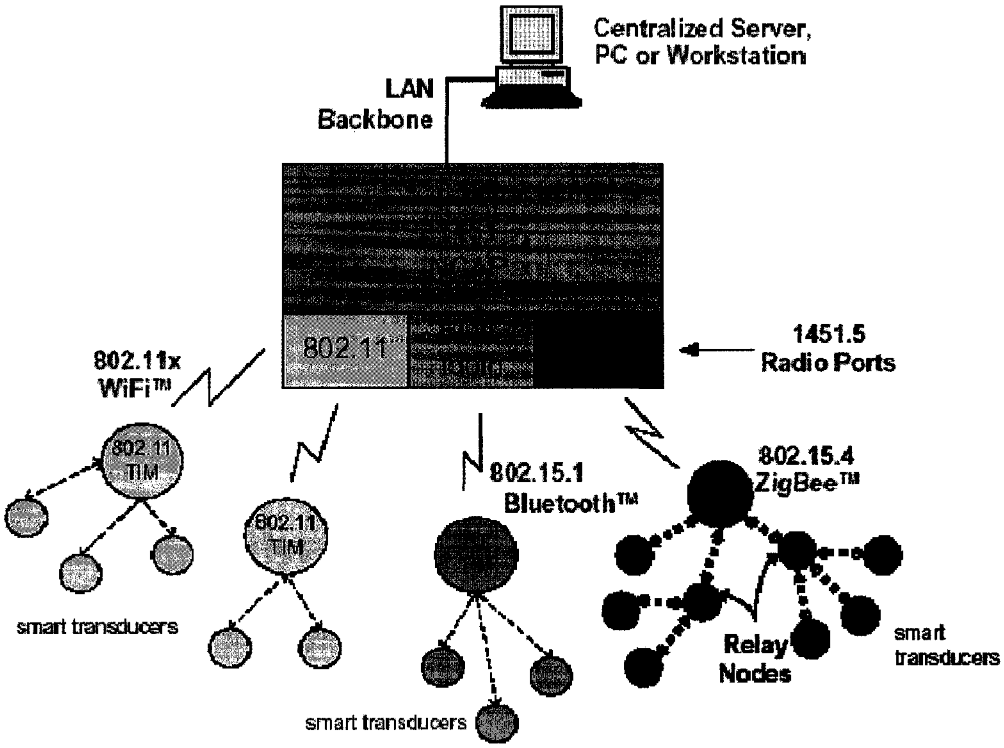


Figure 1.19: Wireless structure for smart sensor network

One will get the same sensor data from the wireless sensor implementing any of these wireless protocols [50, 54]. IEEE 1451 family of smart transducer interface standards has shown in Figure 1.20 (redrawn from [53]).

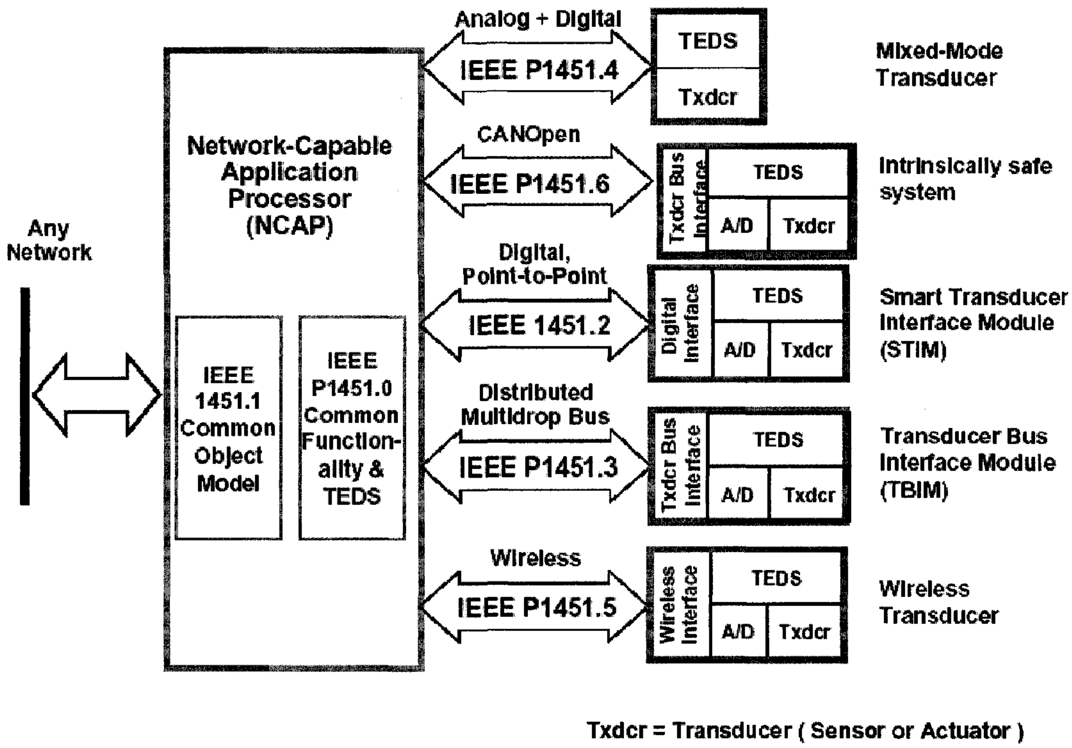


Figure 1.20: IEEE 1451 family of smart transducer interface standards

1.7 Proposed Research

1.7.1 Objectives of the proposed research

Small battery capacity, ubiquity of nodes, and operational diversity of wireless sensor networks create unprecedented energy management challenges. The energy consumption of a sensor node is determined not only by the node's physical hardware, but also by the algorithms and protocols that impart functional demands on the hardware. Many researchers have proposed various schemes for minimizing power consumption in sensor networks, and hence maximizing the life time of the network. Survey of literature revealed that in sending data from sensor node to the cluster head or to the local base station most commonly assumed is one of the following communication modes: a) multi-hop mode, b) direct transmission (single-hop) mode. In the direct transmission mode however, the nodes which are most distant from the cluster head or base station experience highest energy drainage. On the contrary, in the multi-hop mode nodes closer to the cluster head or base station have the highest energy drainage due the data chunk relaying effect of other nodes located further away. As a result, nodes in certain area of the cluster die faster than other nodes and it shortens the overall life of a sensor network.

Motivated to achieve extended network life time, energy efficiency, computational efficiency, data latency and operational cost minimization, we are presenting an Average Load Distance (ALD) radio communication model for data transferring from sensor node to the cluster head / sink node. The proposed approach shall minimize the drawbacks of direct and multi-hop mode of data forwarding and extend the network life time by reducing the energy consumption and the uneven load distribution among the sensor nodes in a cluster.

1.7.2 Solution Approach Methods

It is a key design issue to efficiently use the battery power in the energy constraints wireless sensor network for increasing life time. The overall life time of sensor network is more important than those individual nodes [4, 6]. Our approach is to prolong the overall network life time by implementing the approach: the Average Load Distance (ALD) radio model. In this paper we considered the lower tier of the hierarchal structured sensor network. To the best of our knowledge gained from the relevant literature review, it is a new approach.

The proposed approach shall formulate an energy efficient and computationally simple information data transmission algorithm to prolong the life of wireless sensor network. In this approach the differences in energy consumption among the nodes of a sensor field shall be minimized by distributing maximum possible equal transmission load among the sensor nodes in a cluster. The algorithm shall find out the data transmission distance form the given locations information of the sensor nodes and cluster head in the field. The even distribution of load shall be achieved by dynamically controlling the transmission distances of sensor nodes. The proposed approach shall use first order radio energy model to calculate the energy consumption in exchanging data between sensor nodes and cluster head. This algorithm shall apply in the Network layer of five layered protocol stack for wireless sensor networks as this layer is responsible for data routing in the network.

1.8 Organization of the Thesis

The remainder of the thesis is organized as follows: Chapter 2 presents the literature review relevant to the energy conserving routing protocols. Chapter 3 describes the algorithm and design of the proposed model. Chapter 4 presents the experiment and results. Chapter 5 presents application overview, market trend, an application of ALD radio communication mode. Chapter 6 contains conclusions, contribution of research and the scope of future works.

CHAPTER 2
LITERATURE REVIEW

The wireless network requires robust wireless communication protocol that is power efficient [3]. Based on the network structure, routing protocols can generally be classified into two categories: flat-based routing and hierarchical-based routing [42]. In flat-based routing, all nodes are treated equally and are typically assigned with equal functionality and role. In hierarchical protocols, sensor nodes grouped into distinct clusters around some specific nodes, known as cluster-head nodes. Figure 2.1 (redrawn from [12]) is a typical hierarchal wireless sensor network. The cluster-head nodes are responsible for collecting data from the sensors of its cluster and forwarding those to the base station.

In sensor networks, scalability is on of the major attributes that requires to be addressed in designing sensor networks. In a flat or single-tier network the gate way/sink node might be overloaded with the increase in sensor node density. The consequences of such over loading can direct to latency in communication and inadequate information for tracking of events. The flat architecture is not scalable for wider area of coverage as there is a limitation to communication distance that can be long haul by typical sensor nodes. Moreover, to allow deployed system to cope with additional coverage of interested area, hierarchical network structure is recommended by some routing approaches [27].

In WSNs, all data flows from the sensor nodes are directed to the base station, whose location is usually fixed and less energy constrained. In some works, some intermediate nodes, called relay nodes, has been proposed for sending data to the base station where the cluster/sensor nodes located further away from the base station use. The job of the relay nodes is only to relay the data generated by others relay/sensor nodes. Use of such nodes are evident in both Flat and Hierarchal network structures.

This rest of this chapter is divided into three sections: the first is the literature review for flat architecture; the second is the literature review for hierarchical architecture; and in third literature review is for other communication approach. At the end, the comments on previous work and scope of the current work are described.

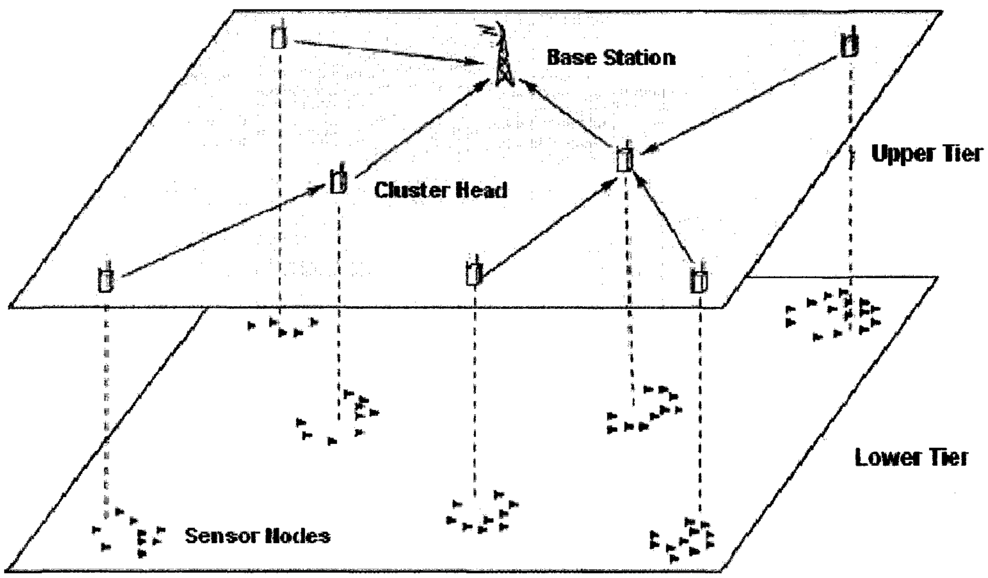


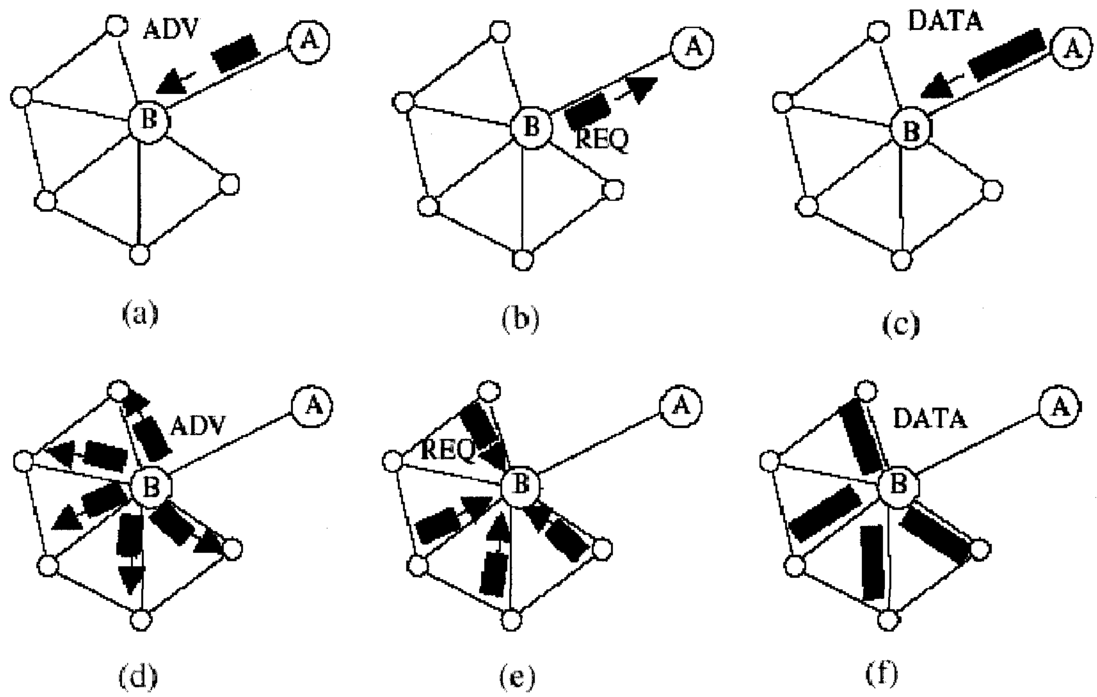
Figure 2.1: Hierarchical sensor network architecture

2.1 Flat Architectures

Multi-hop flat routing protocol probably is the first category WSN routing protocol. In this type of networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing tasks. As there are large number of nodes in such network architecture, assigning global identifier for each node of the network is not feasible [43]. Lack of global identification along with random deployment of sensor node makes it difficult to select specific set of sensor to be queried [27]. In terms of energy consumption, it is also not efficient to transmit data by every sensor deployed in the region with sufficient redundancy. This consideration led the base/sink station to send attribute-based naming queries to certain regions and wait for data from the sensor nodes located in the selected region. Such type of data exchange is called data centric routing.

In flat or data centric architecture flooding and gossiping are two classical techniques to relay data in sensor networks, where no routing protocol is required. In flooding mechanism of data transfer, when a sensor receive a data packet it broadcasts the same to all of its neighbors. Such process continues until the data packet arrives to it's destination node. In the case of gossiping mechanism when a sensor receives a data packet, it then sends the packet to its randomly selected neighbors. These mechanisms are easy to implement but has drawbacks. Flooding has drawbacks of implosion, overlap and resource blindness. Implosion occurs when duplicate message are sent to same node. Overlap happens when two nodes sensing same region and sensing the similar packets to the same neighbor. And resource blindness occurs by consuming large amount of energy without considering the energy constraints. Gossiping although avoids the implosion but, randomly selecting neighbor node causes delay in propagation of data through the nodes [27].

In [44, 45] Heinzelman et al. proposed protocol for Information via Negotiation (SPIN). The authors proposed a family of adaptive protocols which efficiently disseminates information among the sensor nodes. The SPIN family of protocol uses high level descriptor, called meta-data, to completely describe their collected data. The key feature of SPIN is to exchange of meta-data negations among the node prior to making any data transmission. These negations ensure that nodes transmit data when necessary and never waste energy on unwanted transmission i.e. the problem of redundant data transmission is eliminated throughout the networks. In this work the nodes can base their communication decisions both on the application-specific knowledge of the data and upon knowledge of resources those are available to them. In this work three messages are defined to exchange data between the nodes. These are: ADV – new data advertisement message, by which a has sensor to advertise a particular meta-data; REQ – request for data, allows node to request for specific data; and DATA – message that carry actual data. In this research they showed the steps of their proposed SPIN protocol in Figure 2.2, redrawn from [44]. The authors claims that their proposed meta-data negotiation based



Node A starts by advertising its data to node B (a). Node B responds by sending a request to node A (b). After receiving the requested data (c), node B then send out advertisements to its neighbors (d), who in turn send requests back to B (e – f)

Figure 2.2: SPIN protocol

SPIN protocols are energy efficient protocol as it eliminates the redundant data transmission, overlapping of sensor areas and resource blindness problems, which exist in classical flooding and gossiping mechanism data relay in sensor networks.

In [46] C. Intanagonwiwat et. al. carried out research on data-centric routing paradigm, called Directed Diffusion, for wireless sensor networks. In this work, data generated by sensor nodes is named by attribute-value pairs and a node requests data by sending interests for the named data. They defined the interests by using a list of attribute-value pairs such as type of objects, interval, duration and geographical region etc. In this work the interest is injected into the network at some node, called sink node. Then sink broadcasts the interest in the network through neighbor node(s). The authors design the algorithm in such a way that each node receiving the interests can cache the interest for future use. After receiving interest, a node may decide to re-send the interest to some subset of its neighbors. Each sensor that receives the interest setup a gradient - a reply link to neighbors from which it receives the interest. The node has the capability to perform in-network data aggregation. Each gradient is characterized by: *data rate* field requested by the specified neighbor, derived from the *interval* attribute of the interest; *duration* field, derived from the *timestamp* and *expiresAt* attributes of the interest; and approximate lifetime of the interest. Then the paths between sources and sink are established by using these interest and gradients. Multiple paths can be established out of which one of the paths is selected by reinforcement. Figure 2.3, redrawn from [46], shows the steps in directed diffusion protocol.

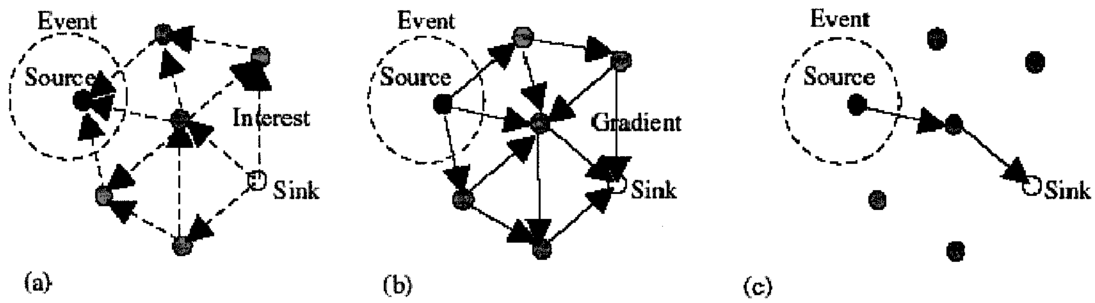


Figure 2.3: Directed Diffusion protocol steps. (a) Interest dissemination step, (b) initial gradient setup, (c) data delivery along reinforced.

Initially sink diffuses an interest for low event-rate notification. After the sink starts receiving these low rate data event, the sink resend the original interest message through selected path with a smaller interval in order to reinforce the sourced node to send data at high rate. The authors evaluated and claimed that their proposed Directed Diffusion is highly energy efficient protocol. It is an on demand protocol and in this paradigm every node is able to cache and perform in network aggregation which minimizes to number of transmission by eliminating redundant data.

In flat architecture based wireless sensor network, the idea of deploying relay nodes was possibly first introduced by Cheng et al. in 2001 [7]. They focused on maintaining connectivity in sensor networks by introducing a small number of relay nodes within the networks, and studied the impact of using these relay nodes on the total power consumption for maintaining minimum-power topology. They focused on finding the answers of two questions: first, if one or two sensor nodes are introduced how it improves the topology secondly, given a restricted transmission power what are the numbers of relay nodes that are required to maintain the global connectivity. For the network, where sensor locations are usually pre-determined & fixed, the authors have formulated a NP-hard network optimization problem, called Steiner Minimum Tree with minimum number of Steiner Points. They introduced relay sensors within the network to provide connectivity so that transmission power of each sensor can be kept low.

In 2003, Dasgupta et al. [8] proposed the use of relay nodes, to maximize the lifetime of sensor networks. They focused on maximizing the lifetime of sensor networks by studying topology-aware nodes' placement problem and the nodes' role-assignment problem in sensor networks. Their works considered a sensor-network model consists of sensor nodes and relay nodes, where all nodes are of similar capabilities. The roles of relay nodes include the aggregation of multiple incoming data packets into one single outgoing packet and transmission of the data packets. With such a network model, they focused on the placement of the nodes within the network and assigning roles to the nodes in such a way that the lifetime of the network is maximized. They called the proposed algorithm the Sensor Placement and Role assignment for energy-efficient Information Gathering (SPRING). With a given location for the base station and an initial assignment of role as well as placement of nodes, the objective of SPRING is to find the location along with the assignment of roles for the nodes so that system lifetime is maximized.

In [9], Falck et al. (2004) have attempted to achieve balanced data gathering against sufficient coverage, using relay nodes in sensor networks and have solved the optimization problem by Linear Programming (LP). They considered a multi-hop network model consisting of sensor nodes, relay nodes and a base station. The relay nodes are less-energy constrained compared to the sensor nodes. The authors have also studied the effect of deployment a small number of less energy-constrained relay nodes within the network and proposed an approximation algorithm for their placement.

In [10], S. C. Ergen and P. Varaiya (2005) have focused on achieving a desired network lifetime using minimum total energy in a sensor network that contains relay nodes. In their model, the sensor nodes may also take part in routing. They attempted to achieve the goal of maximizing the network lifetime by determining the optimal locations along with the optimal energy provisioning of the relay nodes within the networks. To formulate the problem, they have assumed that the sensor nodes' placement and their sampling rate are predetermined and fixed. Authors have proposed two different formulations, one is Linear Programming (LP) and the other is Non-Linear Programming (NLP). For the LP formulation, they have attempted to minimize the total cost with a further assumption that the locations of the relays are also predetermined. The NLP formulation attempts to reach the same goal but with no prior assumption about the locations of the relay nodes.

2.2 Hierarchical Architectures

Like other communication networks, scalability is one of the major design attribute to be considered in wireless sensor networks. With the increase of sensor nodes density, single tier network can cause an overload to the sink/gateway nodes. Latency in communication caused by such overloading and hence there will be inadequacy in tracking of events. To overcome these drawbacks of overloading and to cover large area of interest without degrading the service, multi-tier hierarchical routings is approached in some works. Following are some of these routing approaches:-

In [6], W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan developed an innovative hierarchical protocol that minimizes the energy dissipation of the networks. The authors considered direct mode communication from the sensors to the cluster-head of the network. Based on the availability of the energy of sensors under a cluster, they suggested rotating the role of the cluster-head among other sensors in the cluster in a round-robin strategy. They claimed, distributing the energy among nodes in the network reduces the energy dissipation from a global perspective and enhances the systems lifetime. They formulated Low Energy Adaptive Clustering Hierarchy (LEACH) protocol for energy-efficient communication. Deployed sensor nodes are considered homogeneous in this work. In round robin strategy, when a sensor node is elected as cluster-head, it compresses the received data from sensors under its command and directly transmits the aggregated data to the base station.

In [11], G. Gupta and M. Younis proposed the deployment of relay nodes in hierarchical architecture. They considered multi-hop communication model from sensor node to gateway node. In their research, they used two types of nodes: energy constrained sensor nodes and less-energy constrained gateway nodes. The gateway node groups the sensors to form the clusters, performs data fusion and transmits the aggregated data towards base station or command node. The authors focused the issue of load-balancing and proposed an algorithm for load-balanced-clustering of hierarchical sensor networks.

They termed the cluster-heads as gateway nodes. In their work they introduced deployment of relatively less energy-constrained gateway nodes and proposed load balancing among these nodes to extend the network lifetime. In order to minimize the overloading and dying out of some overloaded gateway nodes, authors have formulated and proposed an optimization heuristics algorithm that clusters the sensor nodes (with gateway nodes as cluster heads) and balances load among these gateway nodes.

In [12], Y. T. Hou et al. considered the additional energy provisioning into the existing cluster-head. In addition to energy provisioning into Aggregation and Forward Node (AFN) they also deployed relay nodes into the networks to mitigate the network's geometrical deficiencies so that lifetime of network is prolonged. They termed the cluster-heads as aggregation and forwarding (AFN) nodes. Nodes of the network are structured in two tiers: lower tier, and upper tier. The lower tier grouped the sensor nodes and the upper tier grouped AFN, Relay nodes (RN) and Base station (BS). The direct mode of communication model is followed for the lower tier sensor nodes but, multi-mode communication model is considered for upper tier nodes. The main functions of AFN are to aggregate data and forwarding the aggregated data to the next hop AFN or RN toward the BS. In this work they identified their proposed problem as NP-hard which is Mixed Integer non-linear Problem (MINLP). Then they developed a heuristic algorithm, Smart Pairing and INtelligent Disc Search (SPINDS), to address the problems. The SPINDS is an iterative way of attempts to move the relay nodes in better location, where minimum transmission energy is required.

S. Lindsey et al. in their works [26] proposed near optimal chain-based routing protocol, Power-Efficient GAthering in Sensor Information System (PEGASIS). Unlike forming multiple cluster for hierarchical cluster structure, they proposed formation of chains from sensor nodes, so that each node transmits and receives from close neighbors and only one node is designated to transmit the combined data to the base station in each round. The authors proposed *energy X delay* metric for data gathering, to optimize tradeoff between the latency and energy efficiency of networks. They proposed simultaneous transmission among pairs of nodes to reduce the delay in data gathering. To avoid collision and possible signal interference during this simultaneous gathering process they investigated two approaches. The first is chain-based scheme with incorporating CDMA nodes and second is chain-based scheme with specially separated non-CDMA nodes allowed to transmit and receive at the same time. In first approach, with CDMA capable nodes, they constructed a chain based node, which formed a tree like hierarchy. Each selected node in the particular level transmitted data to the designated node of the next upper level. In the second approach with non-CDMA nodes, a three level hierarchy of the sensor nodes were created. The signal interference was reduced by careful scheduling of simultaneous transmissions. They claimed such approaches ensured parallel data transmission and hence, reduced the delay in data gathering.

A. Manjeshwar et al. [28] proposed time critical applications Threshold sensitive Energy Efficient sensor Network protocol (TEEN) for proactive sensor network. They claimed it as a hierarchical protocol which reacts on sudden changes on the measured phenomenon. In this research they grouped closer sensor nodes to form the cluster. After formation of cluster the cluster, head broadcasts hard and soft threshold signals for the sensed attributes to its respective sensor nodes. When the sensor node's sensed signal is at or above the hard threshold value, the sensor node switches on its transmitter and transmit the data to the cluster head. But, the transmitter shall transmit the sensed value at or beyond the hard threshold only when the changed attribute value equals or greater than the soft threshold value. The authors claimed their protocol reduces the number of unwanted transmissions as the sensor nodes has to satisfy two threshold values before transmitting data to the cluster head. It conserves the node's energy consumption and prolongs the network lifetime.

The sensor node shall not transmit any data until the thresholds are not reached for the proposed protocol in [28]. Consequently the user will not get any data from the network. Thus the protocol, TEEN can not be used in applications where periodic data is required by the user(s). In [29] authors extended their work by proposing, the Adaptive Periodic Threshold-sensitive Efficient sensor Network protocol (APTEEN). The structure of this proposed protocol is same as TEEN. They claimed, in addition to the tasks of TEEN protocol, APTEEN protocol in an energy efficient manner facilitates the sensor nodes to gives the overall scenario of the network at periodic interval. In this protocol, after forming the cluster, the cluster head broadcasts to sensor under its command: the attributes; threshold values; and transmission schedules. The authors claimed that APTEEN supports three different queries: *historica*l, to analyze past data value; *on-time*, to take a snapshot view of the network; and *persistent,* to monitor the a network over time interval with respect to some parameters.

In [30] M. Younis et al. proposed a cluster-based energy aware routing algorithm. In this work they proposed three types of node: Sensor node, gateway node/cluster head, and Command node/base station. The gateway nodes are: less energy constraint, performs the task of cluster management and interface the sensor nodes with command node. The sensor nodes are energy constraints and do the task of sensing and transmitting the sensed data towards the gateway node. In their works it is assumed that the sensor node in a cluster can be in four main states: sensing only, relaying only, sensing-relaying and inactive. It is also assumed that the sensor node is capable of operating in active mode or a low power stand-by mode. In their works, the node's transmission powers are programmable to required power level based on the range of transmission. To save the energy, they proposed sensing, processing, radio transmitting and receiving electronics of the sensor nodes can be powered on or off independently as per requirement. In this research it is considered, sensor which is active in data processing, sensing, or in data forwarding and relaying are to be continuously monitored by gateway in order to assess the energy level at those sensors. A cost function is defined between any two nodes in terms of energy consumptions, delay optimization and other performance matrices. A least cost path is between sensor and gateway figured out by using this cost function.

Bari et al. [31] , in their works proposed to use higher power relay nodes for cluster head/ Gate way for two-tiered networks to maximize the life time of networks. They formed upper tier network with these gate ways for routing data to the base station. In this approach, unlike approach of splitting outgoing load flow of a gateway, they proposed to allow a gateway node to receive loads of any number of sensor nodes but shall have out going flow of data to only one relay/gateway node or base station, using directional antenna. To optimize their proposed routing of data flow in gate way / relay nodes network, authors presented ILP formulation to maximize the network life time. They also proposed proactive data gathering for predefined schedule for relay node. They claimed, computation of such data gathering schedule after predetermined interval will increase the lifetime further over their proposed optimal ILP solution.

2.3 Other Communication Approach

In [13], Z. Shelby et al. considered two multi-hops cases: equidistance spacing and optimal spacing. In the equidistance scenario, authors assumed placement of nodes at an equal distance and in other scenario used a node spacing considering the minimization of the energy consumption. They compared the energy consumption of the two multi-hop scenarios with the direct transmission mode. They found, depending on the topology, simple multi-hop strategy does not always extend the network lifetime.

In [14], I, Howitt et al. proposed Energy Balanced Chain (EBC) to prolong the network lifetime. In EBC they formulated energy balance optimization problem in terms of segmentation space. They proposed power adjustment so that the nodes with higher traffic have longer hop distance than the node with lower traffics. Authors claimed that the EBC performs better than the traditional hop-by-hop transmission.

In [15], Q. Gao et al. deduced the relationship between optimal radio range and traffic. For multi-hop communication, they conducted experiment in two configurations: by dividing the network into an unequal grid according to the optimal range-traffic relationship; and by dividing network into a size-traffic relationship. Authors found later configuration is more energy saving than the earlier one. In this work a number of sensor node's set is formed for each of the divided grid. Each set of sensor node is activated in turn and remaining sets are in sleep mode. If there are m set of sensor then the network lifetime is increased by m times.

In [5], V. Mhatre et al. determined the optimum mode of communication of the sensor to the cluster head. To find out the energy drainage in multi-hop communication, they assumed the cluster as a circular region. The circular area is divided into concentric rings of width R (which can be optimized) with the cluster head at the centre of the circle. A comparative study of single hop and multi-hop mode was conducted and proposed hybrid mode of communication. Hybrid mode is a scheme in which sensor node alternates periodically between single hop and multi-hop to communicate with the cluster head.

2.4 Comments on previous work and Scope of the present work

All of the above reviewed works under the flat and hierarchical structure adopted either single-hop or multi-hop mode of communications in data routing. For such modes of communication, the life time of the network could be affected by sensor nodes dying out in a certain area faster than others. Moreover, reviewed research involved complex computation to discover the route to sink or cluster head. The consequences of such computational effort has significant energy overhead, which also reduces the life time of the network. The complex computation results in network latency due to the processing time and memory space constraints in the node's processing unit. In the reviewed works under other communication approach, the random deployment of nodes is not considered and the base station is always assumed at one end of the network. In one paper [5] it is assumed that the relationship between the deployed numbers of sensor nodes in the ring is proportional to the area of the ring. In the case of random sensor deployment, however, the number of sensor nodes in the different section of a sensor field may not be proportional to the area of the section.

It is apparent from literature review that there is a research opportunity to explore energy efficient communication mode for routing data in a sensor field, where sensor nodes are deployed randomly. This mode shall demand minimum computation and energy to set up the data communication route in between sensor nodes and sink node or base station. Minimizing the drawbacks of direct and multi-hop mode of communication, such a mode shall be able to extend the life time of the network.

Hence, we proposed Average Load Distance (ALD) mode of radio communication model to minimize the drawbacks of faster die out of farthest and nearest nodes in the direct and multi-hop mode of communication respectably. This data transmission mode is simple and computationally inexpensive but, relatively energy efficient model for randomly deployed sensor network.

CHAPTER 3
ALD COMMUNICATION MODE

This chapter outlines the proposed approach, Average Load Distance (ALD) communication mode, for routing data from sensor node to cluster head or sink node in a hierarchically structured network. The main objective of our approach is the energy efficient data routing to extend the lifetime of network. A standard way to measure the lifetime is by determining the number of transmission rounds until one of the sensor node ceases its functioning.

3.1 Energy Calculation

In our approach we adopted the first order radio model [6, 13, and 16] to determine the energy dissipation for communication among sensor nodes in a wireless sensor network. The first order radio model for energy consumption is shown in Figure 3.1 (redrawn from [6]).

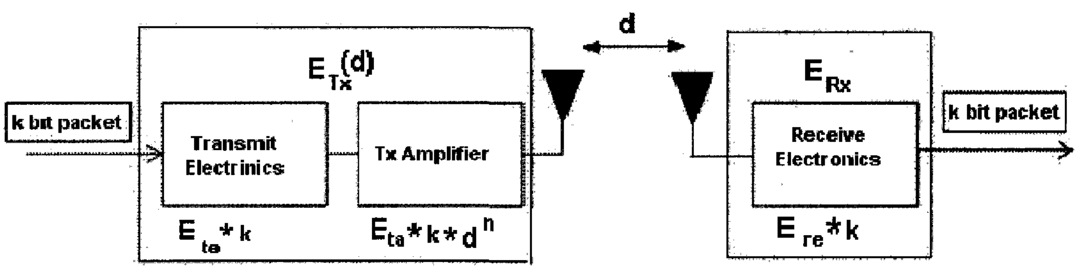


Figure 3.1: Energy consumption model

According to the model, the energy consumption in the radio transmitter to transmit a k bits of message at a distance d is:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d) = E_{te} * k + E_{ta} * k * d^{n}$$

In the receiver side, the energy dissipation to receive the message of k bits is:

$$E_{Rx}(k) = E_{Rx-elec}(k)$$
$$E_{Rx}(k) = E_{re} * k.$$

Table 3.1 summarizes the meaning of the terms used above and value [6] of the terms

Term	**Meaning and value**
E_{te}, E_{re}	Energy dissipation in transmitter and receiver electronics to transmit and receive unit bit of message. 50nJ/bit
E_{ta}	Energy dissipation in transmitter amplifier to achieve acceptable signal to noise ratio (SNR) at the receiver node. 100 pJ/bit /m^2
k	Number of bit in the message
n	Path loss exponent
d	Distance between the transmitter and receiver

Table 3.1: Communication energy parameters

3.2 ALD Routing

3.2.1 Strategy

The sensor node expends its power to accomplish the following three tasks: *sensing, communicating* and *data processing.* Of these three tasks, a sensor node expends maximum energy in data communication. As discussed in Section 1.4, network layer is responsible for discovery of the route for data communication. In this layer, the communication route selecting algorithm is to be designed in such a manner so that the energy efficient links are discovered to exchange information among the nodes of the network. In our approach we developed an energy efficient algorithm for network layer of the sensor network. The power conservation for node's data transmission tasks can also depend on the efficient design of data link layer of the network. For example, depending on application, the data link layer can be designed in such a way that node can maintain *active, idle* and *sleep* states. When a node has to wait long time for the turn of its data transmission then the transmitter can go in sleep state, which can save node's power. The algorithm for energy efficient data link layer is beyond the scope of our proposed work.

It was revealed from energy model discussed in Section 3.1, that the energy consumption in the transmitter and receiver electronics can not be optimized by network layer algorithm design. This is due to the fact that design of low power consumption transceiver falls in the domain of hardware engineering. In general, low laying antenna is used to establish the communication among the nodes in the sensor network. The path loss exponent, n, in such scenario is close to 4 [1, 17]. The only parameter we can vary to achieve the energy efficiency in data routing is the transmission distance. It is also found that, only energy efficient route set up for the node does not increase the overall lifetime of the sensor network. In addition to energy efficiency, lowering the difference of energy dissipation among the nodes in the sensor field is also required to increase the overall lifetime of network.

3.2.2 Network Set up and Assumptions

We considered a two-tier cluster based network, where two kinds of nodes are used: a) sensor node, and b) cluster head. The sensor nodes are energy constrained and deployed randomly. Each sensor node belongs to only one cluster. The sensor node senses the phenomenon and sends data to its respective cluster head. Cluster head is not energy constrained. It collects data from the sensor nodes of its own cluster and then aggregates the received data to forward it to the base station.

A typical cluster with 100 sensor nodes and a cluster head at the centre is shown in Figure 3.2. All sensor nodes are aware of their position through Global Positioning

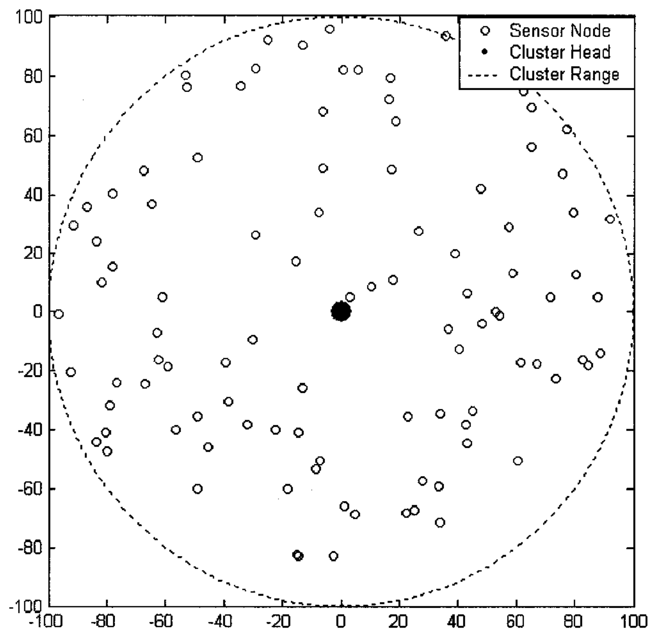


Figure 3.2: 100-sensor nodes cluster

System (GPS). All communication is over wireless links. The network set up is performed in two phases: Bootstrapping, and Clustering. In bootstrapping phase, cluster head discovers the sensor nodes that are located within its communication range. The location data of the sensor nodes shall be used to find out the direct transmission distance in between sensor nodes and cluster head. Cluster broadcasts a message indicating the start of clustering [11]. Since the cluster head has a cluster-wide view of the network, the route selection decision making tasks are carried by cluster head for the sensor nodes under its command. It will offload the routing decisions from the energy constrained sensor nodes. The environment of the sensor network consists of buildings, factories and regions with dense vegetation. It is assumed that each sensor node generates same amount of data. For the purpose of presented analysis it is assumed that the sensor and cluster head are stationary. All sensors report their position to the cluster head during bootstrapping by turning on the GPS for a brief period of time. All sensor nodes have enough power to reach the cluster head. Node can also use power control to vary the transmitted power [3]. In the data link layer, the Time Division Multiple Access (TDMA) based Media Access Control (MAC) protocol is assumed to be implemented. It is also assumed that the communication environment is contention and error free. The slot assignment to sensor nodes is managed by the cluster head. The cluster head informs each node about allocated time slots for data transmission. This allows collision avoidance among the nodes in transmitting data with non-overlapping time slots allotment.

3.2.3 Transmission Distance Formulation

The transmission distance is the main contributing factor to energy consumption in transmitting data by the transceiver of a sensor node. We can set the transmission distance dynamically to a distance required by the average load in a cluster of randomly deployed sensor nodes. Then we can minimize the energy dissipation and the difference of energy dissipation among the sensor nodes in a cluster.

We use the following notations to formulate the average energy consumption and average load distance:

N = Total number of sensors in a cluster field

k_i = Per transmission round data generation at sensor node i

E_{tei} = Energy dissipation in transmitter electronics to transmit one bit of message for sensor node i.

E_{rei} = Energy dissipation in receiver electronics to receive one bit of message for sensor node i.

E_{tai} = Energy dissipation in transmitter amplifier to achieve acceptable signal to noise ratio (SNR) at the receiver for i sensor node.

d_{ic} = Distance of the sensor i from cluster head

d_{ald} = Average load distance

E_{avg} = Average load per sensor

E_{txi} = Energy consumed by node *i* in transmitting k_i bits data

E_{Rxi} = Energy consumed by node I in receiving k_i bits data

E_i = Total energy consumed by node i

E = Total energy consumption for the sensors in a cluster per transmission round

Following the first order radio mode energy consumed by sensor node *i* to transmit and receive k_i bits of data at a distance d_{ic} with path loss factor n is:

$$E_{Tx}(k, d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k, d)$$

$$E_{Tx}(k, d) = E_{te} * k + E_{ta} * k * d^n \quad (1)$$

Total energy consumed by node *i* is:

$$E_i = E_{Txi} + E_{Rxi} \quad (2)$$

The total energy consumed by N nodes in a cluster is

$$E = \sum_{i=1}^{N} E_i \quad (3)$$

Using (1), (2) and (3)

$$E = \sum_{i=1}^{N} (E_{tei} * k_i + E_{tai} * k_i * d_{ic}^{n} + E_{rei} * k_i) \qquad (4)$$

The average load:

$$E_{avg} = \frac{E}{N} \qquad (5)$$

For direct transmission $E_{rei} = 0$. For simplicity, it is assumed that all nodes generate the same amount of k bits of data. Hence $E_{e1} = E_{e2} = ... = E_{en} = E_e$ and $E_{ta1} = E_{ta2} = ...$ $= E_{tan} = E_{ta}$

Hence (1) become

$$E = (NE_e * k + \sum_{i=1}^{N} E_{ta} * k * d_{ic}^{n})$$

$$E = (NE_e * k + E_{ta} * k [d_{1c}^{n} + d_{2c}^{n} + d_{3c}^{n} + ... + d_{Nc}^{n}]) \qquad (6)$$

$$E_{avg} = E_e * k + E_{ta} * d_{ald} \qquad (7)$$

Using (5) and (6)

$$E_{avg} = \frac{(NE_e * k + E_{ta} * k [d_{1c}^{n} + d_{2c}^{n} + d_{3c}^{n} + \cdots\cdots\cdots + d_{Nc}^{n}])}{N} \qquad (8)$$

Using (7) and (8)

$$E_e * k + E_{ta} * d_{ald}^{n} = \frac{(NE_e * k + E_{ta} * k [d_{1c}^{n} + d_{2c}^{n} + d_{3c}^{n} + \cdots + d_{Nc}^{n}])}{N}$$

$$N*E_e*k+N*E_{ta}*d_{ald}^n = (NE_e*k+E_{ta}*k[d_{1c}^n+d_{2c}^n+d_{3c}^n+......+d_{nc}^n])$$

$$N*d_{ald}^n = (d_{1c}^n+d_{2c}^n+d_{3c}^n+......+d_{nc}^n)$$

Hence radius of average load distance ring is:

$$d_{ald} = \sqrt[n]{\frac{(d_{1c}^n+d_{2c}^n+d_{3c}^n+\cdots\cdots+d_{Nc}^n)}{N}} \quad (9)$$

3.2.4 Algorithm

The energy dissipation trend for multi-hop and single hop communication from sensor nodes to cluster head/local base station is shown in Figure 3.3 (redrawn from [5]). Figure 3.3 shows that in single hop mode the sensor nodes most distant from the cluster head experience maximum energy drainage. In the multi-hop mode, on the other hand, it is the sensor nodes nearest to the cluster head experience maximum energy drainage.

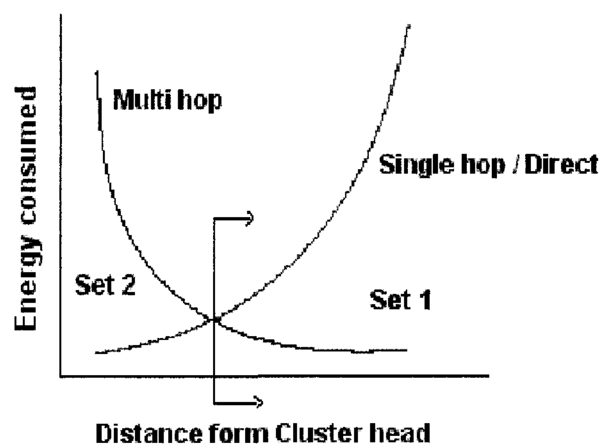


Figure 3.3: Distance vs. Energy dissipation for multi-hop and single-hop communication

This uneven distribution of power among the sensor nodes in a cluster can be minimized by breaking all deployed sensor nodes into two sub-sets:

1. Set 1 consisting of sensor nodes located in the area between the distance near intersection point (figure 3.3) and outer boundary (outer ring of fig. 3.4)

2. Set 2 consisting of sensor nodes in the area between the distance near intersection point (Figure 3.3) and the centre (inner ring of Figure 3.4)

3. Forward the information data of sensors from set 1 to the base station by relying it through sensors in Set 2

4. Make sure that in addition to own load, the nodes in set 2 relay only loads from a single node form Set 1 each

5. Prioritize relay assignments: If a node in set 2 is common for relaying more than one node's data for sensor in set 1, then the node in set 1,which is farthest from sink node has the priority to relay through it. The rest node(s) in set 1 shall find out next available shortest distance node in set 2 for relaying its load

To address the above algorithm in our network set up, we divided the sensor nodes in following two groups: a) a set of sensor nodes which are within the average load distance ring and b) sensor nodes which are out side of the average load distance ring. Formation of sets within a cluster is shown in Figure 3.4.

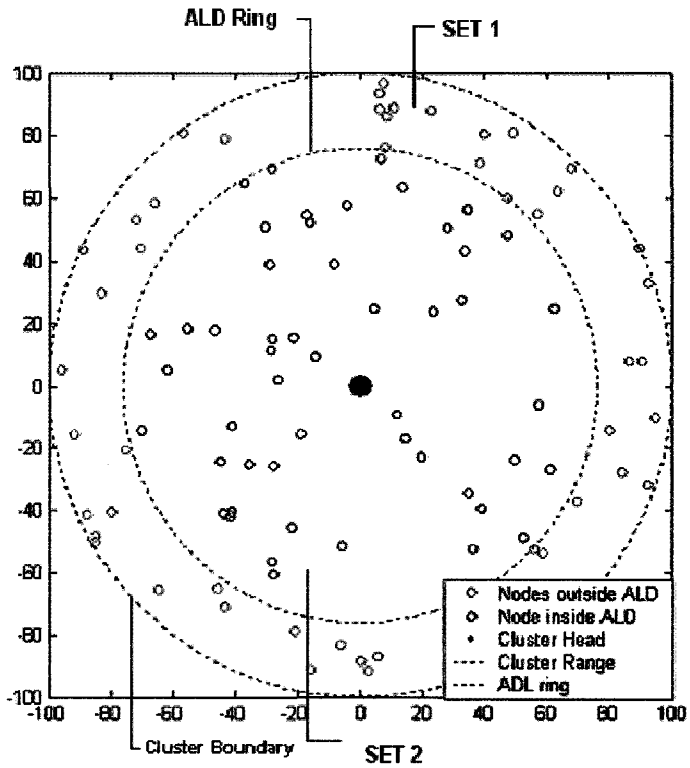


Figure 3.4: Two set of sensor nodes in a cluster

The average load distance is calculated on the basis of total load and number of sensor nodes under a cluster head. The sensor nodes inside the ALD ring work as routers in addition to their sensing tasks, to convey information data from nodes outside the ALD ring to the cluster head.

CHAPTER 4
EXPERIMENT AND RESULT

The algorithms developed in chapter 3 for the ALD communication model were coded in MATLAB. We described experiments and analysis of the results in this chapter.

4.1 Setup of environment

We have simulated our model with 100 sensor nodes and one cluster head or local base station. The sensor nodes are deployed randomly in a sensor field of radius varied from 20m to 100m. For simplicity, the cluster head was placed at (0, 0) coordinate. We assumed that each sensor node generates data at the rate of 1000 bits/round. The model described in section 3.2 is followed for calculation of transmitted and received energy consumption for data communications. In our simulation, the initial energy given to each sensor node was 0.5J. As discussed in Section 3.2 the energy consumption for transmitter and receiver electronics is 50 nJ/bit and for transmitter amplifier is 100 pJ/bit/m^2. The system lifetime is the time when death of a first node occur [21]. We have computed per round of transmission energy requirement for each of the sensor nodes to forward data towards the cluster head. From these energy data, we identified the maximum energy consuming sensor(s) of the cluster and found out the percentage of improvement of the ALD mode of communication model over direct mode of communication model.

4.2 Input and output parameters of the simulation model

input

a. The radius of cluster head
b. The number of nodes in cluster
c. Path loss exponent value

output

a. The maximum energy consumed by a node(s) for each transmission
    i. In direct mode
    ii. In ALD mode
b. The distance versus energy trend for
    i. Direct mode
    ii. ALD mode
c. The lifetime of network, measured in terms of the number of transmission round for
    i. Direct mode
    ii. ALD mode
d. Improvement of ALD over direct mode

4.3 Description of experiments and analysis

4.3.1 Experiment to calculate energy efficiency

The value of the path loss exponent, *n*, depends on the specific propagation environment. In an environment where obstructions are present in the line of sight of the radio signal, the path loss factors will have a larger value [17]. Generally low laying antennas are used to establish radio communication in wireless sensor networks. The low height of antenna results insufficient clearance, causing obstruction to the transmission path of the radio signal. In traveling through such an environment the radio signals encounter greater path losses then that of traveling through the free space environment. A path loss exponent, *n* equal to 2 is applied to free space propagation. Hence the value of *n* shall be greater then 2 for the radio path in the obstructed wireless sensor network. As described in Section 3.2.1, we considered a path loss value of 3 and 4 for our experiments. We ran the simulation model at a cluster radius of 100 m, 80 m, 60 m, 40 m and 20 m for each of path loss exponent value 3 and 4. For these run, we used the parameters and environment described in Section 4.1. A total of ten simulations were run in this phase of experiment.

4.3.1.1 Result and discussion

Table 4.1 shows the improvement of ALD over direct mode at different values of path loss exponent factor. Data indicates that ALD can up to 88% more efficient over Direct mode in terms of energy consumption. The table 4.1 also revealed that the improvement of ALD over the direct mode is proportional to the cluster radius irrespective of the value of path loss factor. It was also found that the proposed ALD model is more effective for increasing path loss factor.

Energy per node in Joule	Cluster radius in meter	Path loss exponent, n = 3			Path loss exponent, n = 4		
		Max energy consumed by a node(s) in ALD model	Max. energy consumed by a node(s) in Direct model	Improvement of ALD model	Max energy consumed by a node(s) in ALD model	Max. energy consumed by a node(s) in Direct model	Percent of improvement
0.5	100	6.883327e-002	9.905895e-002	43.911%	5.023665e+000	9.450911e+000	88.128%
0.5	80	3.569257e-002	5.067360e-002	41.972%	2.316836e+000	4.088323e+000	76.462%
0.5	60	1.559825e-002	2.151165e-002	37.911%	7.377528e-001	1.276021e+000	72.960%
0.5	40	4.674929e-003	6.318305e-003	35.153%	1.463029e-001	2.420308e-001	65.431%
0.5	20	6.683777e-004	8.473824e-004	26.782%	9.439443e-003	1.531898e-002	62.287%

Table 4.1: Life time improvement at different cluster radius and path loss factor

Figure 4.1 shows the energy dissipation curves for ALD and Direct mode. It indicates that energy consumption among the nodes in a cluster is less uneven in ALD mode while in Direct mode it is widely varied with distance from cluster head.

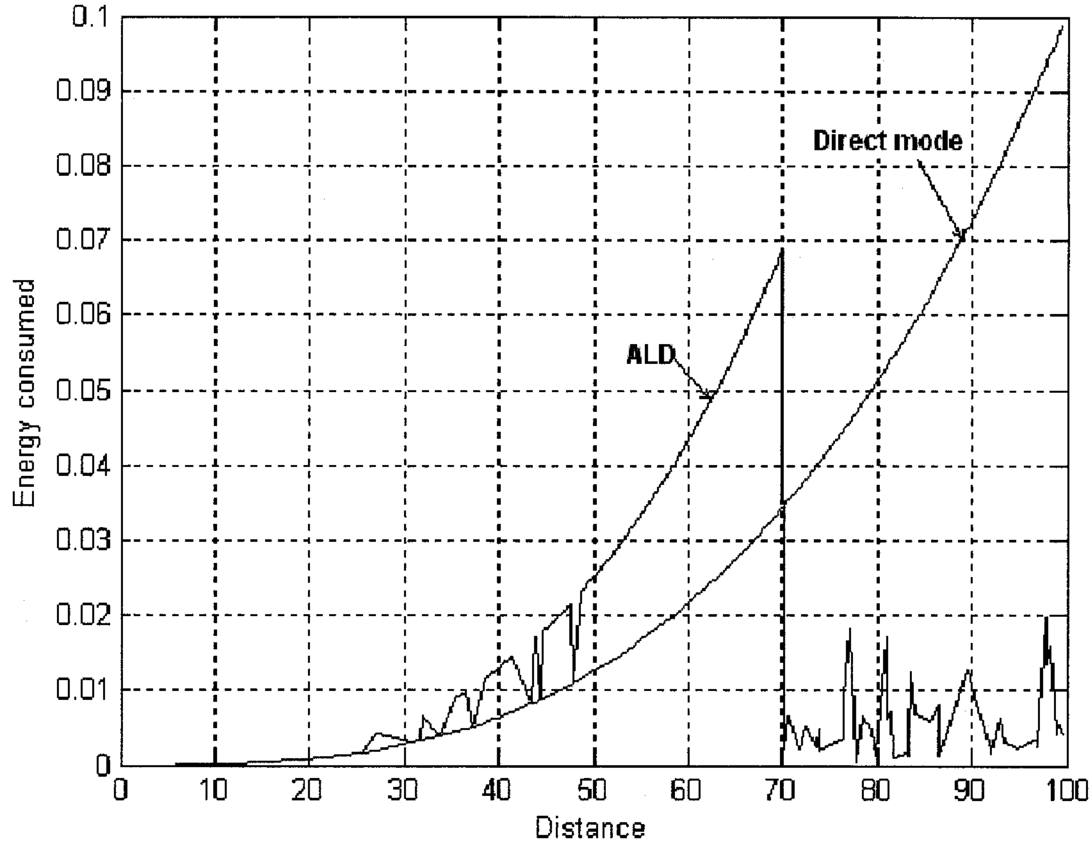
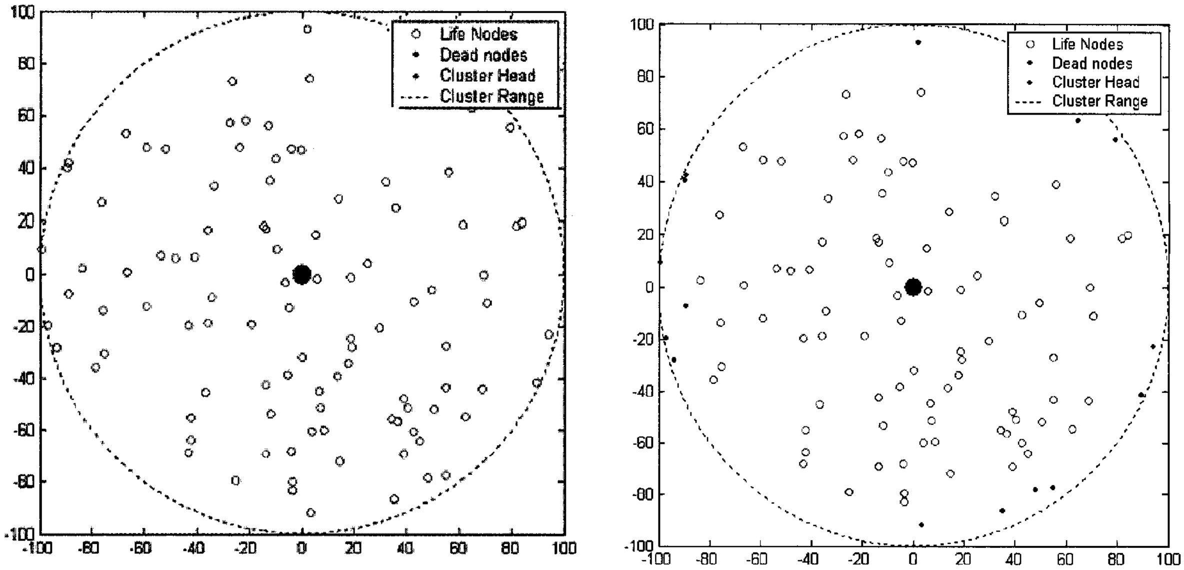


Figure 4.1: ALD and Direct mode per round energy dissipation curve

4.3.2 Experiment and analysis for life status of nodes

Experiment was also conducted to identify the life status of nodes in cluster. To find the status of nodes, the model was run for same number of transmissions at both ALD and direct mode of transmission. For this experiment a cluster with a radius of 100 meter was set up, with 100 nodes deployed randomly. The life status of the nodes obtained after 8 rounds of transmission with the path loss exponent factor of 3 is shown in Figure 4.2. The experiment result shows, for same rounds of transmission no dead node(s) for ALD mode of transmission where as 14% nodes were found dead in direct mode of transmission.



(a) (b)

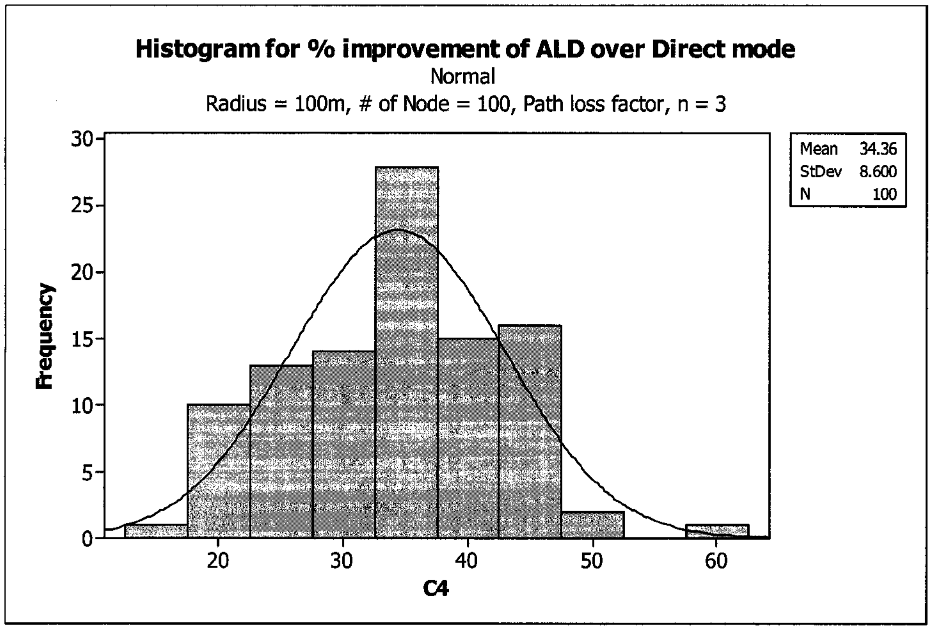
(a) ALD mode of transmission b) Direct mode of transmission

Figure 4.2: Life status of sensor in a 100 nodes cluster

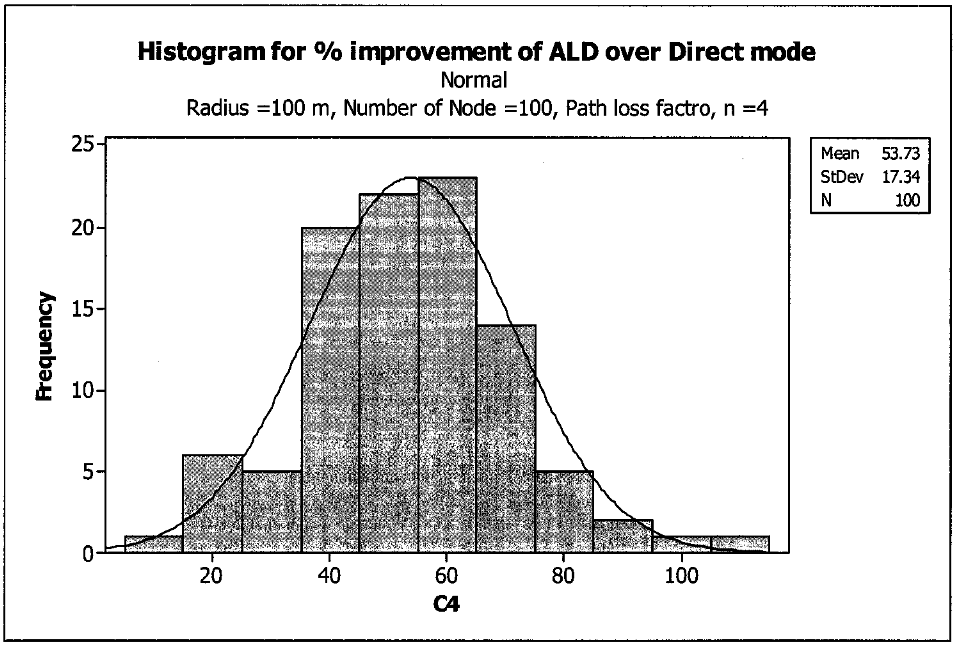
4.3.3 Experiment to draw statistical inference

We have conducted additional experiments to draw the statistical inference for percent improvement value in ALD transmission mode at different sets of uniformly randomly deployed nodes. In these experiments we kept the radius of cluster constant at 100m and run the program for 30 times for path loss factor value of 3 and 4 each. A total of 60 simulations were run in this phase of experiment. We recorded the percent improvement value for each of the experiment and found the mean and standard deviation for this percent improvement values.

Using these descriptive statistics we generated 100 values by using ProModel simulation software. The Stat::Fit option of ProModel was used to find the statistical



(a)



(b)

(a) Improvement of ALD for n =3 (b) Improvement of ALD for n=4

Figure 4.3: Histogram with normal distribution for percent Improvement in ALD with 100 nodes cluster of 100m radius

distribution for percent improvement in ALD mode. We used Chi Squared test, the Kolmogorov Smirnov test, and the Anderson Darling test for goodness of fit for the distribution. It was found that the normal distribution curve fits with the trend of the percent improvement in ALD mode. Figure 4.3 has shown the histogram with normal distribution (Minitab output). From the statistical analysis it was found that at a path loss factor of 3, the mean percent improvement for ALD mode is 34.38, standard deviation is 8.60 and the 95% confidence interval for ALD improvement average is 32.6944 to 36.0656 ($34.38 \pm 1.96\frac{8.6}{\sqrt{100}} = 34.38 \pm 1.6856$). At path loss factor 4, the mean percent improvement for ALD is 53.73, standard deviation is 17.34 and the 95% confidence interval for the ALD improvement average is 50.33 to 57.123 ($53.73 \pm 1.96\frac{17.34}{\sqrt{100}} = 53.73 \pm 3.39864$). It was also found that when path loss factor increased by 1, the improvement for ALD mode of transmission increased by 56.28%.

CHAPTER 5
APPLICATION OF ALD MODEL

In this section, an application of ALD model for wireless sensor network is presented. The application is to assess how our proposed model can save cost by prolonging the life time of wireless sensor networks.

5.1 Wireless sensor vs. wired sensor networks; market trends

Wireless sensor networks are being used in a variety of applications - from monitoring machine and structural stress in factories, to oil rigs, pipelines, bridges and buildings. The network can be also applied in monitoring and controlling secure access to high-value assets including shipping containers, important buildings or refrigerated perishables.

The advances in wireless sensor communication and electronics have accelerated the development of many wireless network solutions to replace the wired networks [48]. Although most of today's sensor networks are still wired, the wireless sensors have significant advantage over wired sensor network. The construction of any wire sensor network is time consuming and it can not be deployed in an application where immediate data collection is needed. This makes the wired sensor networks not useful in situations where there is need to sense the mobile objects and deployment has to rapid. Deployment of wired sensor networks will not only cost more, but is also hard to maintain and mend. Wireless sensor network eliminates the restriction of node position setup and has advantage in maintaining and mending over wire sensor networks. The potential of cost saving by use of wireless sensor networks over wired sensors is enormous. An obvious advantage of wireless transmission is a significant reduction and simplification in wiring infrastructure. The typical per-meter estimated wiring cost for wired sensor network in industrial installation is \$130 – \$650. This cost can be reduced by 20-80%, if wireless sensor network technology is adopted [50]. For example, BP Plc. installed five wireless sensors at its Cherry Point refinery in Washington to monitor the temperature inside giant on-site fans. Using wireless sensor node cost it \$500 per point monitoring, while the cost was \$10,000 for per point in old way of measurement [65].

The different types of sensors embedded in the node of wireless sensor network made it able to track, monitor and control wide variety of parameters including the following [1, 3]

- Temperature
- Humidity
- Vehicular movement
- Lighting conditions
- Pressure
- Soil make up
- Noise level
- Vibrations
- Present or absence of certain kind of objects
- Mechanical stress levels on attached objects and,
- The current characteristics such as speed, direction, and size of an object

The wireless sensor network marketplace is in the early stage of development but, a recent study by ABI Research suggests that the wireless sensor network market should begin to realize its potential in 2007 [58]. In 2005 the total deployed endpoints/nodes of wireless sensor network were 246,000 but it may rise to 41 million by 2010. The projected growth of wireless sensor network nodes is shown in Figure 5 [59]. An estimated value of \$5.3 billion for the industrial control segment only shall be opened for wireless sensor networks in 2010 [59]. According to another aggressive forecast [60] there could be total $8 billion market in 2010 for all wireless sensor networks, up from $300 million in 2006. A study by ON World found that besides saving hundreds or thousands of dollars per hour on labor for installation of wire sensor network, wireless sensors can be installed and monitored in places which previously were not considered, as they were prohibitively expensive with wire sensor networks [59].

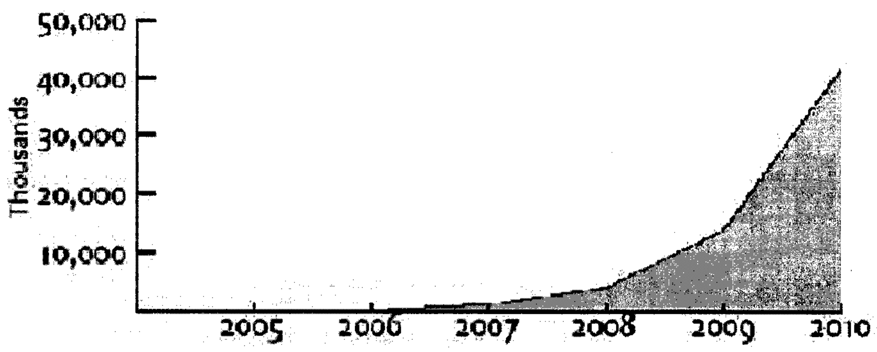


Figure 5.1: Thousands of endpoints deployed, 2005 – 2010

5.2 Case Study – Bridge Health Monitoring

The combined civil structures assets of USA and Canada have an estimated value of US$25 trillion [57]. Precisely detecting, localizing and estimating the extent of damage of such structures and hence assessing the residual life of these structures have a great social and economic impact. Structural health monitoring is the process of detection/identification of damage to the structure by continuous monitoring of its status. Timely and detailed assessment of the damage may not always be possible by visual inspection of the structure alone. To ensure safety and to undertake the conditioned based maintenance of civil infrastructures, autonomous monitoring in order to continuously collect the information about the health of the structures over its operational life time. Structures like bridges are vulnerable component of the transportation system. An out of service bridge could cause the losses to both lives and resources. The invisible damage to the bridge can occur due to an earthquake, traffic vibration, wind and environmental conditions such as temperature, humidity, salinity etc. In September 30, 2006, a 20 meter section of highway overpass at Laval of Montreal, Canada has collapsed. It caused severe casualties of lives and negatively affected the local economy through disruption of transportation systems. Such losses due to catastrophic failure of structures can be avoided if the transport authority is aware of the symptoms at early-stage by analyzing of the data collected through autonomous remote monitoring. A near real time structural monitoring of a civil structure reduces the risks of loss of human lives by warning of hazardous structures and preventing the collapses through providing the information to emergency response services ahead of time [55]. The extent of damage, casualty and disruption can be assessed almost immediately by real time acquisition of data from the array of sensors of the network. In summary, the real-time health monitoring technology has a great importance to the economics and society to minimize risks associated with the highway bridges in transportation systems. The reduced price and rapid development of key technologies such as sensors, microprocessors, wireless networks and integrated circuits makes it possible to provide real-time wireless sensor network for such structural health monitoring system, instead of high cost and vulnerable cabled based system.

In [55] author proposed a two-tier wireless sensor network for structural monitoring systems for civil infrastructure. In their work a two-tierd WSN are proposed and adopted LEACH [6] as their communication protocol. They portioned the system into two sub-systems: the lower tier sub-system, consisting of low data rate, low transmission range and energy constrained sensor nodes; and the upper tier sub-system, consisting of high data rate, long transmission range with no energy constraints.

The wireless sensor system has to support long-term monitoring of structural health in order to minimize the operating cost and maximize the utility of the structure. To achieve this goal through establishing the wireless sensor network, the sensor nodes should be energy efficient so that overall life time of the network can prolong for maximum possible period. Our proposed ALD communication model can be used to facilitate prolonged life time of wireless sensor network for such structure monitoring systems. The LEACH protocol uses rotation of the cluster heads. The lower tier sensor nodes in a cluster communicate with their elected cluster heads using single hop or direct mode of communication. Figure 5.2 has shown a typical snapshot of direct mode of communication for lower tier of LEACH protocol. The cluster head aggregate the data and transmits it to a distant station. In LEACH protocol, Instead of using direct mode of communication we can apply our proposed ALD mode of communication for the lower

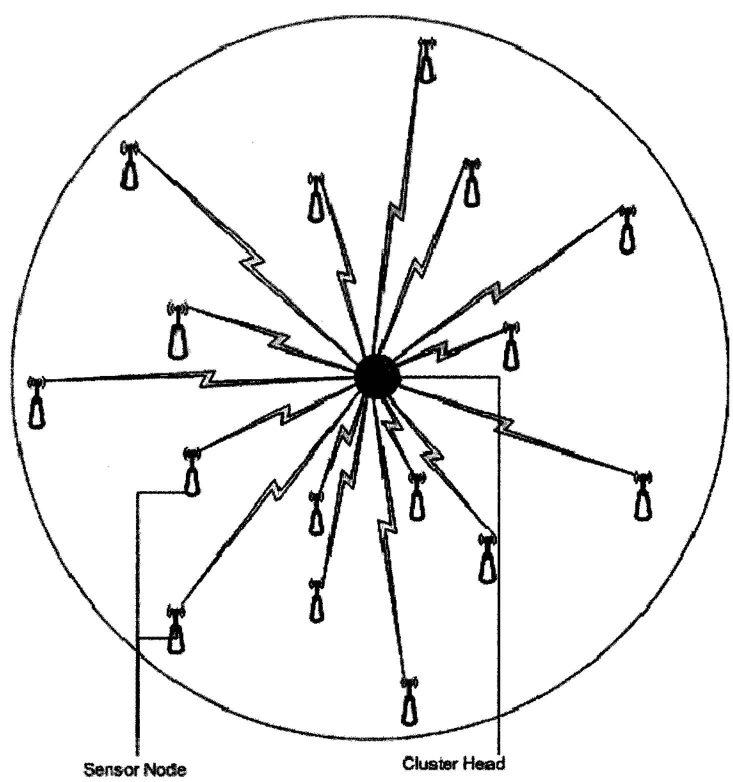


Figure 5.2: Typical direct mode communication for lower tier

tier dynamic cluster of LEACH protocol. Figure 5.3 shows a typical ALD mode application in the lower tier of a two-tiered sensor network for information transmission in a bridge monitoring systems.

Consider a bridge of 60 meter width and 300 m span with an estimated operating life of 50 years. If we made a cluster of 30 nodes with cluster radius of 60 meters then to monitor the health of 300 meters long bridge with two tier sensor network, minimum five clusters will be required. For bridge status monitoring the nodes can be deployed in deterministic way. In our case study we deployed nodes in a cluster randomly and assumed that the sensor nodes in all other clusters are placed in similar configuration.

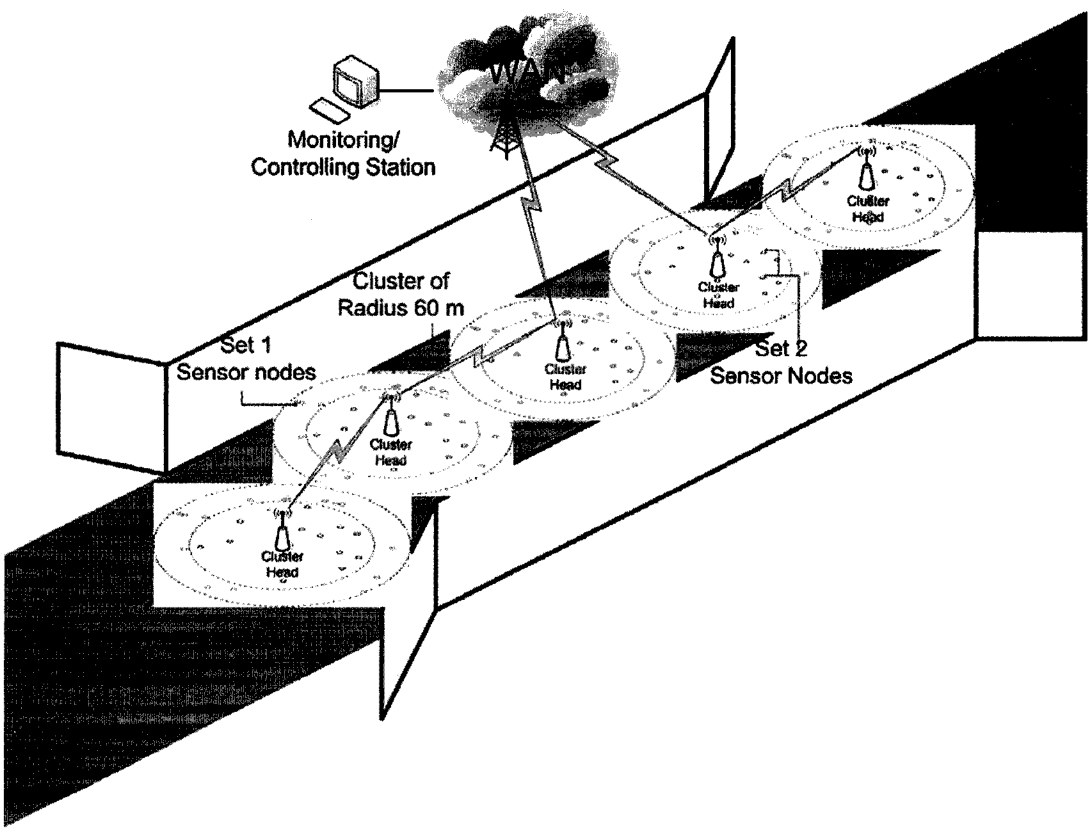


Figure 5.3: Application of ALD mode in two-tiered WSN for bridge health monitoring

5.2.1 Proposed Hardware and set up cost

For this study we proposed to use MICA2 series mote in the lower tier and MICAz series mote as cluster head in the upper tier of two-tier wireless sensor network. The MICA2 mote is equipped with Atmel ATMega's microcontroller running on 868/916 MHz multi-channel RF transceiver. The maximum raw data rate i. e. nominal bandwidth of MICA2 is 19.2 Kbps. It is powered with $2 \times$AA batteries. The MICAZ mote is equipped with Atmel ATMega's 128L microcontroller. The MICAz transceiver is 250 Kbps multi-channel IEEE 802.15.4/ZeegBee complaint RF radio. Both the proposed upper and lower tier transceivers are designed for 1000+ points wireless sensor nodes application. For storing the measured data, 512 KB of serial flash memory are available in these motes configuration [61]. A sensor board with Analog Device's ADXL210 accelerometer is proposed to attach to the main mote. The ADXL210 is low cost, -/+10 g, dual-axis MEMS acceleration sensor on a single IC chip having shock withstand capability of 1000 g.

To setup the network following hardware is required [61]: –

Item	Description of materials	Qty.	Unit price $	Total price $
1.	MICA2 Motes with connectors and housing	150	216.00	32,400.00
2.	MICAz Motes with connectors and housing	5	216.00	1,080.00
3.	MTS 300 Sensor board with ADXL 210 Accelerometer	150	138.00	20,700.00
4.	MIB 520 Interface Board	5	109.00	545.00
			Total Hardware cost	**54,725.00**

In the overall IT computing infrastructure, 19% is comprised of hardware costs [62]. This implies a computing infrastructure of our above set has a cost of $2, 88,026.00. Software accounts for 9% of the typical computing structure [62], which implying a total software cost for the network $25,922.00. Thus the total estimated cost for set up of the proposed wireless sensor network monitoring system is $313,948.00.

We run our model with following parameters: path loss factor, n = 4; per round sensor node data transmission 1000 bits; 30 numbers of nodes in a cluster; and cluster of radius of 60 meters. The simulation result shows up to 85% improvement in respect to energy consumption by our proposed ALD over Direct mode of communication.

5.2.2 Network life time and cost savings

The lithium primary batteries are ideal for remote wireless sensing [64]. For our proposed motes of the network, 2 numbers of AA type batteries are required. We could consider 1.5 V primary ultra high capacity LF-AA2900 Lithium batteries for nodes of proposed network. The capacity of this type Lithium battery is 2900mAh [63].

The total watt-hour for 2 $\times$ AA type battery = 3v $\times$ 2,900mAh = 8.70 watt-hour.

1 Joule = 2.777 778 $\times$ 10^{-4} watt – hour

Or 1 watt–hour = 3,600 joule

Hence 8.70 watt-hour = 31,320 Joules

For this network configuration, simulation results show the following maximum energy requirement per round:

Direct mode is 1.997937 $\times$ 10^{-2} joules

ALD mode is 1.078052 $\times$ 10^{-2} joules

So the total number of rounds for each transmission of 1000 bits is:

1,567,617 rounds in Direct mode

2,905,240 rounds in ALD mode

Now if we set up the network so that the each sensor node transfers data to the cluster head at every 1 minutes then the life of the network for –

Direct mode = $1567617 \div (365 \times 24 \times 60) = 2.9825 \approx 3$ years

ALD mode = $2905240 \div (365 \times 24 \times 60) = 5.527 \approx 5.5$ years

In 50 years estimated operating life of the bridge, the number of times nodes' battery replacement required is:

In Direct mode at every 3 years or $(50 \div 3) = 16.67 \approx 17$ times and

In ALD mode in every 5.5 years or $(50 \div 5.5) = 9$ times

The one time cost for replacing the batteries in a 100 sensor nodes installation is $1,000 and above [56]. So for network of 150 sensor nodes, the one time battery replacement cost should be $1,500 and higher. Then the replacement cost during the operation life time of the bridge is:

In Direct mode = $\$1{,}500 \times 17 = \$25{,}500.00$ and

In ALD mode = $\$1{,}500 \times 9 = \$13{,}500.00$

Thus in the sample bridge monitoring case of study, our proposed ALD mode of radio communication can have operating cost savings of

$((25{,}500.00 - 13{,}500.00) \div 13{,}500.00) \times 100 = 88.88\% \approx 89\%$

over Direct mode radio communication.

The battery replacement cost during the life time of the bridge:

In Direct mode is 8.1% and

In ALD mode 4.3%

of the capital investment for setting up the bridge monitoring wireless sensor network.

CHAPTER 6
CONCLUSIONS

6.1 Conclusions

From the literature review it can be concluded that the wireless sensor networks are composed of battery-powered sensor nodes. The battery-powered nodes of network are intended to operate in unattended manner for monitoring and surveillance of the applications. The data communication among the nodes of these networks should be energy-efficient so that the overall life time of the network can be prolonged in order to avoid battery replacement. Moreover, these networks are to be deployed in inhospitable physical environment, so the replacement of exhausted battery is not feasible for nodes in the networks. This constraint of node power is to be addressed while design such network. The life time of the network can be prolonged if the efficient way of data transfer from the node to the cluster head is designed. This objective necessitates developing of energy–efficient communication technique that makes less non-uniform and less energy drainage for information processing among nodes of the network.

In this thesis, an energy efficient radio communication model named Average Load Distance (ALD) Model is developed for data communication from the sensor nodes to the sink node/cluster head of the network. In convention, direct and multi-hope modes of communication are used to transfer data from sensor nodes to the sink node/cluster head. In these modes of communication the nodes nearer to the sink or the nodes farthest from the sink die out faster. Such drawback results the reduction of the over all network life time. The objective of our developed ALD mode of radio communication model is to minimize the possibility that particular node(s) drain its battery faster than the other nodes in the network. And hence saves the operating cost of the network by prolonging the overall life time of the network. In the proposed mode of transmission the main energy consumption factor, the transmission distances, are controlled dynamically to minimize the differences in gap of energy dissipation among the nodes.

6.2 Research Contribution

ALD mode of radio communication reduces the speed of depletion of battery energy for nodes farthest from or nearest to the sink nodes. The mechanism is very important because, it minimizes the non-uniformity of energy consumption among the nodes in a cluster and hence maximizes the overall life of the network. Experimental result shows that the proposed ALD can be up to 88% more efficient than direct mode of communication in respect of energy consumption. A mean percent improvement of 34.38 for path loss factor 3 and 53.73 for path loss factor 4 was found for ALD over direct mode, where 100 sensor nodes were randomly deployed in a cluster of 100 m radius. Sample application of ALD for bridge health monitoring with the set up of 30 nodes in a 60 m cluster radius shows that the proposed approach can save up to 89% operating cost over direct mode of communication. Based on our experiment and application described in chapter 4 and 5, we are confident that the ALD mode of data communication will outperform conventional direct and multi-hop mode of communication in respect of energy consumption among the nodes and overall lifetime of the network. Application of ALD mode of communication in the sensor network lowers the network operating cost and shall pave the way towards deployment of future sensor networks in monitoring and controlling the physical world.

6.3 Limitations

Although experimental and application results shows that ALD mode performs well with respect to energy efficiency routing and global energy balancing in the sensor networks, it has some limitations too. For instance, the ALD mode in its current form is not applicable for three dimensional fields as the algorithm is developed for sensor nodes deployed in two dimension field. When topology of the deployed network changes due to the failure of any node(s), the under laying data link layer of the network takes care and cope with the changed topology. ALD algorithm did not define how to synchronize with such a situation. ALD model of data communication will significantly improve the network life, even though there are ample avenues of improving the model.

6.3 Recommendations for Future Research

The present work can be further extended in a number of ways as outlined below:

- In the current work we considered that each node generates equal amount of data i.e. we considered homogeneous environment of data generation. In future work, the ALD model can be tested in the scenarios of heterogeneous data generation. This will lead the study closer to the real environment of data generation.
- In this work we have assumed that communication environment is contention and error free; the future work may take consideration of underlying medium access protocol and investigate how it affect the transmission energy in ALD communication mode.
- The effect on the overall lifetime of network when the transmission mode rotates in between ALD, direct and multi-hop mode at some pre-compute transmission rounds can be studied in the future works.

All of the above-mentioned works remain open for further study. Though these will be challenging works but the study will make significant contribution in extending the lifetime of sensor network.

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APPENDIX – I

Matlab Programming Script for Simulation of ALD model

```
clear, clc;
     % ASKED USER TO INPUT DESIRED NODE NUMBERS

fprintf('Enter or input the number of Sensor Nodes in cluster=');
     %VARIABLE TO STORE THE INPUT NODE NUMBERS
num_sens_cord = input(' ');
%num_sens_cord =100;

     %ASKED USER TO INPUT DESIRED CLUSTER RADIUS

fprintf('Enter Radius of cluster=');

     %VARIABLE TO STORE THE INPUT CLUSTER RADIUS

clus_rad = input(' ');
%clus_rad = 100;

     % NUBER OF REQURIED NUMBER OF NODE LOCATIONS TO BE
     %GENERATED RANDOMLY
    sng = num_sens_cord+50;

     %PER BIT ENERGY DISSIPATION BY TRANSMITTER AND RECEIVER
     %ELECTRONICS

Tx_elec=50*10^(-9);
Rx_elec=Tx_elec;

     %PER BIT ENERGRY DISSIPATION BY OPERATIONAL APMLIFIER

Tx_amp = 100*10^(-12);

     % PATH LOSS EXPONENT FACTOR, n
path_loss_fac = 3;

     % INITIAL BATTERY ENERGY IN JOULS FOR EACH SENSOR NODES
ini_sens_energy = 0.5;

     %PER ROUND INFORMATION BIT GENERATION BY A SENSOR NODE

     b=1000;
```

```
    %TABLE FOR STORING PER ROUND ENERGY CONSUMED BY A
    %NODE IN TRANSMISSION INFORMATION
Tx_energy_table= zeros(num_sens_cord, 1);

    %TABLE TO STORE TOATAL CONSUMED BY A NODED TO FOREARD
    %DATA TO CLUSTER HEAD

dir_tx_energy = ones(num_sens_cord, 1);

    %CLUSTER HEAD'S POSITION
clust_cen =zeros(1,2);

    %TABLE TO HOLD DISTANCE OF A SENSOR NODE FORM CLUSTER
    %HEAD
dist_clus_sens = ones(num_sens_cord, 1);

    %TABLE TO HOLD CO-ORDINATES (LOCATIONS) OF DEPLOYED
    %SENSOR NODES

sens_cord=ones(num_sens_cord, 2);
l=length(sens_cord);
sens_count=1;

    %TABLE TO HOLD RESIDUAL ENEGRY OF NODES

dir_res_energy = zeros (num_sens_cord, 1);
adl_res_energy =zeros(num_sens_cord, 1);


    %INITIALIZE RESIDUAL ENERGY TABLE WITH INITIAL BATTERY
    %ENERGY OF NODE

for i=1:num_sens_cord
  dir_res_energy(i) = ini_sens_energy ;
  adl_res_energy(i)= ini_sens_energy ;
end

    % GENERATION OF SENSOR NODES LOCATIONS RANDOMLY

z=rand(sng,2);
%p = ((clus_rad) - (-clus_rad))*z +(-clus_rad);

    %STORES IN AND RETRIVE FORM THE FILES THE LOCATIONS OF
    NODES GENERATED RANDOMLY FOR n=3
    %CLUSTER RADIUS = 100M TO 20M
```

```
%dlmwrite('coordSensorGenFor100n100r.txt',p);
%p = load('coordSensorGenFor100n100r.txt');

%dlmwrite('coordSensorGenFor100n80r.txt',p);
%p = load('coordSensorGenFor100n80r.txt');

%dlmwrite('coordSensorGenFor100n60r.txt',p);
%p = load('coordSensorGenFor100n60r.txt');

%dlmwrite('coordSensorGenFor100n40r.txt',p);
%p = load('coordSensorGenFor100n40r.txt');

%dlmwrite('coordSensorGenFor100n20r.txt',p);
%p = load('coordSensorGenFor100n20r.txt');

%dlmwrite('coordSensorGenFor10n100r.txt',p);
%p = load('coordSensorGenFor10n100r.txt');


    %STORES IN AND RETRIVE FROM FILES THE NODES LOCATIONS
    %FOR STATISTICAL INFERENCE FOR IMPROVEMENT BY ALD OVER
    %DIRECT FOR n = 3,

%dlmwrite('coordSensorGenFor100n100r1.txt',p);
%p = load('coordSensorGenFor100n100r1.txt');

%dlmwrite('coordSensorGenFor100n100r2.txt',p);
%p = load('coordSensorGenFor100n100r2.txt');

%dlmwrite('coordSensorGenFor100n100r3.txt',p);
%p = load('coordSensorGenFor100n100r3.txt');

%dlmwrite('coordSensorGenFor100n100r4.txt',p);
%p = load('coordSensorGenFor100n100r4.txt');

%dlmwrite('coordSensorGenFor100n100r5.txt',p);
%p = load('coordSensorGenFor100n100r5.txt');

%dlmwrite('coordSensorGenFor100n100r6.txt',p);
%p = load('coordSensorGenFor100n100r6.txt');

%dlmwrite('coordSensorGenFor100n100r7.txt',p);
%p = load('coordSensorGenFor100n100r7.txt');

%dlmwrite('coordSensorGenFor100n100r8.txt',p);
%p = load('coordSensorGenFor100n100r8.txt');
```

```
%dlmwrite('coordSensorGenFor100n100r9.txt',p);
%p = load('coordSensorGenFor100n100r9.txt');

%dlmwrite('coordSensorGenFor100n100r10.txt',p);
%p = load('coordSensorGenFor100n100r10.txt');


%dlmwrite('coordSensorGenFor100n100r11.txt',p);
%p = load('coordSensorGenFor100n100r11.txt');

%dlmwrite('coordSensorGenFor100n100r12.txt',p);
%p = load('coordSensorGenFor100n100r12.txt');

%dlmwrite('coordSensorGenFor100n100r13.txt',p);
%p = load('coordSensorGenFor100n100r13.txt');

%dlmwrite('coordSensorGenFor100n100r14.txt',p);
%p = load('coordSensorGenFor100n100r14.txt');

%dlmwrite('coordSensorGenFor100n100r15.txt',p);
%p = load('coordSensorGenFor100n100r15.txt');

%dlmwrite('coordSensorGenFor100n100r16.txt',p);
%p = load('coordSensorGenFor100n100r16.txt');

%dlmwrite('coordSensorGenFor100n100r17.txt',p);
%p = load('coordSensorGenFor100n100r17.txt');

%dlmwrite('coordSensorGenFor100n100r18.txt',p);
%p = load('coordSensorGenFor100n100r18.txt');

%dlmwrite('coordSensorGenFor100n100r19.txt',p);
%p = load('coordSensorGenFor100n100r19.txt');

%dlmwrite('coordSensorGenFor100n100r20.txt',p);
%p = load('coordSensorGenFor100n100r20.txt');

%dlmwrite('coordSensorGenFor100n100r21.txt',p);
%p = load('coordSensorGenFor100n100r21.txt');

%dlmwrite('coordSensorGenFor100n100r22.txt',p);
%p = load('coordSensorGenFor100n100r22.txt');

%dlmwrite('coordSensorGenFor100n100r23.txt',p);
%p = load('coordSensorGenFor100n100r23.txt');
```

```
%dlmwrite('coordSensorGenFor100n100r24.txt',p);
%p = load('coordSensorGenFor100n100r24.txt');

%dlmwrite('coordSensorGenFor100n100r25.txt',p);
%p = load('coordSensorGenFor100n100r25.txt');

%dlmwrite('coordSensorGenFor100n100r26.txt',p);
%p = load('coordSensorGenFor100n100r26.txt');

%dlmwrite('coordSensorGenFor100n100r27.txt',p);
%p = load('coordSensorGenFor100n100r27.txt');

%dlmwrite('coordSensorGenFor100n100r28.txt',p);
%p = load('coordSensorGenFor100n100r28.txt');

%dlmwrite('coordSensorGenFor100n100r29.txt',p);
%p = load('coordSensorGenFor100n100r29.txt');

%dlmwrite('coordSensorGenFor100n100r30.txt',p);
%p = load('coordSensorGenFor100n100r30.txt');

    %STORES IN AND RETRIVE FORM THE FILES THE LOCATIONS OF
    %NODES GENERATED RANDOMLY FOR n=3 FOR n = 4,CLUSTER
    %RADIUSF = 100m TO 20M AND #OF NODES 100

%dlmwrite('coordSensorGenFor100n100rn4.txt',p);
%p = load('coordSensorGenFor100n100rn4.txt');

%dlmwrite('coordSensorGenFor100n80rn4.txt',p);
%p = load('coordSensorGenFor100n80rn4.txt');

%dlmwrite('coordSensorGenFor100n60rn4.txt',p);
%p = load('coordSensorGenFor100n60rn4.txt');

%dlmwrite('coordSensorGenFor100n40rn4.txt',p);
%p = load('coordSensorGenFor100n40rn4.txt');

%dlmwrite('coordSensorGenFor100n20rn4.txt',p);
%p = load('coordSensorGenFor100n20rn4.txt');
```

```
%STORES IN AND RETRIVE FROM FILES THE NODES LOCATIONS TO
%DRAW STATISTICAL INFERENCE OF IMPROVEMENT BY ALD OVER
%DIRECT FOR n = 4, CLUSTER RADIUS = 100m AND #OF NODES 100

%dlmwrite('coordSensorGenFor100n100r1n4.txt',p);
%p = load('coordSensorGenFor100n100r1n4.txt');

%dlmwrite('coordSensorGenFor100n100r2n4.txt',p);
%p = load('coordSensorGenFor100n100r2n4.txt');

%dlmwrite('coordSensorGenFor100n100r3n4.txt',p);
%p = load('coordSensorGenFor100n100r3n4.txt');

%dlmwrite('coordSensorGenFor100n100r4n4.txt',p);
%p = load('coordSensorGenFor100n100r4n4.txt');

%dlmwrite('coordSensorGenFor100n100r5n4.txt',p);
%p = load('coordSensorGenFor100n100r5n4.txt');

%dlmwrite('coordSensorGenFor100n100r6n4.txt',p);
%p = load('coordSensorGenFor100n100r6n4.txt');

%dlmwrite('coordSensorGenFor100n100r7n4.txt',p);
%p = load('coordSensorGenFor100n100r7n4.txt');

%dlmwrite('coordSensorGenFor100n100r8n4.txt',p);
%p = load('coordSensorGenFor100n100r8n4.txt');

%dlmwrite('coordSensorGenFor100n100r9n4.txt',p);
%p = load('coordSensorGenFor100n100r9n4.txt');

%dlmwrite('coordSensorGenFor100n100r10n4.txt',p);
%p = load('coordSensorGenFor100n100r10n4.txt');


%dlmwrite('coordSensorGenFor100n100r11n4.txt',p);
%p = load('coordSensorGenFor100n100r11n4.txt');

%dlmwrite('coordSensorGenFor100n100r12n4.txt',p);
%p = load('coordSensorGenFor100n100r12n4.txt');

%dlmwrite('coordSensorGenFor100n100r13n4.txt',p);
%p = load('coordSensorGenFor100n100r13n4.txt');

%dlmwrite('coordSensorGenFor100n100r14n4.txt',p);
```

```
%p = load('coordSensorGenFor100n100r14n4.txt');

%dlmwrite('coordSensorGenFor100n100r15n4.txt',p);
%p = load('coordSensorGenFor100n100r15n4.txt');

%dlmwrite('coordSensorGenFor100n100r16n4.txt',p);
%p = load('coordSensorGenFor100n100r16n4.txt');

%dlmwrite('coordSensorGenFor100n100r17n4.txt',p);
%p = load('coordSensorGenFor100n100r17n4.txt');

%dlmwrite('coordSensorGenFor100n100r18n4.txt',p);
%p = load('coordSensorGenFor100n100r18n4.txt');

%dlmwrite('coordSensorGenFor100n100r19n4.txt',p);
%p = load('coordSensorGenFor100n100r19n4.txt');

%dlmwrite('coordSensorGenFor100n100r20n4.txt',p);
%p = load('coordSensorGenFor100n100r20n4.txt');

%dlmwrite('coordSensorGenFor100n100r21n4.txt',p);
%p = load('coordSensorGenFor100n100r21n4.txt');

%dlmwrite('coordSensorGenFor100n100r22n4.txt',p);
%p = load('coordSensorGenFor100n100r22n4.txt');

%dlmwrite('coordSensorGenFor100n100r23n4.txt',p);
%p = load('coordSensorGenFor100n100r23n4.txt');

%dlmwrite('coordSensorGenFor100n100r24n4.txt',p);
%p = load('coordSensorGenFor100n100r24n4.txt');

%dlmwrite('coordSensorGenFor100n100r25n4.txt',p);
%p = load('coordSensorGenFor100n100r25n4.txt');

%dlmwrite('coordSensorGenFor100n100r26n4.txt',p);
%p = load('coordSensorGenFor100n100r26n4.txt');

%dlmwrite('coordSensorGenFor100n100r27n4.txt',p);
%p = load('coordSensorGenFor100n100r27n4.txt');

%dlmwrite('coordSensorGenFor100n100r28n4.txt',p);
%p = load('coordSensorGenFor100n100r28n4.txt');

%dlmwrite('coordSensorGenFor100n100r29n4.txt',p);
%p = load('coordSensorGenFor100n100r29n4.txt');
```

```
%dlmwrite('coordSensorGenFor100n100r30n4.txt',p);
%p = load('coordSensorGenFor100n100r30n4.txt');



    %REMOVE THE SENSOR NODES WHIC ARE OUT SIDE OF CLUSTER
    %RADIUS OR IF THE NUMBER OF SENSOR MORE THAN THE
    %DESIRED NODES

for i=1:sng

  dist=sqrt(p(i, 1)^2 + (p(i, 2))^2);
  if (dist<=clus_rad)&(sens_count<num_sens_cord+1)
      dist_clus_sens (sens_count, 1)= dist;
      sens_cord(sens_count, 1)= p(i, 1);
      sens_cord(sens_count, 2) = p(i, 2);
      sens_count = sens_count +1;

  end
 end

disp(sens_cord);


     %PLOTTING TO SEE THE PSITION OF GENERATED SENSOR NODES
    %IN A CLUSTERCODE (FIGURE 1)

scatter_plotX=ones(num_sens_cord, 1);
scatter_plotY=ones(num_sens_cord, 1);

for i=1:num_sens_cord
  scatter_plotX(i) = sens_cord(i, 1);
  scatter_plotY(i) = sens_cord(i, 2);
end


x=0;
y =0;
theta =linspace(0,2*pi, 1000);
x1 = clus_rad*cos(theta);
y1 = clus_rad*sin(theta);

Figure(1);
plot(scatter_plotX, scatter_plotY,'ob', 'markersize', 5);
hold on;
```

```
plot(x,y,'.r', 'markersize', 40);
hold on;
plot (x1, y1,':k','markersize', 10);
hold on;
legend('Sensor Node','Cluster Head','Cluster Range');
%grid on;

    %END OF PLOTTING FIG. 1


    %DISPLAY THE DISTANCE OF SENSOR NODES FROM CLUSTER
    %HEAD

fprintf('Cluster head to sensor distance: \n\n');
disp(dist_clus_sens);


    %DIRECT MODE ENERGY CONSUMPTION CALCULATION

for i=1:l
  Tx_energy_table(i, 1) = Tx_amp*b*(dist_clus_sens(i,1))^ path_loss_fac;
  dir_tx_energy(i,1)=Tx_elec*b + Tx_energy_table(i, 1) ;
end

    %FIND OUT THE MAXIMUM ENEGRY CONSUMPTION PER ROUND OF
    %TRANSMISSION

[dmode_energy, i] = max(dir_tx_energy);

    %SORTING THE DISTANCE OF SENSOR NODES FORM THE CLUSTER
    %HEAE
[sort_clus_sens_dist, in]=sort(dist_clus_sens);

    %PLOTTING OF ENERGY VS. DISTANCE CURVE FOR DIRECT MODE
    %(FIGURE 2)

Figure(2);
plot(sort_clus_sens_dist,sort(dir_tx_energy));
title('Direct Mode Energy Cosumption for a Round');
xlabel('Distance');
ylabel('Energy consumed');
grid on;
%END OF FIG.2


     %FIND OUT THE LIFE TIME OF NETWORK IN DIRECT MODE
```

```
dir_tx_net_life = ini_sens_energy/ dmode_energy;

      %FIND OUT THE AVERAGE LOAD DISTANCE

avg_tx_energy = mean(Tx_energy_table);
avg_load_dist = ((avg_tx_energy - Tx_elec)/(b*Tx_amp))^inv(path_loss_fac);
fprintf('Average load distance for sensor nodes:\n\n');
disp(avg_load_dist);

      %MAKING TABLES FOR TWO SETS OF NODES: ONE SET WHICH
      %INSDE THE AVERAGE LOAD DISTANCE RING AND ANOTHER WHICH
      %ARE OUTSIDE THE AVERAGE LOAD DISTANCE

relay_node_sens_detail_1 = ones(I,4);
trans_node_sens_detail_1 = ones(I, 4);

relay_node_count = 1;
Trans_node_count = 1;
for i = 1:I

if dist_clus_sens(i, 1)>avg_load_dist

  trans_node_sens_detail_1(Trans_node_count, 1) = i;
  trans_node_sens_detail_1(Trans_node_count, 2)=dist_clus_sens(i, 1);
  trans_node_sens_detail_1(Trans_node_count, 3) = sens_cord(i, 1);
  trans_node_sens_detail_1(Trans_node_count, 4) = sens_cord(i, 2);
  Trans_node_count= Trans_node_count+1;
else
  relay_node_sens_detail_1(relay_node_count, 1) = i;
  relay_node_sens_detail_1(relay_node_count, 2)=dist_clus_sens(i, 1);
  relay_node_sens_detail_1(relay_node_count, 3) = sens_cord(i, 1);
  relay_node_sens_detail_1(relay_node_count, 4) = sens_cord(i, 2);
  relay_node_count= relay_node_count+1;
end
end
relay_node_count =relay_node_count -1;
Trans_node_count =Trans_node_count - 1;

relay_node_sens_detail = ones(relay_node_count,4);
trans_node_sens_detail = ones(Trans_node_count, 4);

for i=1:Trans_node_count
  trans_node_sens_detail(i, 1) = trans_node_sens_detail_1(i, 1);
  trans_node_sens_detail(i, 2)= trans_node_sens_detail_1(i, 2);
```

```
  trans_node_sens_detail(i, 3) = trans_node_sens_detail_1(i, 3);
  trans_node_sens_detail(i, 4) = trans_node_sens_detail_1(i, 4);
end

for i=1:relay_node_count
  relay_node_sens_detail (i, 1) = relay_node_sens_detail_1(i, 1);
  relay_node_sens_detail (i, 2) = relay_node_sens_detail_1(i, 2);
  relay_node_sens_detail (i, 3) = relay_node_sens_detail_1(i, 3);

 relay_node_sens_detail (i, 4) = relay_node_sens_detail_1(i, 4);
end

     %DISPLY FOR TRANSMISSON (SET 1) AND RELAY (STE 2) NODES
     %DETAILS

%fprintf('Transmission nodes details:\n');
%disp(trans_node_sens_detail);

%fprintf('Relay nodes details:\n');
%disp (relay_node_sens_detail);


%disp(Trans_node_count);
%disp(relay_node_count);

rely_node_dist = ones(relay_node_count, 1);

for i=1:relay_node_count

   rely_node_dist (i, 1)= relay_node_sens_detail (i, 2);
end

[ascending_rely_node_dist, indexr]  = sort( rely_node_dist );

%disp(ascending_rely_node_dist);
%disp(indexr);
sort_relay_node_sens_detail = ones(relay_node_count, 4);

 for i= 1:relay_node_count

  sort_relay_node_sens_detail (i, 1) = relay_node_sens_detail(indexr(i), 1);
  sort_relay_node_sens_detail (i, 2) = ascending_rely_node_dist(i);
  sort_relay_node_sens_detail (i, 3) = relay_node_sens_detail(indexr(i), 3);
  sort_relay_node_sens_detail (i, 4) = relay_node_sens_detail(indexr(i), 4);
end
```

```
%disp(sort_relay_node_sens_detail );


trans_node_dist = ones(Trans_node_count, 1);

for i=1:Trans_node_count


 trans_node_dist (i, 1)= trans_node_sens_detail (i, 2);
end

[ascending_trans_node_dist, indext]  = sort( trans_node_dist );


%disp(ascending_trans_node_dist);
%disp(indext);
des_sort_trans_node_sens_detail = ones(Trans_node_count, 4);
 dcount= Trans_node_count;

 for i= 1:Trans_node_count

  des_sort_trans_node_sens_detail (i, 1) =
     trans_node_sens_detail(indext(dcount), 1);
  des_sort_trans_node_sens_detail (i, 2) = ascending_trans_node_dist(dcount);
  des_sort_trans_node_sens_detail (i, 3) =
     trans_node_sens_detail(indext(dcount), 3);
  des_sort_trans_node_sens_detail (i, 4) =
     trans_node_sens_detail(indext(dcount), 4);
  dcount = dcount -1;
end

fprintf('Transmission nodes details:\n');
disp(des_sort_trans_node_sens_detail);

fprintf('Relay nodes details:\n');
disp (sort_relay_node_sens_detail);



     % PLOTTING FOR TWO SET OF SENSOR NODES IN A CLUSTER
     (FIGURE#3)

trans_set_nodes_Xcords = ones(Trans_node_count, 1);
trans_set_nodes_Ycords = ones(Trans_node_count, 1);

relay_set_nodes_Xcords = ones(relay_node_count, 1);
relay_set_nodes_Ycords = ones(relay_node_count, 1);
```

```
for i=1:Trans_node_count
   trans_set_nodes_Xcords(i, 1) =trans_node_sens_detail(i,3);
   trans_set_nodes_Ycords(i, 1) =trans_node_sens_detail(i,4);
end


for i=1:relay_node_count
  relay_set_nodes_Xcords(i, 1) =relay_node_sens_detail(i,3);
   relay_set_nodes_Ycords(i, 1) =relay_node_sens_detail(i,4);
end

bx=0;
by =0;
theta_1 =linspace(0,2*pi, 1000);
xt = avg_load_dist*cos(theta);
yt = avg_load_dist*sin(theta);
Figure(3);
plot(trans_set_nodes_Xcords, trans_set_nodes_Ycords,'om', 'markersize', 5);
hold on;
plot(relay_set_nodes_Xcords, relay_set_nodes_Ycords,'ok', 'markersize', 5);
hold on;
plot(bx,by,'.r', 'markersize', 40);
hold on;
plot (x1, y1,':k','markersize', 5);
hold on;
plot (xt, yt,':b','markersize', 5);
hold on;
legend ('Nodes outside ALD','Node inside ALD','Cluster Head ','Cluster Range',
     'ADL ring');
%grid on;

        %END OF FIGURE#3 PLOTTING



        %CALCULATION THE DISTANCE OF NODES IN SET
        %1(TRANSMISSION NODE) TO EACH NODE IN SET 2
         %(RELAY NODES)

trans_realy_node_distance=ones(Trans_node_count, relay_node_count);

for i= 1:Trans_node_count
   for j=1:relay_node_count
        d_trans_Xcord = des_sort_trans_node_sens_detail(i,3);
        d_trans_Ycord =des_sort_trans_node_sens_detail(i, 4);
```

```
        d_relay_Xcord = sort_relay_node_sens_detail(j, 3);
        d_relay_Ycord = sort_relay_node_sens_detail(j, 4);


        trans_realy_node_distance (i, j)= sqrt((d_trans_Xcord -d_relay_Xcord)^2
      + (d_trans_Ycord -d_relay_Ycord)^2);
    end
end

fprintf('Transmission to realay node distance table:\n');
disp(trans_realy_node_distance);
[min_dist, index]= min(trans_realy_node_distance');

Trans_node_minimum_distance_table=ones(num_sens_cord, 1);


display(min_dist);
display(index);
[ascending_sorted_distance, index_1]=sort(trans_realy_node_distance');
display (ascending_sorted_distance);

ascending_sorted_distance=ascending_sorted_distance';
index_21=index_1';

fprintf ('Minimum distance from tansmission -\n' );
%a = index';
for i=1:length(index)

  fprintf (' node#%d (to realy node#%d) = %.2f\n',
     trans_node_sens_detail(i),relay_node_sens_detail(index(i)), min_dist (i));
end


sort_dist_clus_sens_1 = sort(dist_clus_sens);
len_dt = length(sort_dist_clus_sens_1);
sort_dist_clus_sens = zeros(len_dt, 1);


for i= 1:len_dt
   sort_dist_clus_sens(i, 1) = sort_dist_clus_sens_1(len_dt, 1);
   len_dt = len_dt - 1;
end

     %FIND OUT THE NODES IN SET 2 WHICH WILL REALY THE LOADS IN
     %SET 1 AND CONFIRM THAT NO NODES IN SET 2 RALAY MORE THAN
     %ONE NODE'S LOAD IN SET 1.
```

```
disp(sort_dist_clus_sens);
hop_count_table=ones(num_sens_cord, 1);

for i=1:Trans_node_count

   h = des_sort_trans_node_sens_detail(i, 1);

   for j=1:relay_node_count
      a = sort_relay_node_sens_detail(index_21 (i, j));
      k = ascending_sorted_distance(i, j);
        if k<dist_clus_sens( h, 1) & hop_count_table(a)<2

           dist_clus_sens(h, 1) = k;
           hop_count_table(a)= hop_count_table(a)+1;

         else
        continue
      end
   end
end

fprintf('hop count table\n');
disp(hop_count_table);
disp(dist_clus_sens);


      %FIND OUT THE ENERGY DISSIPATION IN ALD MODE

Avg_dist_mod_tans_energy_table= ones(num_sens_cord, 1);

for i=1:length(hop_count_table)

   Tx_energy_table(i, 1) = Tx_amp*b*hop_count_table(i,
      1)*(dist_clus_sens(i,1)).^path_loss_fac;

   Rx_energy_consumed = (hop_count_table(i, 1)-1)*Rx_elec*b;
   Tx_energy_consumed = hop_count_table(i, 1)*Tx_elec*b;
   Avg_dist_mod_tans_energy_table(i,1)= Rx_energy_consumed +
      Tx_energy_consumed + Tx_energy_table(i, 1);
end

%FIND OUT MAX. ENEGRY CONSUMED IN A ROUND

Avg_mode_energy = max(Avg_dist_mod_tans_energy_table);
```

```
%DISPLAY MAX. ENERGY CONSUMED IN ALD AND DIRECT MODE

fprintf('ALD mode max. energy consume = %e\n',  Avg_mode_energy);
fprintf('Direct mode max. energy consume = %e\n',dmode_energy  );


%PLOTTING OF DISTANCE VS. ENERGY CONSUMPTION IN ALD AND
%DIRECT MODE

energy_table= ones(num_sens_cord, 1);
for i=1:num_sens_cord
   energy_table(i)=Avg_dist_mod_tans_energy_table(in(i));
end

Figure(4)
plot(sort_clus_sens_dist, energy_table);
hold on;
plot(sort_clus_sens_dist,sort(dir_tx_energy), 'r');
title('Average load Distance Mode Energy Cosumption for a Round');
xlabel('Distance');
ylabel('Energy consumed');
grid on;

%FIND OUT THE NUBER OF ROUNDS FOR ALD AND DIRECT MODE

avg_energy_dist_lifeTime = ini_sens_energy/Avg_mode_energy;

fprintf('Number of roud for ALD = %.3f\n',avg_energy_dist_lifeTime);
fprintf('Number of roud for Direct  = %.3f\n',dir_tx_net_life);

%FIND OUT THE PERCENT OF IMPROVEMENT OF ALD OVER DIRECT
%MODE
improv= ((avg_energy_dist_lifeTime -dir_tx_net_life)*100)/dir_tx_net_life;
fprintf('improvement over direct mode = %.3f\n',improv);

% FINDING LIFE STATUS OF NODES FOR DIRECT TRANSMISSION

round_d =0;
num_d_die_node=1;
num_d_life_node=1;
die_node_d_1 = zeros(round_d, 2);
life_node_d_1 = zeros(round_d, 2);

%DIRECT MODE

for j = 1:7
```

```
for i=1:num_sens_cord

      dir_res_energy (i) = dir_res_energy (i)-dir_tx_energy(i);
end
round_d = round_d +1;
end


for i = 1:num_sens_cord

   if dir_res_energy(i)>0
      life_node_d_1(num_d_life_node, 1) = sens_cord(i, 1);
      life_node_d_1(num_d_life_node, 2) = sens_cord(i, 2);
      num_d_life_node= num_d_life_node + 1;

   else
      die_node_d_1(num_d_die_node, 1) = sens_cord(i, 1);
      die_node_d_1(num_d_die_node, 2) = sens_cord(i, 2);
      num_d_die_node=num_d_die_node + 1;
   end
end

num_d_die_node = num_d_die_node-1;
num_d_life_node = num_d_life_node - 1;

die_node_d = zeros(num_d_die_node, 2);
life_node_d = zeros(num_d_life_node, 2);


for i = 1:num_d_life_node

      life_node_d(i, 1) = life_node_d_1(i, 1);
      life_node_d(i, 2) = life_node_d_1(i, 2);

 end

for i = 1:num_d_die_node

      die_node_d(i, 1) = die_node_d_1(i, 1);
      die_node_d(i, 2) = die_node_d_1(i, 2);
 end


      %PLOTTING FOR DIRECT TRANSMISION LIFE AND DEAD NODES
      %(FIGURE#5)
```

```
die_node_d_Xcords = ones(num_d_die_node, 1);
die_node_d_Ycords = ones(num_d_die_node, 1);

life_node_d_Xcords = ones(num_d_life_node, 1);
life_node_d_Ycords = ones(num_d_life_node, 1);

for i=1:num_d_die_node
   die_node_d_Xcords(i, 1) =die_node_d(i,1);
   die_node_d_Ycords (i, 1) =die_node_d(i,2);
end

for i=1:num_d_life_node
  life_node_d_Xcords(i, 1) =life_node_d(i,1);
  life_node_d_Ycords(i, 1) =life_node_d(i,2);
end

bx=0;
by =0;
theta_1 =linspace(0,2*pi, 1000);

Figure(5);


plot(life_node_d_Xcords, life_node_d_Ycords,'om', 'markersize', 5);
hold on;
plot(die_node_d_Xcords, die_node_d_Ycords,'.k', 'markersize', 5);
hold on;
plot(bx,by,'.r', 'markersize', 40);
hold on;
plot (x1, y1,':k','markersize', 5);

hold on;
legend ('Life Nodes','Dead nodes','Cluster Head ','Cluster Range');
%grid on;

   %END OF PLOTTING FIG. 5


   %ALD MODE

round_ald =0;
num_ald_die_node=1;
num_ald_life_node=1;
die_node_ald_1 =zeros(round_ald ,2);
life_node_ald_1 =zeros(round_ald , 2);
```

```
for j = 1:7
for i=1:num_sens_cord

    adl_res_energy (i) = adl_res_energy (i)-Avg_dist_mod_tans_energy_table(i);

   end

round_ald = round_ald +1;
end

for k = 1:num_sens_cord

if adl_res_energy (k)>0
   life_node_ald_1(num_ald_life_node, 1) = sens_cord(k, 1);
   life_node_ald_1(num_ald_life_node, 2) = sens_cord(k, 2);
   num_ald_life_node= num_ald_life_node + 1;


else
   die_node_ald_1(num_ald_die_node, 1) = sens_cord(k, 1);
   die_node_ald_1(num_ald_die_node, 2) = sens_cord(k, 2);
   num_ald_die_node=num_ald_die_node + 1;
end
end

num_ald_die_node = num_ald_die_node-1;
num_ald_life_node = num_ald_life_node - 1;

die_node_ald = zeros(num_ald_die_node, 2);
life_node_ald = zeros(num_ald_life_node, 2);


for i = 1:num_ald_life_node

      life_node_ald(i, 1) = life_node_ald_1(i, 1);
      life_node_ald(i, 2) = life_node_ald_1(i, 2);
end

for i = 1:num_ald_die_node

      die_node_ald(i, 1) = die_node_ald_1(i, 1);
      die_node_ald(i, 2) = die_node_ald_1(i, 2);
 end
```

```
%PLOTTING FOR ALD TRANSMISION LIFE AND DEAD NODES
%(FIGURE#6)

die_node_ald_Xcords = ones(num_ald_die_node, 1);
die_node_ald_Ycords = ones(num_ald_die_node, 1);

life_node_ald_Xcords = ones(num_ald_life_node, 1);
life_node_ald_Ycords = ones(num_ald_life_node, 1);

for i=1:num_ald_die_node
   die_node_ald_Xcords(i, 1) =die_node_ald(i,1);
   die_node_ald_Ycords (i, 1) =die_node_ald(i,2);
end

for i=1:num_ald_life_node
  life_node_ald_Xcords(i, 1) =life_node_ald(i,1);
  life_node_ald_Ycords(i, 1) =life_node_ald(i,2);
end

cx=0;
cy =0;
theta =linspace(0,2*pi, 1000);
theta_d =linspace(0,2*pi, 1000);
xcr = clus_rad*cos(theta_d);
ycr = clus_rad*sin(theta_d);

Figure(6);
plot(life_node_ald_Xcords, life_node_ald_Ycords,'om', 'markersize', 5);
hold on;
plot(die_node_ald_Xcords, die_node_ald_Ycords,'.k', 'markersize', 5);
hold on;
plot(cx,cy,'.r', 'markersize', 40);
hold on;
plot (xcr, ycr,':k','markersize', 5);
hold on;
legend ('Life Nodes','Dead nodes','Cluster Head ','Cluster Range');
grid off;

   %END OF PLOTTING FIG. 6
```

Appendix II

Randomly Generated Node's Locations for cluster of 100m radius

-5.2971, -79.4563	-3.5974, -92.2467	-59.4392, 47.8514	66.8814, 79.6563
94.0793, -22.9193	-3.7347, -28.0699	42.779, -60.2728	18.6594, -1.2786
-2.1765, -55.3124	-9.5547, -63.1673	-93.6603, -28.5081	-99.224, 9.4031
76.423, -94.5172	25.0754, 4.3225	-93.177, -97.6151	35.4087, -86.5662
84.2622, 19.8936	62.4303, -54.6758	70.8638, -11.1296	49.3246, -6.223
6.4613, -44.7406	-5.9235, -18.741	44.8815, -64.3696	-19.2739, -18.9557
55.1271, -77.2832	-23.8844, 47.8641	61.3449, 18.6121	8.5798, -59.982
-3.7328, -69.3624	-26.5986, 73.0652	-47.9895, 95.8112	-43.1735, -19.8551
85.043, -63.0804	-69.9532, 82.6557	79.9276, -61.0558	-66.763, 0.78366
-1.8874, -53.4406	-75.5654, -30.5037	5.2596, 14.7033	92.8835, 41.4842
81.9344, 18.1966	66.507, -94.5939	38.8501, -69.1004	-0.21912, 47.0353
-6.1169, -3.2386	-36.6681, -45.3391	34.269, -55.446	-78.7557, -35.6845
-9.8537, 40.2543	-82.9562, -81.1874	42.5143, -10.6139	-4.0592, -68.413

14.5895, -72.0824	-33.5138, 33.3388	2.9383, 73.9035	18.4808, -24.7293
78.4584, -97.6082	-74.3333, 67.0217	29.8792, -20.8141	-34.1922, -9.1973
-88.9516, 41.9952	-47.6188, 93.1417	-3.9714, 47.5463	32.0614, 34.5122
3.269, -92.0336	14.2605, 28.4189	48.3258, -78.3712	5.7659, -1.4764
-59.0359, -12.1983	-66.9784, 53.1168	89.6545, -41.698	36.8535, -56.5895
-76.2745, 26.9186	-13.462, 17.0591	-51.9565, 47.2848	-40.8178, 6.4343
50.5999, -51.8374	-42.0332, -63.8637	56.0455, 38.7118	-69.5307, -88.0611
-4.8394, -12.9324	-82.1539, 97.4769	35.6106, 25.011	-70.1012, 96.0113
-27.5239, 57.0816	13.7065, -39.0561	6.9773, -51.3738	0.3511, -31.8626
91.8463, 64.1187	17.947, -34.0749	19.0037, -27.793	55.2831, -27.2114
-12.1663, 35.0543	-89.2087, -7.497	-73.6723, -93.8878	-3.5138, -83.1232
-12.8998, 56.0257	-84.577, -83.1693	38.907, -47.787	68.9007, -43.8143
97.0607, -80.1187	69.4382, -0.28087	56.3793, 95.3787	-83.5597, 2.3089
-53.8109, 6.8852	-10.0119, 43.2218	72.4853, 86.9351	-21.2082, 58.1685
-5.4536, -38.4662	-48.2761, 6.1503	-94.6328, -76.8903	-32.1782, -96.3207

-75.8757, -13.7346	4.1402, -60.3509	-82.1772, 77.1527	87.3931, 21.6365
98.13, 33.1972	-35.8804, 16.9807	54.9023, -43.4707	8.755, 84.4694
-74.5957, -76.1448	-71.6225, -91.2626	-3.5782, -79.7566	-73.087, -27.2703
-13.5055, -42.4659	-14.6429, 18.2837	12.4767, 71.1613	78.5801, -18.861
-9.5113, 9.2539	-43.1474, -68.4721	-79.459, -3.8639	-70.4057, -88.8402
40.4463, -51.2028	92.0458, 97.4643	23.5324, 77.7664	58.8068, 16.3942
-79.0539, -87.1932	79.3503, 55.6204	-77.6638, -74.6799	90.1034,- 37.4948
-74.5008, -90.1291	93.7135, 72.5697	54.2069, -44.0616	-73.0291, -21.937
2.1464, 92.8791	80.7257, -96.6644	-95.8451, 85.0775	
64.8157, 62.9146	-97.0627, -19.8547	-35.7805, -25.834	

Appendix III

Data for Statistical Inference

Data generated to draw statistical inference for improvement of ALD over Direct for a 100 m radius cluster with 100 nodes at path loss 3 and 4

Simulation number	Path loss factor, n= 3	Path loss factor, n= 4
1.	34.984	37.263
2.	34.208	51.420
3.	22.582	51.173
4.	20.443	40.400
5.	23.460	44.413
6.	41.183	32.888
7.	17.101	53.951
8.	42.195	35.976
9.	43.190	77.311
10.	36.069	65.007
11.	32.958	66.182
12.	43.409	43.764
13.	22.880	85.838
14.	43.375	48.907
15.	11.100	88.128
16.	23.897	55.515
17.	29.600	42.952
18.	38.705	33.038

19.	29.163	30.028
20.	43.763	84.583
21.	36.948	51.641
22.	33.771	57.313
23.	44.171	30.596
24.	33.298	46.767
25.	36.810	33.003
26.	9.744	50.649
27.	36.622	35.584
28.	36.350	56.596
29.	38.029	72.448
30.	39.657	50.649

Appendix iv

Result for Goodness of distribution curve fit test

data points	30
estimates	maximum likelihood estimates
accuracy of fit	3.e-004
level of significance	5.e-002

summary distribution	Chi Squared	Kolmogorov Smirnov	Anderson Darling
Exponential(17., 17.)	14. (3)	0.31	3.76
Lognormal(17., 2.56, 1.07)	24.1 (3)	0.277	3.28
Normal(34., 7.84)	1.73 (3)	0.149	0.943
Triangular(17., 44.6, 43.7)	0.667 (3)	0.169	1.37
Uniform(17., 44.2)	5.47 (3)	0.287	5.36

Exponential

minimum	17. [fixed]
beta	16.9697
Chi Squared	
total classes	4
interval type	equal probable
probable	4
net bins	14.
chi**2	3
degrees of freedom	5.e-002
alpha	7.81
chi**2(3,5.e-002)	2.91e-003
p-value	*REJECT*
result	

Kolmogorov-Smirnov

data points	30
ks stat	0.31
alpha	5.e-002
	0.242
ks stat(30,5.e-002)	4.74e-003
p-value	*REJECT*
result	

Anderson-Darling

	30
data points	3.76
ad stat	5.e-002
alpha	2.49
ad stat(30,5.e-002)	1.14e-002
p-value	*REJECT*
result	

Lognormal

minimum	17. [fixed]
mu	2.56247
sigma	1.07072

Chi Squared

total classes	
interval type	4
net bins	equal probable
chi**2	4
degrees of freedom	24.1
alpha	3
chi**2(3,5.e-002)	5.e-002
p-value	7.81
result	2.34e-005
	REJECT

Kolmogorov-Smirnov

data points	30
ks stat	0.277
alpha	5.e-002
ks stat(30,5.e-002)	0.242
p-value	1.59e-002
result	*REJECT*

Appendices

Anderson-Darling	30
data points	3.28
ad stat	5.e-002
alpha	2.49
ad stat(30,5.e-002)	1.98e-002
p-value	*REJECT*
result	

Normal

mean	33.9697
sigma	7.84332
Chi Squared	
total classes	4
interval type	equal probable
net bins	4
chi**2	1.73
degrees of freedom	3
alpha	5.e-002
chi**2(3,5.e-002)	7.81
p-value	0.63
result	*NOT REJECT*

Kolmogorov-Smirnov	
data points	
ks stat	30
alpha	0.149
ks stat(30,5.e-002)	5.e-002
p-value	0.242
result	0.476
	DO NOT REJECT
Anderson-Darling	
data points	
ad stat	30
alpha	0.943
ad stat(30,5.e-002)	5.e-002
p-value	2.49
result	0.388
	DO NOT REJECT

Triangular

minimum	17. [fixed]
maximum	44.6315
mode	43.7105

Chi Squared

total classes	4
interval type	equal probable
net bins	4
chi**2	0.667
degrees of freedom	3
alpha	5.e-002
chi**2(3,5.e-002)	7.81
p-value	0.881
result	*DO NOT REJECT*

Kolmogorov-Smirnov

data points	30
ks stat	0.169
alpha	5.e-002
ks stat(30,5.e-002)	0.242
p-value	0.322
result	*DO NOT REJECT*

Anderson-Darling

data points	30
ad stat	1.37
alpha	5.e-002
ad stat(30,5.e-002)	2.49
p-value	0.212
result	*DO NOT REJECT*

Uniform

minimum	17. [fixed]
maximum	44.171

Chi Squared

total classes	4
interval type	equal probable
net bins	4
chi**2	5.47
degrees of freedom	3
alpha	5.e-002
chi**2(3,5.e-002)	7.81
p-value	0.141
result	*DO NOT REJECT*

Kolmogorov-Smirnov

data points	30
ks stat	0.287
alpha	5.e-002
ks stat(30,5.e-002)	0.242
p-value	1.1e-002
result	*REJECT*

Anderson-Darling

data points	29
ad stat	5.36
alpha	5.e-002
ad stat(29,5.e-002)	2.49
p-value	1.94e-003
result	*REJECT*

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