"Design Constraint in Single-hop and Multi-hop Wireless Sensor Network Using Different Network Model Architecture"

By

Ajit Kumar Singh (111120)

Sandeep Rajoriya (111070)

Subham Nikhil (111077)

under the supervision of

Prof. Tapan Jain

May-2015

Dissertation submitted in partial fulfilment

of the requirement for the degree of

BACHELOR OF TECHNOLGY

IN

ELECTRONICS & COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,

WAKNAGHAT, SOLAN- 173234, INDIA

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

(Established under the Act 14 of Legislative Assembly of Himachal Pradesh)

Waknaghat, P.O. DomeharBani. Teh. Kandaghat, Distt. Solan- 173234(H.P.)

Phone: 01792-245367, 245368, 245369

Fax- 01792-245362

DECLARATION

We hereby declare that the work reported in the B. Tech report entitled "**Design Constraint in Single-hop and Multi-hop Wireless Sensor Network Using Different Network Model Architecture"** submitted by "**Ajit Kumar Singh, Sandeep Rajoriya, and Subham Nikhil"** at Jaypee University of Information Technology, Waknaghat is an authentic record of our work carried out under the supervision of **Prof. Tapan Jain.** This work has not been submitted partially or wholly to any other university or institution for the award of this or any other degree or diploma.

Ajit Kumar Singh (111120)

Sandeep Rajoriya (111070)

Subham Nikhil (111077)

Department of Electronics and Communication Engineering

Jaypee University of Information Technology (JUIT)

Waknaghat, Solan- 173234, India

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

(Established under the Act 14 of Legislative Assembly of Himachal Pradesh)

Waknaghat, P.O. DomeharBani. Teh. Kandaghat, Distt. Solan- 173234(H.P.)

Phone: 01792-245367, 245368, 245369

Fax- 01792-245362

CERTIFICATE

This is to certify that the work titled "**Design Constraint in Single-hop and Multi-hop Wireless Sensor Network Using Different Network Model Architecture**" submitted by "**Ajit Kumar Singh, Sandeep Rajoriya and Subham Nikhil**" in the partial fulfilment of the degree of Bachelor of Technology (ECE) of Jaypee University of Information Technology, Waknaghat has been carried out under my supervision. This work has not yet been submitted partially or wholly to any other university or institution for the award of this or any other degree or diploma.

Date:

Prof. Tapan Jain

(Assistant Professor)

Department Of Electronics and Communication Engineering

Jaypee University of Information Technology (JUIT)

Waknaghat, Solan- 173234, India

(Supervisor)

Acknowledgements

We are profoundly grateful to **Prof. Tapan Jain** Project mentor whose invaluable guidance supported us in completing this project and for his expert guidance and continuous encouragement throughout to see that this project rights its target since its commencement to its completion.

We would like to express deepest appreciation towards **Prof. Dr. T. S. Lamba**, Dean (Academic and Research) , Jaypee University of Information Technology and **Prof. Dr. Sunil Bhooshan** , Head of Department of Electronics and Communication Engineering.

At last we must express our sincere heartfelt gratitude to all the staff members of Electronics and Communication Engineering Department and our families who helped us directly or indirectly during this course of work.

AJIT KUMAR SINGH
SANDEEP RAJORIYA
SUBHAM NIKHIL

PUBLICATION

Ajit Kumar Singh, Sandeep Rajoriya, Subham Nikhil and Prof. Tapan jain "Design Constraint in Single-hop and Multi-hop Wireless Sensor Network Using Different Network Model Architecture" IEEE Conference held at Galgotia University in May 2015.

ABSTRACT

Wireless sensor networks have created new opportunities across the spectrum of human endeavors including engineering design and manufacturing, monitoring and control of systems. Involvement of restrained resources in the deployment of WSNs makes it a subject of concern. So its usage needs to be very efficient in order to maximize operational life of network. In this paper a detailed analysis is made between single-hop and multi-hop approaches which are used in the process of transfer of data and queries from source to sink. Different dimensions are used for the purpose of analysis with their respective applications in order to increase the scope of analysis in real world scenarios. Implementation of single-hop and multi-hop is done with the help of MATLAB simulation tool in order to get accurate results and also the comparison of different design constraint.

Keywords: End-to-End Delay; Channel Capacity; Cluster Based; Energy Efficiency; Signal to Noise Ratio; Wireless Sensor Network.

Contents

List of Figures

List of Tables

ACRONYMS

WSN	Wireless Sensor Network
CH	Cluster Head
LEACH	Low Energy Adaptive Clustering Hierarchy
CDMA	Code Division Multiple Access
SNR	Signal to Noise Ratio
BS	Base Station
CM	Cluster Member
GSM	Global System for Mobile
AWGN	Additive White Gaussian Noise
HEED	Hybrid Energy Efficient Distributed
LOS	Line Of Sight

Chapter 1

Introduction

1.1 Motivation

Wireless sensor networks (WSN) [1] consists of densely deployed group of sensors used for environmental, military automation and home application and they are spatially distributed networks. These nodes have restrained resources such as limited energy battery power, processing power and memory storage [2]. Wireless communication system consists of source node, destination node and multiple relay nodes placed randomly.

This paper is based on two important assumptions i.e. the nodes do not cooperate with each other, not try to access the channel simultaneously and we consider a linear wireless network for our analysis. In practical deployment when network coverage area is often much larger than radio range of single node, so in order for efficient communication we use relay nodes. This type of communication is known as multi-hop routing in WSNs.

Wireless networks such as ad hoc and sensor networks puts a fundamental question that routing over long hop is better or using large number of short hop is advantageous. Patron of multi-hop routing argue that more short hops are preferable to fewer long hops[4] because signal to noise ratio along the route is larger i.e. if a long hop of distance d is divided into n hops with distance d/n, the energy benefit is $n^{\alpha-1}$ where α = path loss exponent [5]. Even more the shorter the hops the higher transport capacity in an interference limited network [6] but with proper persual factors like end-to-end delay, error propagation, bandwidth requirement are not considered when we take practical environment into account. Wireless transreceivers cannot both receive and transmit at the same time on the same frequencies, so the cost associated with multi-hop due to more bandwidth required than single-hop fades the benefit of SNR gain. In the practical application such as military operations and in medical environment delay cannot be neglected but when we consider multi-hop the accumulated delay incurred when coded packets are decoded and re-encoded at each hop can never be ignored. Different classes have multifarious ramifications so meticulous trade-off between various energy and network parameters are required when we consider single-hop and multi-hop.

This project is divided into chapters in which chapter II gives a brief description of related work, chapter III depicts the system model with different network models, chapter IV talks about the applications of analysis done in the project and chapter V shows the results and conclusions drawn from the analysis.

1.2 Classification of Routing Protocols for WSN

Different routing protocols are designed to circumvent the weaknesses of the resource constrained nature of the WSNs. WSN Routing Protocols can be classified in four main categories based upon: the type of communication routes processed within the network for data transmission from the source to sink, the type of the network structure, the network operations carried out using these protocols and the initiator of communications as seen in Figure 1.1.

1.2.1 Proactive Routing Protocols

All the paths from sources to sinks are regularly computed before they are really needed and then these routes are stored in a routing table in each node so that routing information is kept for every node in the network. A certain amount of control traffic, is needed to keep routing tables up to date and consistent over the whole network. Example: Optimized Link State Routing (OLSR).

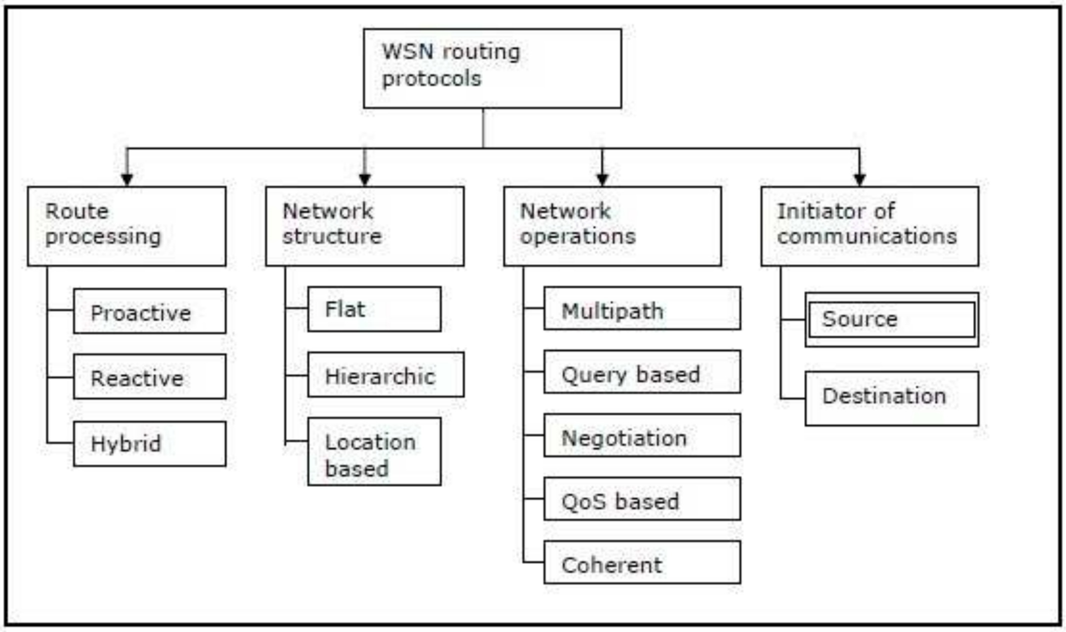

Figure 1.1: WSN routing protocols

1.2.2 Reactive Routing Protocols

Paths are acquired by nodes on demand when data needs to get forwarded and no path to the destination is currently known. Whenever a sink wants to contact a particular node, the path values are calculated and the best path is selected for data transmission. Example: Ad-hoc On-Demand Distance Vector (AODV).

1.2.3 Hybrid Routing Protocols

Combine features of proactive and reactive protocols. The network is divided into specified regions or zones. Data distribution within a zone is table driven (proactive) and when a node needs to send data to a node of another zone, it is accomplished through on-demand (reactive) routing protocol. Examples: Dynamic Zone Topology Routing protocol (DZTR) and Zone Routing Protocol (ZRP).

1.2.4 Flat Routing Protocols

All nodes participating in routing play the same role of collecting data and communicating with the sink. Example: Sensor Protocols for Information via

Negotiation (SPIN).

1.2.5 Hierarchical Routing Protocols

The goal of the protocol is to perform energy-efficient routing in WSNs by avoiding an overloading of sink nodes by too many received messages, as well as reducing the amount of overall message transmissions. To achieve this, nodes are grouped into clusters, where the higher energy nodes are used to process and send the information while low energy nodes are used to perform the sensing in the proximity of the target. Example: Low energy adaptive clustering hierarchy (LEACH) protocol.

1.2.6 Location-Based Routing Protocols

Sensor nodes are addressed by means of their locations. In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Each node calculates the distance to his neighboring node from the incoming received power signal strength. In some location-based schemes in order to save energy, the nodes must change their state from active to sleep if there is no activity.

1.2.7 Multipath Routing Protocols

Several paths are discovered between the source and the destination and are used to provide a backup route. When the primary path fails, the backup is used and this increases the network performance at the expense of increasing the cost of energy consumption and traffic generation. Example: Ad hoc On-demand Multipath Distance Vector routing (AOMDV).

1.2.8 Query Based Routing Protocols

Destination node sends queries requesting certain data from the nodes in the network. If a node has the data that match the query, it sends them back to the requested node. This process is known as Directed Diffusion. Examples:

Directed Diffusion (DD), COUGAR, Sensor Protocols for Information via Negotiation (SPIN).

1.2.9 Negotiation Based Routing Protocols

The main idea is to suppress duplicate information and prevent redundant data from being sent to the next sensor or the base station by conducting a series of negotiation messages before the real data transmission begins. Examples: SPIN family protocols.

1.2.10 QoS Based Routing Protocols

The network has to balance between energy consumption and data quality. In particular, the network has to satisfy certain QoS metrics (delay, energy, bandwidth, etc.) when delivering data to the base station. Example: SPEED (Stateless Protocol for Real-Time Communication in Sensor Networks).

1.2.11 Coherent Based Routing Protocols

All the nodes within the network collect the data and perform minimum processing (time stamping or duplicate suppression). Then the data is forwarded to nodes that perform further processing on the data. These nodes are called aggregators.

1.2.12 Source Initiated Routing Protocols

The nodes send data to the base station soon after they take new measurements. Source initiated protocols use either time-driven or event-driven data reporting.

1.2.13 Destination Initiated Routing

The nodes only send data in response to a request for data. Destination initiated protocols use query driven data reporting. The drawback of destination initiated protocols is the fact that requests are usually flooded through the network, draining the energy sources of nodes.

1.3 Technologies For WSNs

Table 1.1: Technologies FOR WSNs

	GPRS/GSM	IEEE 802.11 b/g	IEEE 802.15.1	IEEE 802.15.4
Market name	2.5G/3G	Wi-Fi	Bluetooth	Zigbee
Network target	WAN/MAN	WLAN and hotspot	PAN and DAN	WSN
Application focus	Wide area voice,data	Enterprise applications	Cable replacement	Monitoring and control
Bandwidth(Mbps)	0.064-0.128+	11-54	0.7	0.020-0.25
Transmission range(ft.)	3000+	1-300+	1-30+	1-300+
Design factor	Transmission quality	Scalability and cost	Cost,ease of use	Power and cost

Table 1.2: Protocols

Protocol distance	Bluetooth 10m	UWB 10-102m	Zigbee 10-1000m	Wi-Fi 100m	WiMax 3-49km	GSM 35km
Maximum signal rate	720kb/s	110Mb/s	250Kb/s	54Mb/s	35-70Mb/s	168kb/s

1.4 Factors Influencing WSN Design

The design of WSNs requires ample knowledge of a wide variety of research fields including wireless communication, networking, embedded systems, digital signal processing, and software engineering. This is motivated by the close coupling between several hardware and software entities of wireless sensor devices as well as the distributed operation of a network of these devices. Consequently, several factors exist that significantly influence the design of WSNs. These factors have been addressed by many researchers in a wide range of areas concerning the design and deployment of WSNs. Moreover, the integration of the solutions for these factors is still a major challenge because of the interdisciplinary nature of this research area.

1.5 Hardware Constraints

The general architecture and the major components of a wireless sensor device (node) are illustrated in Figure 1.2. A wireless sensor device is generally composed of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit. Moreover, additional components can also be integrated into the sensor node depending on the application. These components as shown by the dashed boxes in Figure 1.2 include: a location finding system, a power generator, and a mobilizer.

1.5.1 Sensing Unit

The sensing unit is the main component of a wireless sensor node that distinguishes it from any other embedded system with communication capabilities. The sensing unit may generally include several sensor units, which provide information gathering capabilities from the physical world. Each sensor unit is responsible for gathering information of a certain type, such as temperature, humidity, or light, and is usually composed of two subunits: a sensor and an analog to digital converter (ADC). The analog signals produced by the sensor based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit.

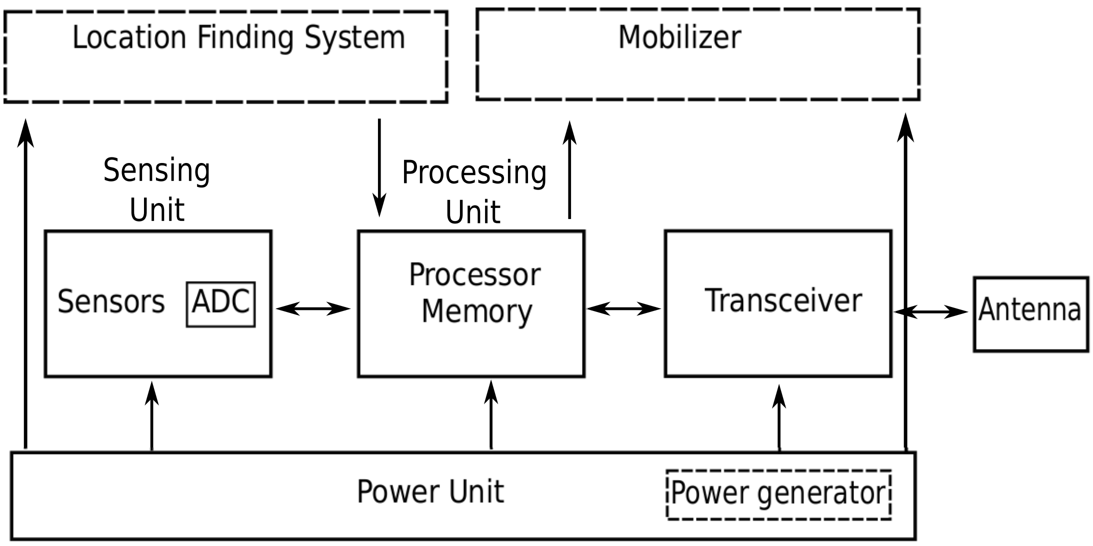

Figure 1.2: General hardware architecture of a sensor node

1.5.2 Processing Unit

The processing unit is the main controller of the wireless sensor node, through which every other component is managed. The processing unit may consist of an on-board memory or may be associated with a small storage unit integrated into the embedded board. The processing unit manages the procedures that enable the sensor node to perform sensing operations, run associated algorithms, and collaborate with the other nodes through wireless communication.

1.5.3 Transceiver Unit

Communication between any two wireless sensor nodes is performed by the transceiver units. A transceiver unit implements the necessary procedures to convert bits to be transmitted into Radio Frequency (RF) waves and recover them at the other end. Essentially, the WSN is connected to the network through this unit.

1.5.4 Power Unit

One of the most important components of a wireless sensor node is the power unit. Usually, battery power is used, but other energy sources are also possible. Each component in the wireless sensor node is powered through the power unit and the limited capacity of this unit requires energy-efficient operation for the tasks performed by each component.

1.5.5 Location Finding System

Most of the sensor network applications, sensing tasks, and routing techniques need knowledge of the physical location of a node. Thus, it is common for a sensor node to be equipped with a location finding system. This system may consist of a GPS(Global Positioning System) module for a high-end sensor node or may be a software module that implements the localization algorithms that provide location information through distributed calculations.

1.5.6 Mobilizer

A mobilizer may sometimes be needed to move sensor nodes when it is necessary to carry out the assigned tasks. Mobility support requires extensive energy resources and should be provided efficiently. The mobilizer can also operate in close interaction with the sensing unit and the processor to control the movements of the sensor node.

1.5.7 Power Generator

While battery power is mostly used in sensor nodes, an additional power generator can be used for applications where longer network lifetime is essential. For outdoor applications, solar cells are used to generate power. Similarly, energy scavenging techniques for thermal, kinetic, and vibration energy can also be used.

Chapter 2

Literature Survey

2.1 Basic Definition

1. Hop: In computer networking, a hop is one portion of the path between source and destination. Data packets pass through routers and gateways on the way. Each time packets are passed to the next device, a hop occurs. To see how many hops it takes to get from one host to another ping or trace route/trace path commands can be used. The hop count refers to the intermediate devices (like routers) through which data must pass between source and destination, rather than flowing directly over a single wire.

2. Node: A node (Latin nodus,'knot') is either a connection point, a redistribution point or a communication endpoint (some terminal equipment). The definition of a node depends on the network and protocol layer referred to. A physical network node is an active electronic device that is attached to a network, and is capable of sending, receiving, or forwarding information over a communication channel. A passive distribution point such as a distribution frame or patch panel is consequently not a node.

3. Node Lifetime: A node consumes energy when receiving and transmitting packets, as well as in any other transceiver state. When energy falls below a given threshold, then node is isolated, with no possibility to contact with other this is termed as lifetime of node.

4. Network Lifetime: Network lifetime can be defined as the interval of time starting with first transmission in the wireless network and ending when

the percentage of nodes that have not terminated their residual energy fails below the threshold level.

5. Transmitting Range: It denotes the range within which transmitted data can be received correctly.

6. Friis Equation: The Friis transmission equation is used in telecommunications engineering, and gives the power received by one antenna under idealized conditions given another antenna some distance away transmitting a known amount of power. In its simplest form, the Friis transmission equation is as follows: Given two antennas,the ratio of power available at the input of the receiving antenna,P_r to output power to the transmitting antenna,P_t is given by :$\frac{P_r}{P_t} = G_t G_r (\frac{\lambda}{4\pi R})^2$, where G_t and G_r are the antenna gains (with respect to an isotropic radiator) of the transmitting and receiving antennas respectively, λ is the wavelength, and R is the distance between the antennas

7. Shannon Capacity Theorem: The Shannon theorem tells the maximum rate at which information can be transmitted over a communications channel of a specified bandwidth in the presence of noise. Considering all possible multi-level and multi-phase encoding techniques, the Shannon-Hartley theorem states the channel capacity C, meaning the theoretical tightest upper bound on the information rate (excluding error correcting codes) of clean (or arbitrarily low bit error rate) data that can be sent with a given average signal power S through an analog communication channel subject to additive white Gaussian noise of power N, is: $C = B\log_2(1+S/N)$ where, C is the channel capacity in bits per second, B is the bandwidth of the channel in hertz (pass-band bandwidth in case of a modulated signal), S is the average received signal power over the bandwidth (in case of a modulated signal, often denoted C, i.e. modulated carrier), measured in watts (or volts squared); N is the average noise or interference power over the bandwidth, measured in watts (or volts squared); and S/N is the signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal to the Gaussian noise interference expressed as a linear power ratio (not as logarithmic decibels).

2.2 Sensor Taxonomy

2.2.1 Data Centric

The sink sends queries to certain WSN regions and waits for data from sensor nodes in the regions selected. Because data are being requested through queries, attribute-based naming is necessary to specify the properties of data. Due to the large number of nodes deployed, in many WSNs ;it is not practical to assign global identifiers to each node. This, along with potential random deployment of WSNs, makes it challenging to select a specific (or a specific set of) nodes to be queried Hence, data are typically transmitted from every WSN with in the deployment region; this gives rise however, to significant redundancy along with inefficiencies in terms of energy consumption. It follows that it is desirable to have routing protocols that will be able to select a set of sensor nodes and utilize data aggregation during the relaying of data. This has led to the development of data-centric routing (in traditional address-based routing, routes are created between addressable nodes managed in the network layer mechanism). EXAMPLE- Sensor protocols for information via negotiation (SPIN)

2.2.2 Hierarchical

A single-tier (gateway or cluster-point) network can cause the gateway node to become overloaded, particularly as the density of sensors increases. This, in turn, can cause latency in event status delivery. To permit WSNs to deal with a large population of WSNs and to cover a large area of interest, multipoint clustering has been proposed. The goal of hierarchical routing is to manage the energy consumption of WSNs efficiently by establishing multi -hop communication within a particular cluster, and by performing data aggregation and fusion to decrease the number of transmitted packets to the sink. EXAMPLE-Low Energy-adaptive clustering hierarchy (LEACH)

2.2.3 Location Based

Location information about the WSNs can be utilized in routing data in an energy- communication efficient manner. Location information is used to calculate the distance between two given nodes so that energy consumption can be determined . For example, if the region to be sensed is known, the query can be diffused only to that specific region, limiting and/or eliminating the number of transmissions in the out-of-region space. Location-based routing is ideal for mobile ad- hoc networks, but it can also be used for generic WSNs. (Note that non-energy-aware location based protocols designed for wireless ad hoc networks, such as Cartesian and trajectory-based routing, are not desirable or ideal in WSNs.) EXAMPLE- Geographic Adaptive Fidelity (GAF) protocol.

2.2.4 QoS-Oriented

Quality of service (QoS) aware protocols consider end-to-end delay requirements in setting up the paths in the sensor network. EXAMPLE- Sequential assignment routing (SAR).

2.3 Radio Technology Primer

The electromagnetic spectrum provides an unguided medium (channel) for point-to-point and/or broadcast radio transmission. Radio transmission is usually (frequency) band limited by design. The analog bandwidth of the channel determines how much information (analog or digital) can be transmitted over the channel. A transmission channel in general, and a radio-based channel in particular, is never perfect because it is subjected to external (and even internal) noise sources; noise has a tendency to degrade, disrupt, or otherwise affect the quality of an intelligence-bearing signal. A lot of radio-transmission engineering has to do with how to deal with the noise problem. The goal is nearly always to optimize the signal-to-noise ratio, subject to specific constraints (e.g. bandwidth requirements, cost, reliability, power consumption, equipment and antenna size).

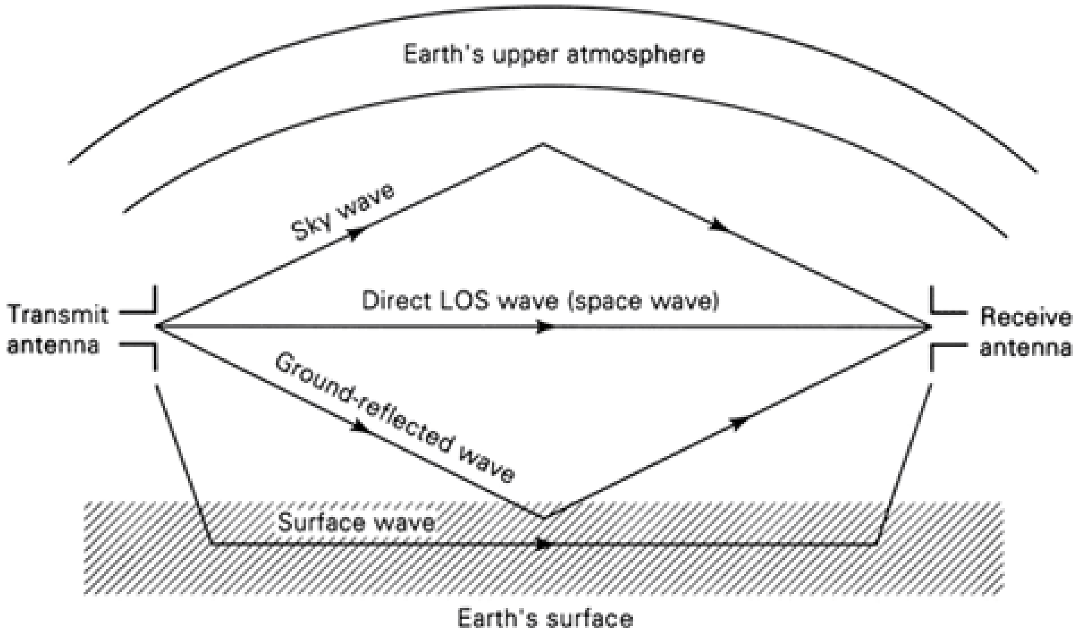

Figure 2.1: Radio propagation modes

2.3.1 Basic Phenomena Affecting Signals

2.3.2 Reflection

A phenomenon that occurs when a propagating electromagnetic wave impinges upon an object that is large compared to the wavelength of the propagating wave. Reflections occur from the surface of the Earth and from buildings and walls.

2.3.3 Diffraction

The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver. At high frequencies, diffraction, like reflection, depends on the geometry of the object as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction.

2.3.4 Scattering

A phenomenon that occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength and where the number of obstacles per unit volume is large. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel .In practice, foliage, street signs, and lampposts induce scattering in a mobile communications system. Reflection, diffraction, and scattering all give rise to additional radio propagation paths beyond the direct line-of-sight path between the radio transmitter and receiver.

2.4 Clustering

In WSNs, high-density deployment is one of the major differences between traditional networks. In the wireless domain, a high density has advantages in terms of connectivity and coverage as well as disadvantages in terms of increased collision and overhead for protocols that require neighborhood information. As a result, scalability is an important problem in WSN protocols as the node numbers increase. The topology control mechanisms discussed so far focus on a flat topology, where each node in the network sends its information to the sink through a multi-hop route. Although these protocols aim to decrease the contention through either power control or node scheduling, scalability is still an issue. The disadvantages of the flat-architecture protocols can be addressed by forming a hierarchical architecture, where the nodes are grouped in clusters. In this section, we discuss a fourth class of topology control mechanisms: cluster-based topology control. Clustering algorithms limit the communication in a local domain and transmit only necessary information to the rest of the network. A group of nodes form a cluster and the local interactions between cluster members are controlled through a cluster head (CH). Cluster members generally communicate with the cluster head and the collected data are aggregated and fused by the cluster head to conserve energy. The cluster heads can also form another layer of clusters among themselves before reaching the sink. Overall, clustering protocols have the following advantages in WSNs:

1. Scalability: Cluster-based protocols limit the number of transmissions between nodes, thereby enabling a higher number of nodes to be deployed in the network.

2. Collision Reduction: Since most of the functionalities of nodes are carried out by the CHs, fewer nodes contend for channel access, improving the efficiency of channel access protocols.

3. Energy Efficiency: In a cluster, the CH is active most of the time, while other nodes wake up only in a specified interval to perform data transmission to the CH. Further, by dynamically changing the CH functionalities among nodes, the energy consumption of the network can be significantly reduced.

4. Local Information: Intracluster information exchange between the CH and the nodes helps summarize the local network state and sensed information of the phenomenon state.

5. Routing Backbone: Cluster-based approaches also enable efficient building of the routing backbone in the network, providing reliable paths from sensor nodes to the sink. Since the information to the sink is initiated only from CHs, route-thru traffic in the network is decreased. Clustering is an integral part of hierarchical routing protocols as explained. Hence, several clustering mechanisms have been developed as part of these routing protocols such as LEACH, PEGASIS, TEEN, and APTEEN.

2.4.1 Hierarchical Clustering

The energy-efficient hierarchical clustering algorithm is developed to minimize the overall energy consumption of the network by constructing clusters in a distributed manner.Each sensor in the network can be selected as a CH according to a probability, p. According to this probability, a node transmits a message indicating its CH duty. In this case, the CH is denoted as the voluntary cluster head. The transmitted message is propagated up to k hops in the network. Each node that receives this message becomes a part of the cluster if it is not a CH. There may be several nodes that do not receive a CH message within a given amount of time (gray nodes). These nodes then designate themselves as a CH and advertise their duty. In this case, the CH is called the forced cluster head. The resulting topology groups each node in the network into one of the clusters. The performance of the energy-efficient hierarchical clustering algorithm depends on the selection of the two parameters p and k. The overall energy consumption can be minimized through an appropriate selection of these parameters.

2.4.2 Heed

The hybrid energy-efficient distributed (HEED) clustering algorithm combines transmit power control with clustering to form single-hop clusters. The main goal is to minimize the energy consumption for communication by constructing clusters in a distributed fashion. This is performed according to the residual energy of the nodes, where nodes with high residual energy are selected as CHs. Furthermore, the overall communication cost inside a cluster, i.e., intracluster communication cost, is also considered in cluster formation.

2.5 Theoretical Analysis

Analysis of results in this paper is done while considering three network models namely direct based, cluster based and chain based network model. In direct based network model we consider only one sink and all the nodes report to this sink and there is no possibility of interaction of one node with other excluding the link with the sink as it can be seen in Figure 2.2. In this network model if node lies in the transmitting range (R_T) of sink, energy is directly proportional to the square of distance(d^2) and if it lies at the distance more than the transmitting range then energy is proportional to d^4. In the cluster based approach [7], [8] there is sink, cluster head and cluster members, if any member senses data it sends to the cluster head and cluster head sends the data to sink as it can be seen in figure 2.3. It can further be classified into two approaches namely single-hop and multi-hop as seen in figure 2.4.

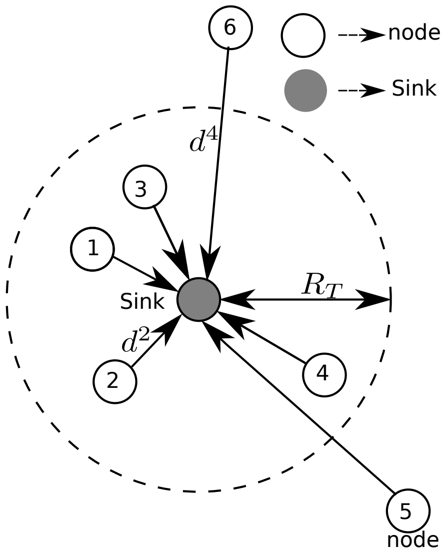

Figure 2.2: Direct communication

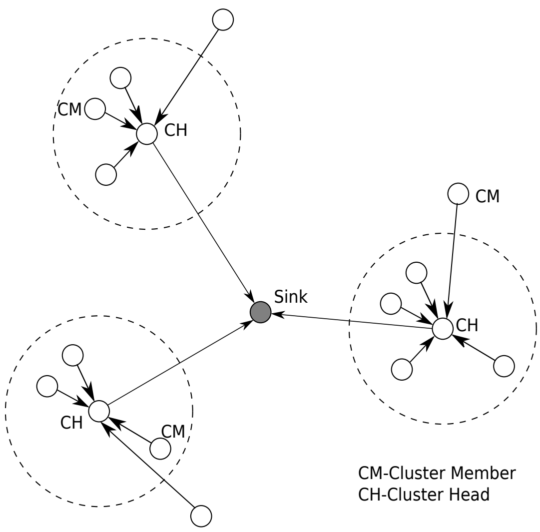

Figure 2.3: Single-hop

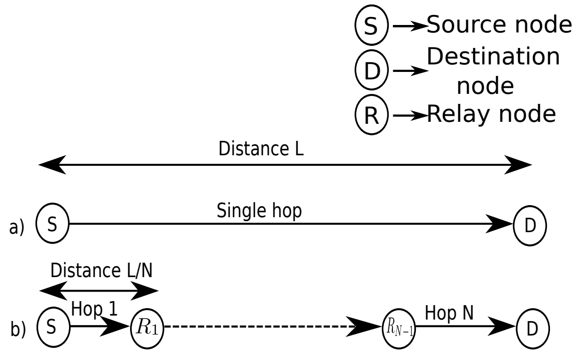

Figure 2.4: Single-hop and multi-hop communication systems

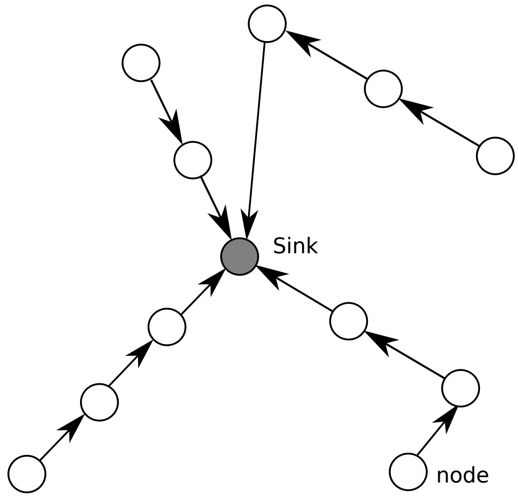

Figure 2.5: Multi-hop

In the chain based approach a fixed path is defined, where there is no need of time synchronization mechanism. In this approach one node sends data to another and finally reaches to sink as it can be seen in figure 2.6, but increases end-to-end delay.

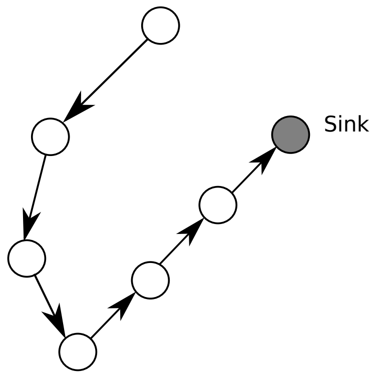

Figure 2.6: Chain based communication

2.6 Data Dissemination And Gathering

The way that data and queries are forwarded between the base station and the location Where the target phenomena are observed is an important aspect and a basic feature of WSNs. A simple approach of accomplishing this task is for each sensor node to exchange data directly with the base station. A single-hop-based approach, however, is costly, as nodes that are farther away from the base station may deplete their energy reserves quickly, thereby severely limiting the lifetime of the network. This is the case particularly where the wireless sensors are deployed to cover a large geographical region or where the wireless sensors are mobile and may move away from the base station. To address the shortcomings of the single-hop approach, data exchange between the sensors and the base stations is usually carried out using multi hop packet transmission over short communication radius. Such an approach leads to significant energy savings and reduces considerable communication interference between sensor nodes competing to access the channel, particularly in highly dense WSNs. Data forwarding between the sensors where data can be collected and the sinks where data are made available. In response to queries issued by the sinks or when specific events occur within the area monitored, data collected by the sensors are transmitted to the base station using multi -hop paths. It is worth noting that depending on the nature of the application, sensor nodes can aggregate data correlated on their way to the base station. In a multi -hop WSN, intermediate nodes must anticipate in forwarding data packets between the source and the destination. Determining which set of intermediate nodes is to be selected to form a data-forwarding path between the source and the destination is the principal task of the routing algorithm. In general, routing in large-scale networks is inherently a difficult problem whose solution must address multiple challenging design requirements, including correctness, stability, and optimality with respect to various performance metrics. The intrinsic properties of WSNs, combined with severe energy and bandwidth constraints, bring about additional challenges that must be addressed to satisfy the traffic requirements of the application supported, while extending the lifetime of the network.

Chapter 3

System Model

3.1 Implementation of Single hop

3.1.1 Low-Energy Adaptive Clustering Hierarchy Protocol

Low-energy adaptive clustering hierarchy (LEACH) is a routing algorithm designed to collect and deliver data to the data sink, typically a base station. The main objectives of LEACH are: Extension of the network lifetime. Reduced energy consumption by each network sensor node Use of data aggregation techniques to reduce the number of communication messages. To achieve these objectives, LEACH adopts a hierarchical approach to organize the network into a set of clusters as seen in Figure 3.1. Each cluster is managed by a selected cluster head. The cluster head assumes the responsibility to carry out multiple tasks. The first task consists of periodic collection of data from the members of the cluster (non cluster heads).Upon gathering the data, the cluster head aggregates it in an effort to remove redundancy among correlated values. The second main task of a cluster head is to transmit the aggregated data directly to the base station. The transmission of the aggregated data is achieved over a single hop. Implementation of the same can be seen in the MATLAB in Figure 3.2

The operation of LEACH is controlled through rounds, which consist of several phases. During each round, each cluster formation stays the same, and the cluster heads are selected at the beginning of each round. A round is separated into two phases, the setup phase and steady state phase. During the setup phase, cluster heads are selected, clusters are formed, and the cluster communication schedule is determined. During the steady state phase, data communication be-

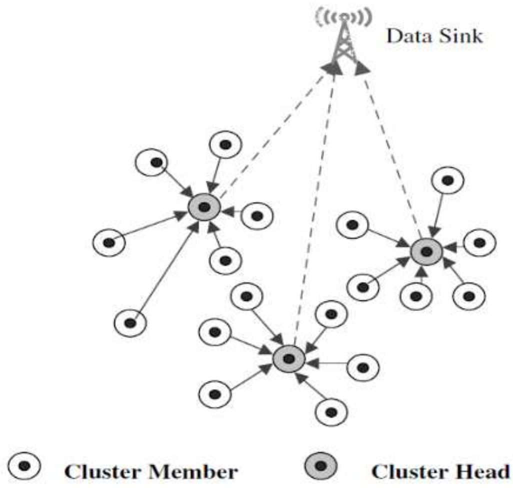

Figure 3.1: Low-energy adaptive clustering hierarchy

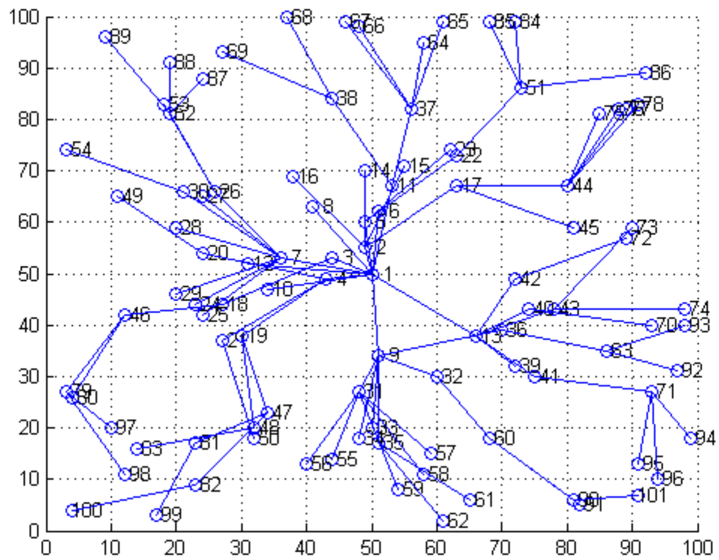

Figure 3.2: Low-energy adaptive clustering hierarchy on MATLAB

tween the cluster members and the cluster head is performed. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize the overhead. The setup phase of LEACH consists of three phases: advertisement, cluster setup, and schedule creation. LEACH aims to randomly select sensors as cluster heads during the beginning of each round. The cluster head selection is performed through the advertisement phase, where the sensor nodes broadcast a cluster head advertisement message. Firstly, a sensor node chooses a random number between 0 and 1. If this random number is less than a threshold $T(n)$, the sensor node becomes a cluster head. $T(n)$ is calculated as

$$T(n) = \begin{cases} \frac{P}{1-P[r \bmod (1/P)]} & \text{if n } \in G \\ 0 & \text{otherwise} \end{cases} \tag{3.1}$$

where P is the desired percentage to become a cluster head, r is the current round, and G is the set of nodes that have not been selected as a cluster head in the last 1/P rounds. The selected cluster heads then advertise to their neighbors in the network that they are the new cluster heads. For this operation, LEACH relies on a CSMA-based random access scheme to avoid advertisement collisions from multiple cluster heads. Once the sensor nodes receive the advertisement, they determine the cluster that they belong to. If a node receives an advertisement from a single cluster head, then it automatically becomes a member of that cluster. However, if a sensor node receives advertisements from multiple cluster heads, the cluster selection is performed based on the signal strength of the advertisement from the cluster heads to the sensor nodes. The cluster head with the highest signal strength is selected. Consequently, the channel quality between the cluster members and the cluster head is aimed to be high. After the advertisement phase, the sensor nodes inform the associate cluster head that they will be members of the cluster, which is called the cluster setup phase. Again, LEACH relies on a CSMA-based random access scheme to prevent collisions between packets sent by each node. Finally, the schedule creation phase is performed, where the cluster heads assign the time during which the sensor nodes can send data to the cluster heads. This selection is based on a time division multiple access (TDMA) approach, which is followed throughout the steady state phase. Once the cluster formation is completed in the setup phase, LEACH switches to the steady state phase. During this phase, the sensor nodes can begin sensing and transmitting data to the cluster heads. The cluster heads also aggregate data from the nodes in their cluster before sending these data to the sink. At the end of the steady state phase, the network goes into the setup phase again to enter into another round of selecting the cluster heads. As a result, energy consumption due to the cluster head duty is equally distributed among sensor nodes. The cluster-based operation of LEACH improves the energy efficiency of WSNs. During the steady state phase, only the cluster heads are active all the time. A cluster member in a cluster is active only during its allocated time slot and the setup phase. Consequently, the energy consumption of a regular node is minimized significantly. Since LEACH performs periodic cluster head selection, the energy consumption burden of the cluster head nodes is also shared. Accordingly, LEACH provides a factor of 4-8 reduction in energy consumption compared to a flat-architecture routing protocol.

3.2 Implementation of Multiple HOP

Radio channel between transmitter and receiver can be established only when strength of the received radio signal is greater then receiver's sensitivity threshold. The reduction in signal power density, on the path between transmitter and receiver, is called path loss component. Realistic path loss modeling can be a very complex task because transmitted radio waves could be reflected, absorbed or scattered by the obstacles. Receivers in a real environment receive not only but many delayed components of the original signal. Such phenomenon is called multipath fading. The simplest path-loss model, called free-space, assumes that there are no obstructions between transmitter and receiver. Free-space path loss is proportional to the square of the distance between the transmitter and receiver. Other models take into account effects of multipath fading and one of the most commonly used is long-distance path loss model This model employees path loss exponent α, which is empirically measured under different propagation scenarios. Typical values of path loss exponent in such scenarios are presented in Table 3.1. Using this model we can express receiving power Pr at distance d from the transmitter: where $P0$ represents known received power at distance $d0$ from a transmitter and α is the path loss exponent. Pure theoretical model of wireless transmission, assumes that all consumed energy is radiated into the air by a transmitter, and a receiver does not spend any energy during a reception.

3.3 Network Parameters

The following network parameters are taken into account for design constraint in single-hop and multi-hop:

1. Delay: There are several sources of delay or latency in a communication system:

    (a) Time taken by data source to emit the bits that has to be transferred over the channel.

    (b) In the process of encoding and decoding.

    (c) Transmission and reception of the encoded message.

    When we consider applications where delay cannot be ignored, judicious design of the network is important. Analysis of delay can be done when datagram packet switching is considered [3]. Total delay = total propagation + total Transmission + total store and forward + total processing

    $$Total\ \ delay = M*L + N*T + (M-1)*T + (M-1)*P \tag{3.2}$$

    where, Number of hops = M, Per hop processing delay = P, Link propagation delay = L, Packet transmission delay = T, Message size = N packets. So,from equation 3.2 it can be observed that on increasing the number of hops end-to-end delay also increases.

    Hence experimentally as seen in Figure 3.3 we can confer that when a minimum delay is of at most concern we prefer single-hop over multi-hop keeping all the network parameters constant [4].

2. Signal to Noise Ratio(SNR): It is the ratio of the strength of signal carrying information to that of unwanted interference. The communication system

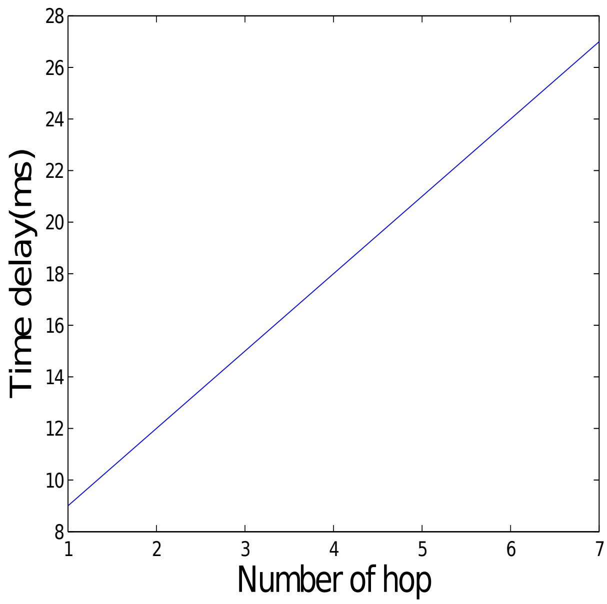

Figure 3.3: Time delay vs No. of hops

under consideration is illustrated in figure 2.4, it consists of source node S and a destination node D at a distance L and N-1 relay nodes $R_j, j = 1 \ldots N-1$ placed equidistant on a line from S to D. The channel is assumed to attenuate the signal with Additive White Gaussian Noise (AWGN) with spectral density (N_0), let received energy of signal be E_s [3] , so for single-hop

$$\left(\frac{S}{N}\right)_{single-hop} = \frac{E_s}{N_0} \tag{3.3}$$

For multi-hop distance between relay nodes is L/N so received energy is $E_s N^{\alpha}$, where N = number of hops and α = path loss exponent which can be seen in table 3.1, so figure 3.4 and 3.5 (drawn from equation 3.3 and 3.4)

$$\left(\frac{S}{N}\right)_{multi-hop} = \frac{E_s}{N_0} N^{\alpha} \tag{3.4}$$

shows that multi-hop has a edge over single-hop in an interference limited network.

3. Bandwidth: The wireless transceiver cannot both receive and transmit at the same time on the same frequency and the resource available for the transmission comprises a band of radio frequencies accounting for a rate

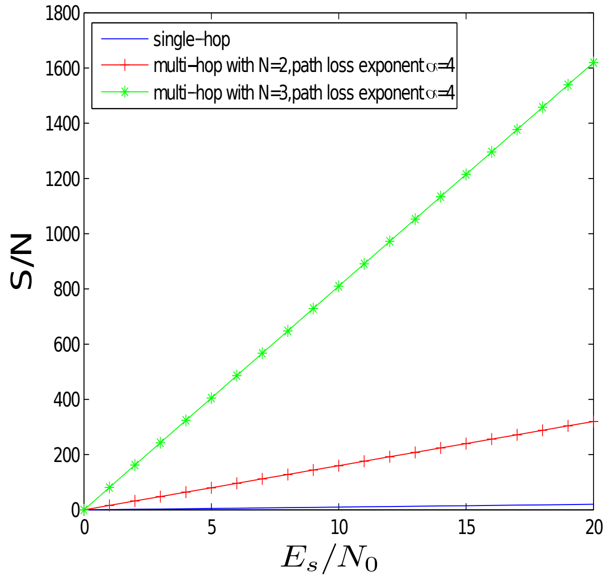

Figure 3.4: SNR v/s E_s/N_0 in single-hop and multi-hop in building no LOS

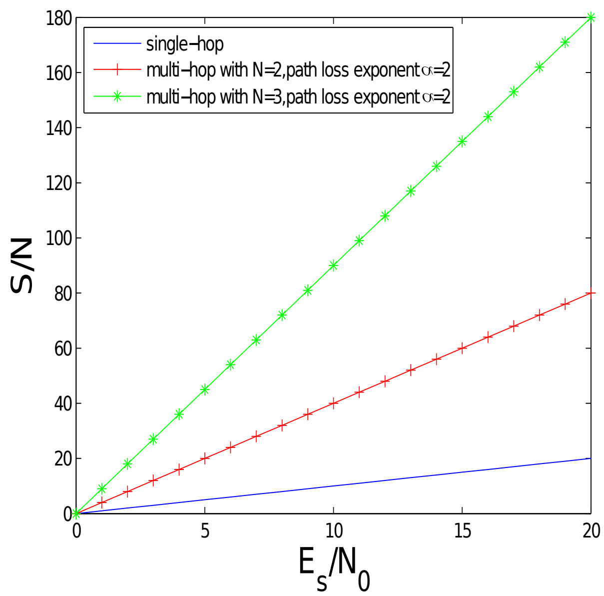

Figure 3.5: SNR v/s E_s/N_0 in single-hop and multi-hop in free space

Table 3.1: Typical values of path loss exponent

Environment	alpha
Free-space	2
Urban area LOS	2.7 to 3.5
Urban area no LOS	3 to 5
Indoor LOS	1.6 to 1.8
Factories no LOS	2 to 3
Buildings no LOS	4 to 6

$1/T_s$. Since by assumption the distance between the relay nodes is equal and all hops uses same amount of resources this means that share of each hop is $(NT_S)^{-1}$ channel per sec [3], where N = number of hops. So in case of multi-hops N times more bandwidth is required when compared to single-hop with all the network parameters are constant and this can be verified by comparison of Shannon capacity [14][15].

4. Energy Efficiency: The main objective of the routing protocols is efficient delivery of information between sensors and the sink. To this end, energy consumption is the main concern in the development of any routing protocol for WSNs. Because of the limited energy resources of sensor nodes, data need to be delivered in the most energy-efficient manner without compromising the accuracy of the information content. Hence, many conventional routing metrics such as the shortest path algorithm may not be suitable. Instead, the reasons for energy consumption should be carefully investigated and new energy-efficient routing metrics developed for WSNs. The major reasons of energy consumption for routing in WSNs can be classified as follows:

   (a) Neighborhood discovery: Many routing protocols require each node to exchange information between its neighbors. The information to be exchanged can vary according to the routing techniques. While most geographical routing protocols require knowledge of the locations of the neighbor nodes, a data-centric protocol may require the information content of the observed values of each sensor in its surrounding. In each case, nodes consume energy in exchanging this information through the wireless medium, which increases the overhead of the protocol. In order to improve the energy efficiency of the routing protocols, local information exchange should be minimized without hampering the routing accuracy.

(b) Communication vs. Computation: It is well known that computation is much cheaper than communication in terms of energy consumption. Moreover, in WSNs, the goal is to deliver information instead of individual packets. Consequently, in addition to the conventional packet switching techniques, computation should also be integrated with routing to improve energy consumption. As an example, data from multiple nodes can be aggregated into a single packet to decrease the traffic volume without hampering the information content. Similarly, computation at each relay node can be used to suppress redundant routing information.

For the effective efficiency analysis [9] we make the assumption that the radio channel is symmetric i.e. the energy required to transmit a message from node X to node Y is same as the energy required to transmit a message from node Y to node X for a given SNR. First order radio model [10] in Figure 3.6 is used for the analysis and the equation 3.5 is used for the computation of results.

$$Residue_{energy} = E_{total} - E_{elec} * k + \varepsilon_{amp} * k * d^2 \tag{3.5}$$

where, E_{total} is the total energy of a node, E_{elec} is transmitter electronics or receiver electronics, ε_{amp} is the transmit amplifier, k is number of bits and d is the distance between receiver and transmitter.

In single-hop scenario [11], P_1 is the power taken which is enough to be received by destination node and the receiver's sensitivity threshold P_s.

In case of single-hop [12]

$$P_s = P_1 . \left(\frac{d_0}{d}\right)^{\alpha} \tag{3.6}$$

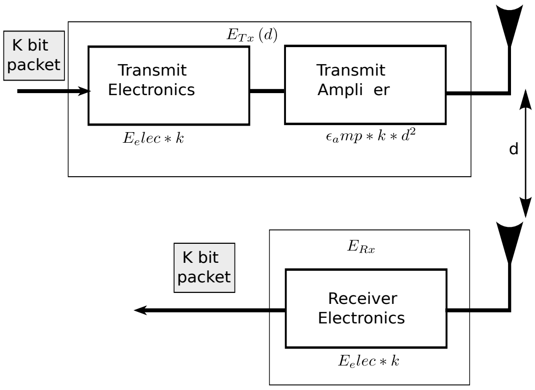

Figure 3.6: First order radio model

In case of two hops

$$P_s = P_2.\left(\frac{d_0}{\frac{d}{2}}\right)^{\alpha} \tag{3.7}$$

In case of three hops

$$P_s = P_3.\left(\frac{d_0}{\frac{d}{3}}\right)^{\alpha} \tag{3.8}$$

So, we can see that

$$P_1 = P_2.2^{\alpha} \tag{3.9}$$

$$P_1 = P_3.3^{\alpha} \tag{3.10}$$

and total transmitter's power consumption for different hops can be seen in Table 3.2 If there are n hops, we can say that total power consumption

Table 3.2: Total transmitter's power consumption for different hops

Single-hop	P_1
Double-hop	$2P_2 = 2\frac{P_1}{2^{\alpha}}$
Third-hop	$3P_3 = 3\frac{P_1}{3^{\alpha}}$

will be

$$P_n = n\left(\frac{P_1}{n^{\alpha}}\right) \tag{3.11}$$

So from the analysis we can say that for any value of path loss exponent greater than one multi-hop will be considered to have an edge over single-hop when energy efficiency is considered.

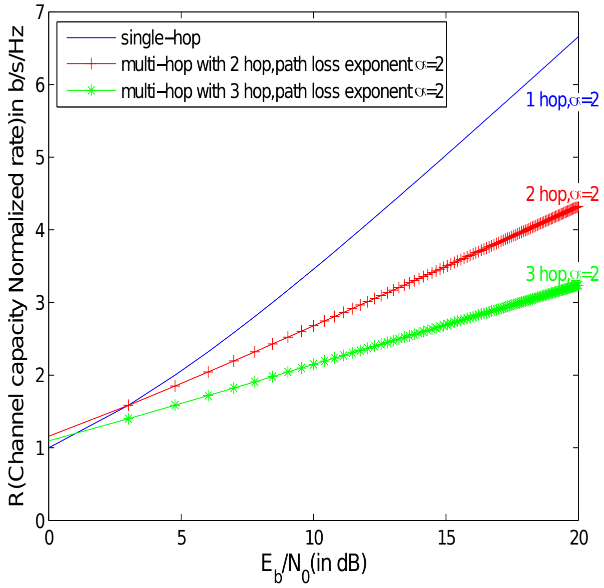

Figure 3.7: Channel capacity in free space when α=2

5. Channel Capacity: A given communication system has a maximum rate of information which is termed as channel capacity. Channel capacity [13], [4] for single hop can be expressed as

$$R = \log_2\left(1 + \frac{E_s}{N_0}\right) \tag{3.12}$$

if we switch to N time shared hops

$$R = \frac{1}{N}\log_2\left(1 + \frac{E_s}{N_0}N^{\alpha}\right) \tag{3.13}$$

The channel is assumed to attenuate the transmitted signal and corrupt it with Additive White aussian Noise(AWGN) with spectrum density N_0 with received energy E_s,number of hops N and α = path loss exponent. So through results obtained from equation 3.12 and equation 3.13 which are shown in Figure 3.7 and 3.8 clearly shows that single-hop with path loss exponent greater than one will have more channel capacity than multi-hop with all other factors being constant. Therefore, a simple rule can be followed if the required end-to-end spectral efficiency exceeds α then transmission from source to destination can be done through single-hop.

6. Routing Overhead and Route Maintenance: It is pointed out that (when we

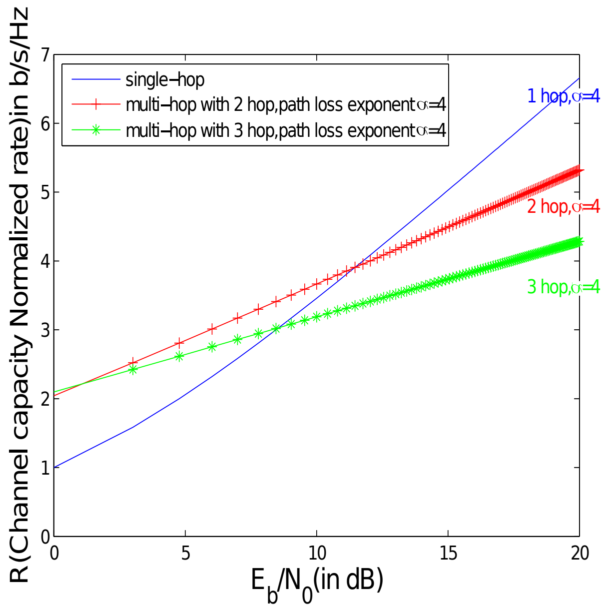

Figure 3.8: Channel capacity in building no LOS when α=4

replace a larger number of short hops by a smaller number of long hops). It is far from clear what happens to the overall transmission energy, since to implement a nearest-neighbor policy , significantly augmented overhead control traffic will be required to coordinate the establishment of the routing paths and access control protocols across the entire network. In a first order approximation, the control traffic for routing and route maintenance is proportional to the number of nodes in the route. Also, the probability of a route break due to energy depletion and node failure clearly increases with the number of nodes involved, as well as the memory requirements for the routing tables. In addition, energy consumption cannot be balanced efficiently among nodes if it is required that all nearest neighbors participate in routing. Long-hop schemes have a drastic advantage when it comes to avoiding low-energy nodes as relays.

7. Sleep Mode: If nearby neighbors are not used as relays, they can be put into very low-power sleep modes, whereas short-hop routes require many nodes to be awake frequently. Sleep modes provide substantial energy savings, particularly for sensor networks. For the mote platforms, the energy consumption in sleep mode is typically 30 dB smaller than in receive or transmit mode and about 27 dB smaller than in idle mode. Thus, in

periods of low activity, it is desirable to have only a few nodes awake as sentries, which requires long hops to keep them connected. Generally, in ad hoc networks, if a given source-destination pair is exchanging bursty traffic, it is often impossible to use sleep modes at the relay nodes due to the limited accuracy of the sleep schedules and the uncertainty in the traffic and wireless channel. Also, the energy consumption at wakeup periods may be substantial compared to the benefit of a short sleep period, so long hops are preferable to reduce the number of active nodes.

Chapter 4

Application specific network model

4.1 Applications

Different applications used different architecture models to achieve the best results moreover objective is to design a network which can be used for telemedicine, transportation, tracking endangered species, detecting toxic agents, and monitoring the security of civil and engineering infrastructures [2]. The type of application is also important for the design of routing protocols. In monitoring applications, usually nodes communicate their observations to the sink in a periodic manner. As a result, static routes can be used to maintain efficient delivery of the observations throughout the lifetime of the network. In event-based applications, however, the sensor network is in sleep state most of the time. However, whenever an event occurs, routes should be generated to deliver the event information in a timely manner. Moreover, event location is not fixed since it is directly related to the event and, hence, new routes should be generated for each event. It can be seen that the routing technique is directly related to the application and significantly different techniques may be required for different kinds of applications. We taxonomized sensor networks and systems into two basic categories and analyized the application which is best suitable for different network models.

1. Single-hop or Direct based: In chapter II we discussed the basic definition and model, the important characterization of applications in which single-hop will be preferred are:

   (a) Sensor nodes (i.e., the WSN) do not support communications on behalf of any other sensor nodes.

(b) The forwarding node supports only static routing to the terrestrial network, and/or only one physical link to the terrestrial network is present.

(c) The radio link is measured in hundreds of meters.

(d) The forwarding node does not support data processing or reduction on behalf of the sensor nodes.

(e) It requires less delay.

(f) It needs maximum channel capacity.

By utilization of above points we refer best suited single-hop applications.

4.1.1 Home Control

Home control applications provide control, conservation, convenience, and safety.
Sensing applications facilitate flexible management of lighting, heating, and cooling systems from anywhere in the home.
Sensing applications automate control of multiple home systems to improve conservation, convenience, and safety.
Sensing applications capture highly detailed electric, water, and gas utility usage data.
Sensing applications embed intelligence to optimize consumption of natural resources.
Sensing applications enable the installation, upgrading, and networking of a home control system without wires.
Sensing applications enable one to configure and run multiple systems from a single remote control.
Sensing applications support the straightforward installation of wireless sensors to monitor a wide variety of conditions.
Sensing applications facilitate the reception of automatic notification upon detection of unusual events.

Body-worn medical sensors (e.g., heartbeat sensors) are also emerging. These are battery-operated devices with network beacons occurring either every few seconds that could be worn by home-resident elderly or people with other medical conditions.These sensors have two ongoing processes: heartbeat time logging and transmission of heart rate and other information (instantaneous and average heart rate, body temperature, and battery voltage).

2. Multi-hop or chain based: The important parameters which makes multi-hop suitable are:
   (a) Sensor nodes can support communications on behalf of other sensor nodes by acting as repeaters.
   (b) The forwarding node supports dynamic routing and more than one physical link to the rest of the network is physically and logically present.
   (c) The radio links are measured in thousands of meters.
   (d) The forwarding node can support data processing or reduction on behalf of the sensor nodes.
   (e) Energy efficient.
   (f) High SNR.

4.1.2 Military Applications

Military Surveillance For military users, an application focus of WSN technology has been area and theater monitoring. WSNs can replace single high-cost sensor assets with large arrays of distributed sensors for both security and surveillance applications. The WSN nodes are smaller and more capable than sensor assets presently in the inventory; the added feature of robust, self-organizing networking makes WSNs deployable by untrained troops in essentially any situation. Distributed sensing has the additional advantages of being able to provide redundant and hence highly reliable information on threats as well as the ability to localize threats by both coherent and incoherent processing among the distributed sensor nodes. WSNs can be used in traditional sensor network applications for large-area and perimeter monitoring and will ultimately enable every platoon, squad, and soldier to deploy WSNs to accomplish a number of mission and self-protection goals.Rockwell Scientific has been working with the U.S. Marine Corps and U.S.Army to test and refine WSN performance in desert, forest, and urban terrain. For the urban terrain, WSNs are expected to improve troop safety as they clear and monitor intersections, buildings, and rooftops by providing continuous vigilance for unknown troop and vehicle activity. The primary challenge facing WSNs is accurate identification of the signal being sensed; one needs to develop state-of-the-art vibration, acoustic, and magnetic signal classification algorithms to accomplish this goal.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

The low cost and rapid deployment characteristics of sensor networks create many applications areas for remote sensing. It is by now clear that to realize the sensor networks a meticulous analysis of design constraint in single-hop and multi-hop is important.

Table 5.1: Comparison between Direct, Cluster and Chain based communication

Factors	Direct	Cluster based		Chain Based
		Single-hop	Multi-hop	
Channel Capacity	High	High	Low	Low
SNR	Low	Low	High	High
Delay	Low	Low	High	High
Energy efficiency	Low	Low	High	High

Table 5.2: Comparison between Single-hop and Multi-hop

Factors	Single-hop	Multi-hop		
		no. of hops	$\alpha = 2$	$\alpha = 4$
Channel Capacity	High	2	Moderate	Moderate
		3	Low	Low
SNR	Low	High		
Delay	Low	High		
Energy efficiency	Low	High		

We analyzed that when delay and channel capacity is considered single-hop must be preferred and when energy efficiency and SNR gain is of main focus multi-hop should be taken into account, Table 5.1 and 5.2 show the analysis of different network models. This project also addressed the applications in which different routing protocols can be used and also included the suitability of different routing protocols with different network parameters.

5.2 Future Scope

The Future work of the project will include more network parameters which would yield more effective trade-off between the two data forwarding technique. Moreover after the effective analysis application will be considered in the practical world and compatibility of different forwarding techniques with different application will be demonstrated so that the practically of this project can be easily seen.

References

[1] D. Culler, D. E. M. Srivastava,“Overview of Sensor Network ”, *IEEE Computer Magazine*, vol. 37, no. 8,pp. 41-49, August 2004.

[2] I. Akyildiz, W. Su*, Y. Sankarasubramaniam and E. Cayirci,“Wireless sensor networks: a survey, ”Computer Networks, p. 30, 2001.

[3] Marcin Sikora, J. Nicholas Laneman, Martin Haenggi, Daniel J. Costello, Jr., and Thomas Fuja, “On the Optimum Number of Hops in Linear Wireless Networks ”, 2012.

[4] M. Haenggi,“Twelve reasons not to route over many short hops,”in *Proc. IEEE Vehicular Technology Conference (VTC04)*, Los Angeles, CA, Sep. 2004.

[5] M. Haenggi,“The Impact of Power Amplifier Characteristics on Routing in Random Wireless Networks ”,2003.

[6] P. Gupta and P. R. Kumar,“The Capacity of Wireless Networks, ”*IEEE Transactions on Information Theory*, vol. 46, pp. 388-404, Mar. 2000.

[7] T. Jain, D. S. Saini, S. V. Bhooshan (2014).“Cluster Head Selection in a Homogeneous Wireless Sensor Network Ensuring Full Connectivity with Minimum Isolated Nodes,”*Journal of Sensors,* 2014 (2014), Article ID 724219-8p.

[8] Vlajic and Xia, D,“Wireless sensor networks: to cluster or not to cluster? ”, 2006.

[9] A. Chauhan, R. Bhargove, T. Sharma, T. Jain (2014). “A framework for energy efficient routing protocol for homogeneous wireless sensor networks using sensing range.”Proceedings of the *International Conference*

on Signal Processing and Integrated Networks [Noida : 20-21 February, 2014], pp.438-443.

[10] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan,"Energy-Efficient Communication Protocol for Wireless Microsensor Networks ".

[11] J. J. Uroš M. Pešović, K. B. Mohorko and Ž. F. Čučej, "Single-hop vs. Multi-hop Energy efficiency,"*Telecommunication*, p. 4, 2010.

[12] T. Rappaport,"Wireless communications: Principles and practice "in Plastics, 2nd ed. McGraw-Hill, 1964, pp. 1-9. Texas instruments, cc2420 datasheet.

[13] M. Haenggi,"On routing in random Rayleigh fad-ing networks,"accepted to *IEEE Transactionson Wireless Communications*, 2004. Available at http://www.nd.edu/ mhaenggi/routing.pdf.

[14] M. Sikora *et al.*,"On the Optimum Number of Hops in Linear Ad Hoc Networks,"*IEEE Info. Theory Wksp.*, San Antonio, TX, Oct. 2004.

[15] M. Haenggi and D. Puccinelli,"Routing in Ad Hoc Networks: A case for Long Hops,"*TOPICS IN AD HOC AND SENSOR NETWORKS*, p. 13, 2005.

[16] P. Bauer, M. Sichitiu, R. Istepanian, K. Premaratne, The mobile patient: wireless distributed sensor networks for patient monitoring and care, Proceedings 2000 IEEE EMBS International Conference on Information Technology Applications in Biomedicine, 2000.

[17] M. Bhardwaj, T. Garnett, A.P. Chandrakasan, Upper bounds on the lifetime of sensor networks, IEEE International Conference on Communications ICC'01, Helsinki,Finland, June 2001.

[18] P. Bonnet, J. Gehrke, P. Seshadri, Querying the physical world, IEEE Personal Communications (October 2000) 10-15.

[19] N. Bulusu, D. Estrin, L. Girod, J. Heidemann, Scalable coordination for wireless sensor networks: self-configuring localization systems, Interna-

tional Symposium on Communication Theory and Applications (ISCTA 2001), Ambleside, UK, July 2001.

[20] B.G. Celler et al., An instrumentation system for the remote monitoring of changes in functional health status of the elderly, International Conference IEEE-EMBS, New York, 1994.

[21] M. Gell-Mann, What is complexity? Complexity 1 (1), 1995.

[22] L. Girod, D. Estrin, Robust range estimation using acoustic and multi-modal sensing, Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001), Maui, Hawaii, October 2001.

[23] K. Govil, E. Chan, H. Wasserman, Comparing algorithms for dynamic speed-setting of a low-power CPU, Proceedings of ACM MobiCom'95, Berkeley, CA, November 1995.

[24] M.P. Hamilton, M. Flaxman, Scientific data visualization and biological diversity: new tools for spatializing multimedia observations of species and ecosystems, Landscape and Urban Planning 21 (1992) 285-297.

[25] M.P. Hamilton, Hummercams, robots, and the virtual reserve, Directors Notebook, February 6, 2000.

[26] B. Halweil, Study finds modern farming is costly, World Watch 14 (1) (2001) 9-10.

[27] S. Hedetniemi, A. Liestman, A survey of gossiping and broadcasting in communication networks, Networks 18 (4) (1988).

[28] J. Heidemann, F. Silva, C. Intanagonwiwat, Building efficient wireless sensor networks with low-level naming, Proceedings of the Symposium on Operating Systems Principles, Banff, Canada, 2001.

[29] W.R. Heinzelman, A. Chandrakasan, H. Balakrishnan,Energy-efficient communication protocol for wireless microsensor networks, IEEE Proceedings of the Hawaii International Conference on System Sciences, January 2000.

[30] W.R. Heinzelman, J. Kulik, H. Balakrishnan, Adaptive protocols for information dissemination in wireless sensor networks, Proceedings of the ACM MobiCom'99, Seattle,Washington, 1999.

[31] C. Herring, S. Kaplan, Component-based software systems for smart environments, IEEE Personal Communications, October 2000.

[32] G. Hoblos, M. Staroswiecki, A. Aitouche, Optimal design of fault tolerant sensor networks, IEEE International Conference on Control Applications, Anchorage, AK,September 2000.

[33] T. Imielinski, S. Goel, DataSpace: querying and monitoring deeply networked collections in physical space, ACM International Workshop on Data Engineering for Wireless and Mobile Access MobiDE 1999, Seattle, Washington, 1999.

[34] C. Intanagonwiwat, R. Govindan, D. Estrin, Directed diffusion: a scalable and robust communication paradigm for sensor networks, Proceedings of the ACM MobiCom'00, Boston, MA, 2000.

[35] C. Jaikaeo, C. Srisathapornphat, C. Shen, Diagnosis of sensor networks, IEEE International Conference on Com- munications ICC'01, Helsinki, Finland, June 2001.

[36] P. Johnson et al., Remote continuous physiological monitoring in the home, Journal of Telemed Telecare 2 (2) (1996).

[37] T. Nandagopal, T. Kim, X. Gao, V. Bhargavan, Achieving MAC layer fairness in wireless packet networks, Proceedings of the ACM MobiCom'00, Boston, MA, 2000.