بسم الله الرحمن الرحيم

ISLAMIC UNIVERSITY OF TECHNOLOGY

DHAKA, BANGLADESH

ORGANIZATION OF ISLAMIC COOPERATION

EEBCDA CO-MIMO SCHEME FOR WIRELESS SENSOR NETWORKS

A thesis submitted to the Department of Electrical and Electronic Engineering (EEE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for degree of Bachlor of Science in Electrical and Electronic Egineering.

PREPARED BY:

Tanvir Islam Dhrubo (ID:122453)

Sarwar Ahmed (ID:122456)

Rafayat Razi Rahman (ID:122459)

Ahmed Tholaal (ID:122479)

Muhammad Haris (ID:122487)

SUPERVISED BY:

PROF.DR. Mohammad Rakibul Islam

DEPARTMENT OF Electrical and Electronic ENGINEERING,

ORGANIZATION OF ISLAMIC COOPERATION, (OIC)

DHAKA, BANGLADHESH.

CERTIFICATE OF RESEARCH:

The thesis title **"EEBCDA CO-MIMO SCHEME FOR WIRELESS SENSOR NETWORKS"** submitted by **Tanvir Islam Dhrubo (ID:122453), Sarwar Ahmed (ID:122456), Rafayat Razi Rahman (ID:122459), Ahmed Tholaal(ID:122479) and Muhammad Haris (ID:122487)** has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of BSc in Electrical and Electronic Engineering on November, 2016.

Approved by:

____

PROF.DR. Mohammad Rakibul Islam
Department of Electrical and Electronic Engineering
Islamic University of Technology, (IUT), Bangladesh
Organization of Islamic Cooperation, (OIC)
Date of Approval: ______________________________

DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Authors:

Tanvir Islam Dhrubo
Student No: 122453

Sarwar Ahmed
Student No: 122456

Rafayat Razi Rahman
Student No: 122459

Ahmed Tholaal
Student No: 122479

Muhammad Haris
Student No: 122487

Supervisor:

PROF.DR. Mohammad Rakibul Islam
Department of Electrical and Electronic Engineering
Islamic University of Technology, (IUT), Bangladesh
Organization of Islamic Cooperation, (OIC)

Table of Contents

List of Tables

List of Figures

List of Acronyms

AM	Acknowledge Mode
APN	Access Point Name Packet Data Network
CH	Cluster Head
CCEM	Clustering-CH Exchange Method
EEBCDA	Energy Efficient Balance Cluster Based Data Aggregation
EE-LEACH	Energy Efficient Low Energy Adaptive Clustering Hierarchy
FND	First Node Dies
HND	Half Node Dies
LND	Last Node Dies
LRCHs	Last Round Cluster Heads
LEACH	Low Energy Adaptive Clustering Hierarchy
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
STBC	Space-Time Block Codes
SISO	Single Input Single Output
SIMO	Single Input Multiple Output
WSNs	Wireless Sensor Networks

Acknowledgements

We express our heartiest gratefulness to Almighty Allah (SWT) for His divine blessings, which made us possible to complete this thesis successfully.

We would like to thank the advisor of this project, Dr. Mohammad Rakibul Islam, Professor, Electrical and Electronic Engineering, IUT for their guidance, continual support towards the advancement and completion of this project.

We would like to thank our department for supporting us. We convey our respect to all the teachers, friends and family members who gave us their support.

Tanvir Islam Dhrubo
Sarwar Ahmed
Rafayat Razi Rahman
Ahmed Tholaal
Muhammad Haris

Abstract

This thesis work is focused on the Cooperative multiple input multiple output (CO-MIMO). In radio, **multiple-input and multiple-output**, or **MIMO** , is a method for multiplying the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation. At one time, in wireless the term "MIMO" referred to the use of multiple antennas at the transmitter and the receiver. In modern usage, "MIMO" specifically refers to a practical technique for sending and receiving more than one data signal simultaneously over the same radio channel by exploiting multipath propagation. MIMO is fundamentally different from smart antenna techniques developed to enhance the performance of a single data signal, such as beamforming and diversity.

MIMO is often traced back to 1970s research papers concerning multi-channel digital transmission systems and interference (crosstalk) between wire pairs in a cable bundle: AR Kaye and DA George (1970), Branderburg and Wyner (1974), and W. van Etten (1975, 1976). Although these are not examples of exploiting multipath propagation to send multiple information streams, some of the mathematical techniques for dealing with mutual interference proved useful to MIMO development.

EEBCDA is one of the efficient cluster based to wireless sensor networks (WSN) protocols. It solves unbalanced energy consumption of cluster based networks by clustering based on energy consumption of the clusters. This results in more balanced energy consumption among the clusters.

In this thesis we combine EEBCDA with cooperative MIMO to make EEBCDA more energy efficient on longer distances. In EEBCDA MIMO scheme, the residual energy of each node is considered in choosing CHs for clustering and in case of cooperative nodes selection. Simulation results demonstrate that this results less energy consumption and in turn better overall life time of nodes EEBCDA SISO.

Chapter 1

Introduction

Wireless sensor networks (WSNs) are composed of nodes typically powered by batteries, so the most important problem while communicating through WSNs is energy consumption and also it is difficult to replace or recharge the batteries, which is discussed by I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci as Energy-constrained networks, such as wireless sensor networks, have nodes typically powered by batteries, for which replacement or recharging is difficult if not impossible [1]. For such networks, minimizing the energy consumption per unit information transmission becomes a very important design consideration. It has been recently shown that multiple nodes can collaborate to achieve significant transmission power reduction via spatial diversity techniques even though each node has only one antenna [2], [3]. Such strategy is termed as cooperative communication.

In cooperative communication systems, two or more nodes form a virtual antenna array to jointly transmit information. In a relay channel context, the diversity performance and the outage behavior of cooperative communication have been analyzed in [3] under different cooperative protocols.

A number of routing protocols have been proposed for WSN in order to reduce the energy consumption, the most well-known are hierarchical protocols like LEACH [4]-[6], and PEGASIS [7]. Hierarchical protocols are defined to reduce energy consumption by aggregating data and to reduce the transmissions to the Base Station. LEACH is considered as the most popular and first routing protocol that use cluster based routing in order to minimize energy consumption.

Dhilip et al. proposed an energy-efficient clustering and data aggregation protocol for the heterogeneous WSN. This protocol was designed based on the ideas of data aggregation on energy-efficient cluster-based routing. The cluster head election technique was used, and the routing path was selected based upon the sum of residual energy used for data transmission [8]. Wei et al. introduced an energy-efficient clustering solution for WSN. A distributed clustering algorithm was used to calculate the appropriate cluster size. It was determined based on the hop distance from the source to sink. An energy-efficient multi hop data-gathering protocol was applied to validate the effectiveness of the cluster and calculate the end-to-end delay [9].

Xiang et al. proposed an energy-efficient clustering algorithm to maximize the lifetime. The clustering algorithm with optimum parameters was used to reduce the energy conservation among the nodes. An analytical clustering with one hop distance and clustering angle was used. Moreover, the optimal one hop distance and clustering angle were conveyed by reducing the energy consumption between inter and intra-cluster. For each cluster, the continuous procedure gets repeated until the optimum number of clusters were obtained. It reduces the frequency of updating the cluster head and significantly reduces energy to establish a cluster head [10].

Fengyuan et al. formulated an energy-balanced routing protocol for data gathering. Enhanced mechanisms were used to identify and eliminate the loops [11]. Dervis et al. utilized an artificial bee colony algorithm for energy-efficient clustering. The artificial bee colony algorithm was used to prolong the lifetime of the sensor nodes and the network [12]. Yuea et al. discussed about the balanced cluster-based data aggregation algorithm. The sensor network was divided into rectangular grids. For each grid, the cluster head was elected to manage the nodes and balance the load among the sensors [13].

Rout et al. introduced an adaptive data aggregation mechanism based on network coding. Here, the group of nodes act as network coder nodes and the remaining nodes were used for relaying purpose. The network coder nodes were sometimes used as aggregation points based on the measure of the data correlation [14]. Hui et al. formulated an exact and heuristic algorithm for data gathering. The data-gathering algorithm was based on the cluster-based approach. A mixed-integer linear-programming model was used to calculate the BS and CH position and also the data flow in the network area. This method utilizes both the energy and position of the sensor for selecting the CH. Hence, it avoids the highest energy consumption. The benders decomposition was incorporated into the upper bound heuristics algorithm [15]. Mathapati et al. designed an energy-efficient reliable data aggregation approach. Clustering approach was used to group the node into clusters. A coordinate node was elected to monitor the cluster nodes. The CH was elected based upon the energy level and the distance from the node to the coordinate node. The messages were gathered by CH and forwarded to the BS [16].

Sheu et al. discussed an efficient path planning and data-gathering protocols in WSN. Here, an infrastructure-based data-gathering protocol and distributed data-gathering protocols were introduced to plan the data-gathering route for a BS. Also, k-hop approach was used to limit the number of hops for routing the data to a mobile sink [17]. Ebrahimi et al. proposed a compressive data-gathering approach based on the random projection. The compressive data gathering improves the energy efficiency among the sensors. The random projection was integrated with the compressive data gathering in order to enhance the energy consumption and load throughout the network. A minimum spanning tree projection was used to randomly select the projection nodes [18]. Min et al. proposed an approximate data-gathering approach called EDGES. It utilizes the temporal and spatial correlations. The multiple-model Kalman filter was used to predict the future values based on the previous single-sensor reading. A redistribution model was used to distribute the energy consumption of CH based on the spatial correlation [19]. Jin et al. presented an adaptive data-gathering mechanism based on compressive sensing. Here, an autoregressive model was used in the reconstruction of the sensed data. The local correlation among the sensed data was included, and hence, local adaptive sparsity was obtained. The sink had recovered the data based on the successive reconstructions. The measurements were modified based on the variation of the sensed data. An abnormal readings detection and identification methods were incorporated based on the combinational sparsely reconstruction [20].

Song et al. proposed a biology-based algorithm to minimal exposure problem (MEP) of WSNs. It explores the biological model of physarum to formulate a biology-inspired optimization algorithm. The MEP with the related models was formulated, and then, it was converted into a Steiner problem through discretizing the monitoring domain [21]. Liu et al. presented a physarum optimization method. It was a biology-inspired algorithm for the Steiner tree problem. A cellular computing model was exploited to solve the Steiner problem [22]. Li et al. designed an opportunistic feeding and routing protocol for reliable multicasting with network coding [23]. Zeng et al. proposed a directional routing and scheduling for green vehicular delay tolerant networks. It solves the routing and scheduling problem as a learning process through geographic routing and flow control toward the optimal direction. A hybrid method with forwarding and replication was presented to speed up the learning process according to the traffic pattern [24]

Yao et al. introduced an energy-efficient, delay-aware and lifetime-balancing data collection protocol for WSN. This method proposed both a centralized heuristic to make the algorithm scalable for huge-scale network operations [25]. Han et al. suggested an algorithm for data communication in duty cycle WSNs. The authors in [26] survey the research problem to reveal the insights into problems of duty cycled WSNs. Liu et al. presented a compressed data aggregation for energy-efficient WSNs. The authors in [27] aimed to reduce the energy consumption with the help of joint routing and compressed aggregation. The optimal solution was characterized to this optimization problem, which has proven the NP-completeness. Moreover, a mixed-integer programming formulation with the greedy heuristic approach was proposed for both the optimal and near-optimal aggregation trees to be obtained.

Chapter 2

Wireless Sensor Network

2.1 Background of WSN:

Sensor nodes offer a powerful combination of distributed sensing, computing and communication. The ever-increasing capabilities of these tiny sensor nodes, which include sensing, data processing, and communicating, enable the realization of WSNs based on the collaborative effort of a number of other sensor nodes. They enable a wide range of applications and, at the same time, offer numerous challenges due to their stringent energy constraints to which sensing nodes are typically subjected.

A Wireless Sensor Network is a self-configuring network of small sensor nodes communicating among themselves using radio signals, and deployed in quantity to sense, monitor and understand the physical world.

WSN provide a bridge between the real physical and virtual worlds. It allows the ability to observe the previously unobservable at a fine resolution over large spatiotemporal scales. It has a wide range of potential applications to industry, science, transportation, civil infrastructure, and security.

2.2 Working Procedure:

Total working of wireless sensor networking is based on its construction. Sensor network initially consists of small or large nodes called as sensor nodes. These nodes are varying in size and totally depend on the size because different sizes of sensor nodes work efficiently in different fields. Wireless sensor networking have such sensor nodes which are specially designed in such a typical way that they have a microcontroller which controls the monitoring, a radio transceiver for generating radio waves, different type of wireless communicating devices and also equipped with an energy source such as battery. The entire network worked simultaneously by using different dimensions of sensors and worked on the phenomenon of multi routing algorithm which is also termed as wireless ad hoc networking.

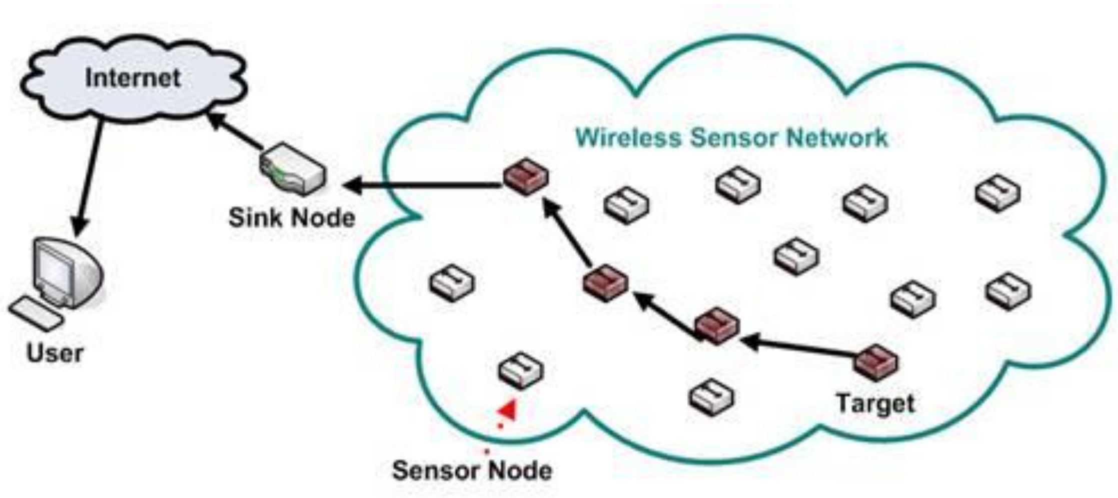

Figure 2.1: Structure of WSN

2.3 Applications of WSN

2.3.1 Area monitoring

Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors detects enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines.

2.3.2 Health Care Monitoring

The medical applications can be of two types: wearable and implanted. Wearable devices are used on the body surface of a human or just at close proximity of the user. The implantable medical devices are those that are inserted inside human body. There are many other applications too e.g. body position measurement and location of the person, overall monitoring of ill patients in hospitals and at homes. Body-area networks can collect information about an individual's health, fitness, and energy expenditure.

2.3.3 Environmental Sensing

There are many applications in monitoring environmental parameters, examples of which are given below. They share the extra challenges of harsh environments and reduced power supply.

2.3.4 Air Pollution Monitoring

Wireless sensor networks have been deployed in several cities (Stockholm, London, and Brisbane) to monitor the concentration of dangerous gases for citizens. These can take advantage of the ad hoc wireless links rather than wired installations, which also make them more mobile for testing readings in different areas.

2.3.4.1 Forest Fire Detection

A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; thanks to Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading.

2.3.4.2 Landslide Detection

A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the impending occurrence of landslides long before it actually happens.

2.3.4.3 Water Quality Monitoring

Water quality monitoring involves analyzing water properties in dams, rivers, lakes & oceans, as well as underground water reserves. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status, and allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval.

2.3.4.4 Natural Disaster Prevention

Wireless sensor networks can effectively act to prevent the consequences of natural disasters, like floods. Wireless nodes have successfully been deployed in rivers where changes of the water levels have to be monitored in real time.

2.3.5 Industrial Monitoring

2.3.5.1 Machine Health Monitoring

Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionality. Wireless sensors can be placed in locations difficult or impossible to reach with a wired system, such as rotating machinery and untethered vehicles.

2.3.5.2 Data Center Monitoring

Due to the high density of server racks in a data center, often cabling and IP addresses are an issue. To overcome that problem more and more racks are fitted out with wireless temperature sensors to monitor the intake and outtake temperatures of racks.

2.3.5.3 Data Logging

Wireless sensor networks are also used for the collection of data for monitoring of environmental information, this can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants. The statistical information can then be used to show how systems have been working. The advantage of WSNs over conventional loggers is the "live" data feed that is possible.

2.3.5.4 Water/Waste Water Monitoring

Monitoring the quality and level of water includes many activities such as checking the quality of underground or surface water and ensuring a country’s water infrastructure for the benefit of both human and animal. It may be used to protect the wastage of water.

2.3.5.5 Structural health monitoring

Wireless sensor networks can be used to monitor the condition of civil infrastructure and related geo-physical processes close to real time, and over long periods through data logging, using appropriately interfaced sensors.

2.4 Major Components of a Sensor Node

A WSN is a collection of nodes with sensing capability that communicate the sensed data from the source to the destination wirelessly with low transmission speed and low transmission power. Each node may have five basic components:

- Controller
- Transceiver
- External Memory
- Power Source
- Sensors

2.4.1 Controller

The controller performs tasks, processes data and controls the functionality of other components in the sensor node. While the most common controller is a microcontroller. A microcontroller is often used in many embedded systems such as sensor nodes because of its low cost, flexibility to connect to other devices, ease of programming, and low power consumption. A general purpose microprocessor generally has higher power consumption than a microcontroller; therefore it is often not considered a suitable choice for a sensor node. Digital Signal Processors may be chosen for broadband wireless communication applications, but in Wireless Sensor Networks the wireless communication is often modest: i.e., simpler, easier to process modulation and the signal processing tasks of actual sensing of data is less complicated. Therefore, the advantages of DSPs are not usually of much importance to wireless sensor nodes.

2.4.2 Transceiver

Sensor nodes often make use of ISM band (Industrial, scientific and medical radio band), which gives free radio, spectrum allocation and global availability. The functionality of both transmitter and receiver are combined into a single device known as a transceiver. Transceivers often lack unique identifiers. The operational states are transmit, receive, idle, and sleep.

Most transceivers operating in idle mode have a power consumption almost equal to the power consumed in receive mode. Thus, it is better to completely shut down the transceiver rather than leave it in the idle mode when it is not transmitting or receiving. A significant amount of power is consumed when switching from sleep mode to transmit mode in order to transmit a packet.

2.4.3 External memory

From an energy perspective, the most relevant kinds of memory are the on-chip memory of a microcontroller and Flash memory—off-chip RAM is rarely, if ever, used. Flash memories are used due to their cost and storage capacity. Memory requirements are very much application dependent. Two categories of memory based on the purpose of storage are: user memory used for storing application related or personal data, and program memory used for programming the device. Program memory also contains identification data of the device if present.

2.4.4 Power source

Since the wireless sensor node is often placed in a hard-to-reach location, changing the battery regularly can be costly and inconvenient. An important aspect in the development of a wireless sensor node is ensuring that there is always adequate energy available to power the system. The sensor node consumes power for sensing, communicating and data processing. More energy is required for data communication than any other process. The energy cost of transmitting 1 Kb a distance of 100 meters (330 feet) is approximately the same as that used for the execution of 3 million instructions by a 100 million instructions per second/W processor. Power is stored either in batteries or capacitors. Batteries, both rechargeable and non-rechargeable, are the main source of power supply for sensor nodes. Current sensors are able to renew their energy from solar sources, temperature differences, or vibration.

2.4.5 Sensors

Sensors are used by wireless sensor nodes to capture data from their environment. They are hardware devices that produce a measurable response to a change in a physical condition like temperature or pressure. Sensors measure physical data of the parameter to be monitored and have specific characteristics such as accuracy, sensitivity etc. The continual analog signal produced by the sensors is digitized by an analog-to-digital converter and sent to controllers for further processing. Some sensors contain the necessary electronics to convert the raw signals into readings which can be retrieved via a digital link and many convert to units such as °C. Most sensor nodes are small in size, consume little energy, operate in high volumetric densities, be autonomous and operate unattended, and be adaptive to the environment. As wireless sensor nodes are typically very small electronic devices, they can only be equipped with a limited power source of less than 0.5-2 ampere-hour and 1.2-3.7 volts.

Sensors are classified into three categories: passive, omnidirectional sensors; passive, narrow-beam sensors; and active sensors. Most theoretical work on WSNs assumes the use of passive, omnidirectional sensors. Each sensor node has a certain area of coverage for which it can reliably and accurately report the particular quantity that it is observing. Several sources of power consumption in sensors are: signal sampling and conversion of physical signals to electrical ones, signal conditioning, and analog-to-digital conversion. Spatial density of sensor nodes in the field may be as high as 20 nodes per cubic meter.

Chapter 3

Overview of Co-operative MIMO

3.1 Wireless Antenna Technology

The different forms of antenna technology refer to single or multiple inputs and outputs. These are related to the radio link. In this way the input is the transmitter as it transmits into the link or signal path, and the output is the receiver. It is at the output of the wireless link.

Based on the number of antennas in the transmitter and receiver, a wireless sensor network can be divided into four basic forms. The different forms are defined as:

- SISO - Single Input Single Output
- SIMO - Single Input Multiple output
- MISO - Multiple Input Single Output
- MIMO - Multiple Input multiple Output

3.1.1 SISO

SISO Systems or the single input, single output communication systems is the simplest form of the communication system out of all four in which there is single transmitting antenna at the source and a single receiving antenna at the destination. SISO systems are used in multiple systems like Bluetooth, Wi-Fi, radio broadcasting, TV etc.

SISO are advantageous in terms of the simplicity. It does not require processing in terms of diversity schemes. The throughput of the system depends upon the channel bandwidth and signal to noise ratio. In some conditions, these systems are exposed to the issues like multipath effects.

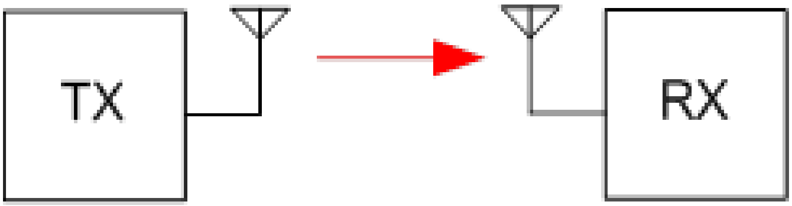

Figure 3.1: SISO Communication System

3.1.2 SIMO

SIMO or the Single input and multiple output form of wireless communication scheme in which there are multiple antennas are present at the receiver and there is single transmitting antenna at the source. In order to optimize the data scheme, various receive diversity schemes are employed at the receiver like selection diversity, maximum gain combining and equal gain combining schemes. SIMO systems were used for short waves listening and receiving stations to counter the effects of ionosphere fading. The SIMO systems are acceptable in many applications but where the receiving system is located in the mobile device like mobile phone, the performance me be limited by size, cost and battery.

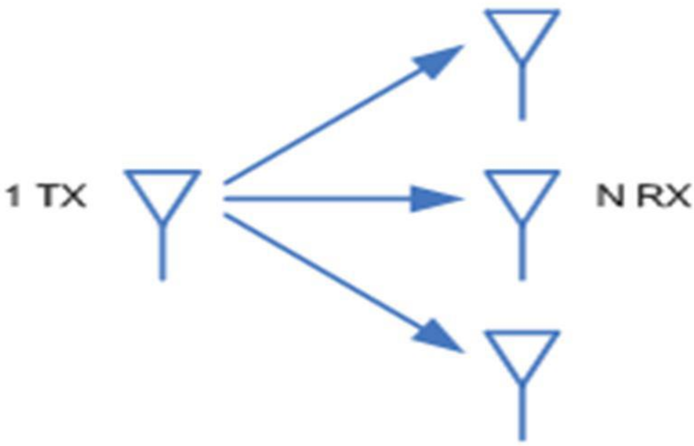

Figure 3.2: SIMO Communication System

3.1.3 MISO

MISO or the multiple input and single output is a scheme of RF wireless communication system in which there are multiple transmitting antennas at the source and single receiving antenna at the system like SIMO but at the destination, receiver has a single antenna. When we use two or more antenna at the receiving end or at destination, the effects of multipath wave propagation, delay, packet loss etc. can be reduced. This scheme has various applications like in Digital television, wireless LANs. MISO systems are advantageous because the redundancy and coding has been shifted from receiving end towards the transmitting end and hence say in examples of mobile phones, less power and processing is required at the user end or the receiver end.

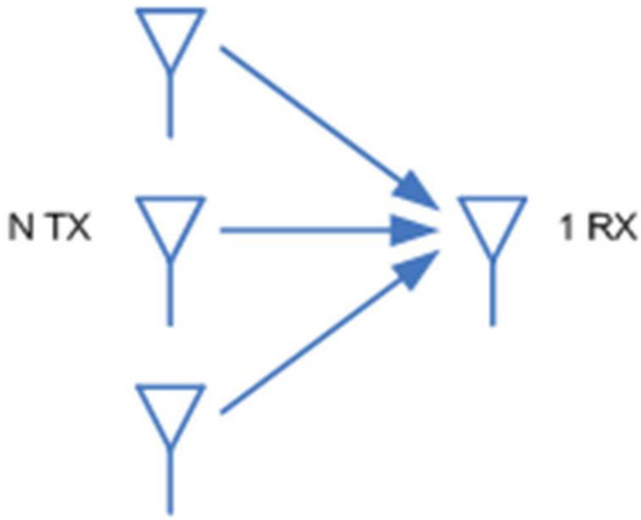

Figure 3.3: MISO Communication System

3.1.4 MIMO

MIMO systems or the multiple input and multiple output systems are the one with multiple antennas at transmitting end and multiple antennas at receiving end as well. Between a transmitter and receiver, signal can go through many paths and if we move the antenna with a small distance, the path used by the signal will change.

Wi-Fi, LTE (Long Term Evolution), and many other radio, wireless and RF technologies are using the new MIMO wireless technology to provide increased link capacity and spectral efficiency combined with improved link reliability using what were previously seen as interference paths.

Even now many there are many MIMO wireless routers on the market, and as this RF technology is becoming more widespread, more MIMO routers and other items of wireless MIMO equipment will be seen.

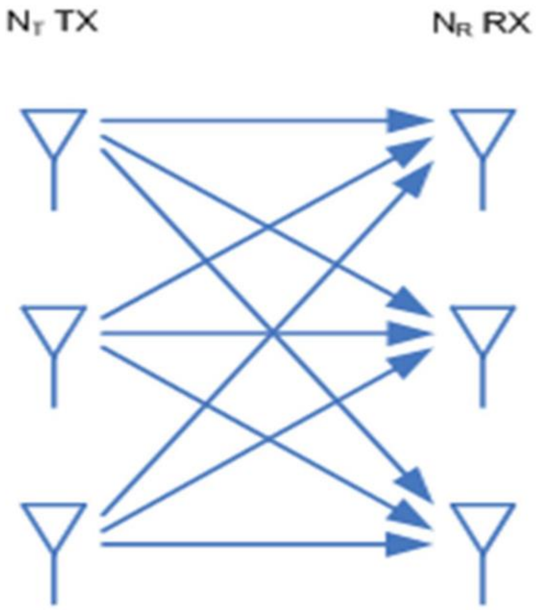

Figure 3.4: MIMO communication System

3.2 Cooperative MIMO (CO-MIMO)

Conventional MIMO systems, known as point-to-point MIMO or collocated MIMO, require both the transmitter and receiver of a communication link to be equipped with multiple antennas. While MIMO has become an essential element of wireless communication standards, many wireless devices cannot support multiple antennas due to size, cost, and/or hardware limitations. More importantly, the separation between antennas on a mobile device and even on fixed radio platforms is often insufficient to allow meaningful performance gains. Furthermore, as the number of antennas is increased, the actual MIMO performance falls farther behind the theoretical gains.**[1]**

Cooperative MIMO uses distributed antennas on different radio devices to achieve close to the theoretical gains of MIMO. The basic idea of Cooperative MIMO is to group multiple devices into a virtual antenna array to achieve MIMO communications. A Cooperative MIMO transmission involves multiple point-to-point radio links, including links within a virtual array and possibly links between different virtual arrays.

3.2.1 Implementation of CO-MIMO

The Multiple-Input Multiple-Output (MIMO) term originally describes the use of the multiple antennas concept or exploitation of spatial diversity techniques. In early research work, the MIMO concept was proposed to fulfil the demand for providing reliable high speed wireless communication links in harsh environments. Subsequently, MIMO technology has been proposed to be used in wireless local area networks and cellular networks, particularly at the base station and access point sides to tackle the challenges of low transmission rates and low reliability with no constraints on energy efficiency. In contrast, Wireless Sensor Networks (WSNs) have to deal with energy constraints due to the fact that each sensor node depends on its battery for its operation. In harsh environments, sensor nodes must be provided with reliable communication links. However, current WSN design requirements do not require high transmission rates.

The concept of cooperative MIMO was introduced in WSNs by utilizing the collaborative nature of dense sensor nodes with the broadcast wireless medium to provide reliable communication links in order to reduce the total energy consumption for each sensor node. Therefore, instead of using multiple antennas attached to one node or device such in the traditional MIMO concept, cooperative MIMO presents the concept of multiple sensor nodes cooperating to transmit and/or receive signals. Multiple sensor nodes are physically grouped together to cooperatively transmit and/or receive. Within a group, sensor nodes can communicate with relatively low power as compared to inter-group communication. Furthermore, by using this cooperative MIMO concept, we can provide the advantages of traditional MIMO systems to WSNs, particularly in terms of energy efficient operation, and we can also provide much better performance compared to SISO system.

3.2.2 Comparison with SISO

Energy-efficient communication techniques typically focus on minimizing the transmission energy only, which is reasonable in long-range applications where the transmission energy is dominant in the total energy consumption. However, in short-range applications such as sensor networks where the circuit energy consumption is comparable to or even dominates the transmission energy, different approaches need to be taken to minimize the total energy consumption.

As MIMO consumes more circuit energy due to complex circuitry than SISO systems, in short range communications thus SISO may have less overall energy consumption than MIMO system. So for short range communication SISO systems may appear better than MIMO system. But as the distance increases, the transmission energy starts to dominate the overall energy consumption and we find that MIMO is providing better overall performance and energy efficiency than SISO system.

3.2.3 Energy Consumption in CO-MOMO

The total energy consumption in Cooperative MIMO can be divided into two parts-

- Circuit energy
- Transmission energy

3.2.3.1 Circuit Energy

Circuit energy consumption includes energy consumption in both transmitter and receiver circuit. The circuit energy consumption includes the energy consumed by all the circuit blocks along the signal path: analog to digital converter (ADC), digital to analog converter (DAC), frequency synthesizer, mixer, lower noise amplifier (LNA), power amplifier, and baseband DSP.

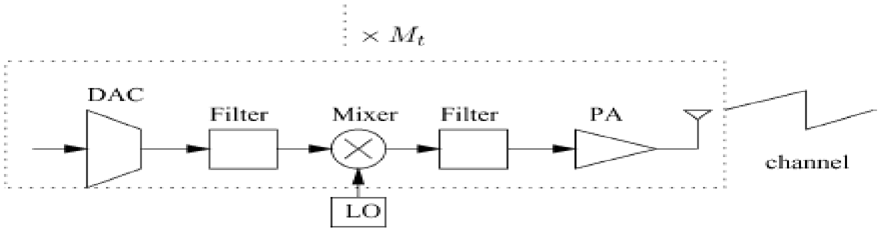

Fig. 1. Transmitter circuit blocks (analog).

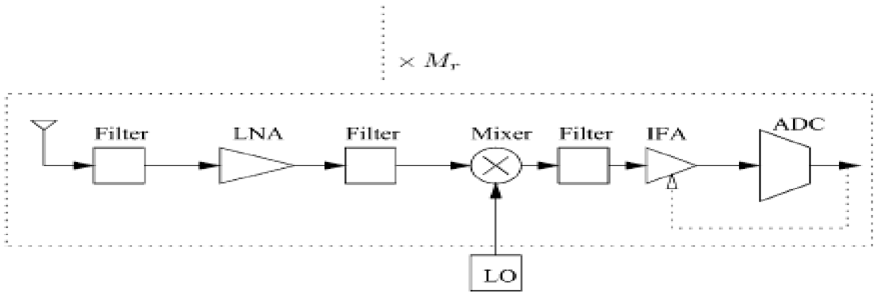

Fig. 2. Receiver circuit blocks (analog).

Figure 3.5: Circuit Blocks

The circuit power consumption can be represented by,

$$P_c \approx M_t(P_{\mathrm{DAC}} + P_{\mathrm{mix}} + P_{\mathrm{filt}}) + 2P_{\mathrm{syn}} + M_r(P_{\mathrm{LNA}} + P_{\mathrm{mix}}$$

$$+P_{\mathrm{IFA}} + P_{\mathrm{filr}} + P_{\mathrm{ADC}}) \quad (1)$$

where P_{DAC}, P_{mix}, P_{LNA}, P_{IFA}, P_{filt}, P_{filr}, P_{ADC}, and P_{sn} are the power consumption values for the DAC, the mixer, the low-noise amplifier (LNA), the intermediate frequency amplifier (IFA), the active filters at the transmitter side, the active filters at the receiver side, the ADC, and the frequency synthesizer, respectively.

3.2.3.2 Transmission Energy

The transmission power can be estimated by calculating the power consumption of all the power amplifiers P_{PA}. P_{PA} is dependent on the transmit power P_{out}. When the channel only experiences a square-law path loss, we can calculate it as:

$$P_{\mathrm{out}} = \bar{E}_b R_b \times \frac{(4\pi d)^2}{G_t G_r \lambda^2} M_l N_f \quad (2)$$

Where E_b is the required energy per bit at the receiver for a given BER requirement, R_b is the bit rate, d is the transmission distance, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, λ is the carrier wavelength, M_l is the link margin compensating the hardware process variations and other additive background noise or interference, and N_f is the receiver noise figure defined as $N_f = (N_r/N_0)$ with $N_0 = -171$ dBm/Hz the single-sided thermal noise power spectral density (PSD) at room temperature and N_r is the PSD of the total effective noise at the receiver input.

The power consumption of the power amplifiers can be approximated as

(3)

$$P_{\mathrm{PA}} = (1+\alpha)P_{\mathrm{out}}$$

Where $\alpha = (\xi/\eta) - 1$ with η the drain efficiency of the RF power amplifier and ξ the peak-to-average ratio (PAR), which is dependent on the modulation scheme and the associated constellation size.

3.2.3.3 Total Power Consumption and Comparison with SISO

The total energy consumption per bit for a fixed-rate system can be obtained as:

$$E_{\mathrm{bt}} = (P_{\mathrm{PA}} + P_c)/R_b. \tag{4}$$

For Rayleigh-fading channels MIMO systems based on Alamouti schemes can achieve lower average probability of error than SISO systems under the same transmit energy budget due to the diversity gain and possible array gain (when $M_r > 1$). In other words, under the same BER and throughput requirement, MIMO systems require less transmission energy than SISO systems. However, if we consider both the transmission energy and the circuit energy consumption, it is not clear which system is more energy-efficient, since the MIMO system has much more energy-consuming circuitry.

In the following sections, we focus on MISO and MIMO systems that use Alamouti schemes with BPSK modulation and compare their energy efficiency with that of a reference SISO system.

Alamouti 2 × 1: We consider a 2 × 1 MISO Alamouti scheme, where $\mathbf{H} = [h_1 h_2]$. The reference SISO system is treated as a special case of MISO systems with $\mathbf{H} = [h_1]$. As shown in (3), the instantaneous received SNR is given by

$$\gamma_b = \frac{\|\mathbf{H}\|_F^2}{M_t}\frac{\bar{E}_b}{N_0}, \quad M_t = 1,2 \tag{5}$$

x the M_t in the denominator comes from the fact that the transmit power is equally split among transmitter antennas. The average BER is given by

$$\bar{P}_b = \mathcal{E}_{\mathbf{H}}\{Q(\sqrt{2\gamma_b})\}. \qquad (6)$$

According to the Chernoff bound (in the high SNR regime)

$$\bar{P}_b \leq \left(\frac{E_b}{M_t N_0}\right)^{-M_t} \qquad (7)$$

So, an upper bound for the required energy per bit is,

$$\bar{E}_b \leq \frac{M^t N^0}{\bar{P}^{1/M_t}}. \qquad [8]$$

Figure 3.6: Transmission energy consumption per bit over d (bound versus numeric solution).

By approximating the bound as equality, we can calculate the total energy consumption (which is actually an upper bound) per bit for both the MISO system and the reference SISO system according to (3) and (4). Thus, we can obtain

$$E_{bt} = (1+\alpha)\frac{M_t N_0}{P_b^{1/M_t}} \times \frac{(4\pi d)^2}{G_t G_r \lambda^2} M_l N_f + P_c/R_b. \quad [9]$$

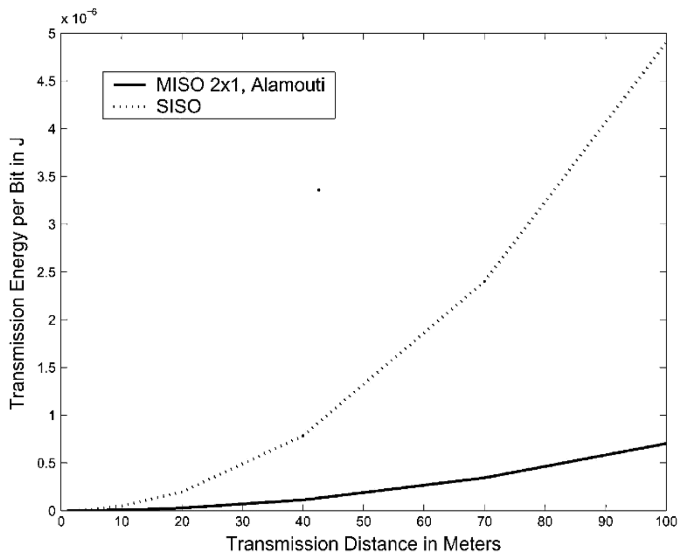

Figure 3.7: Total energy consumption per bit over d, MISO versus SISO.

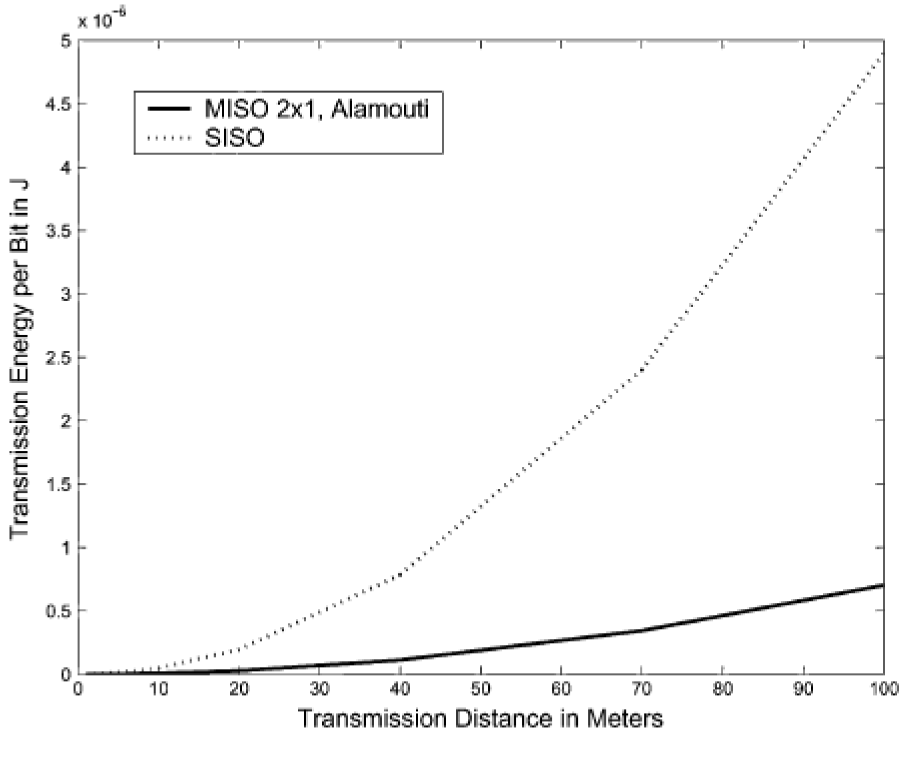

Figure 3.8: Transmission energy per bit over d, MISO versus SISO

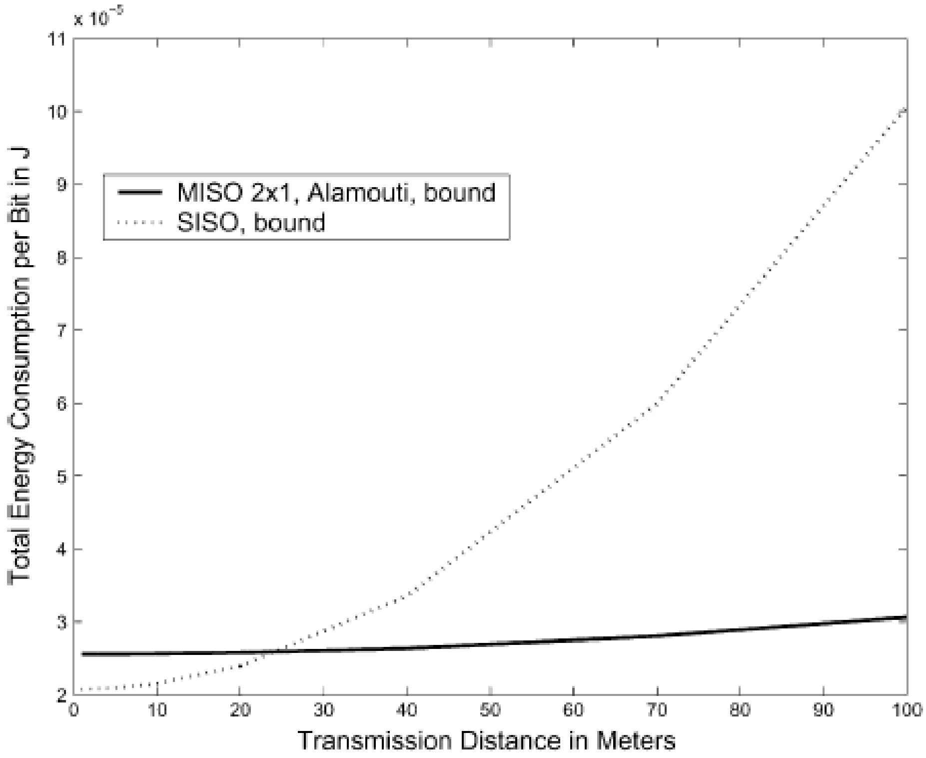

Figure 3.9: Total energy consumption (bound) per bit over d, MISO versus SISO

We can also compute the E_b exactly using numerical techniques. We find the required E_b by evaluating P_b over 10 000 randomly generated channel samples according to (6) at each transmission distance and then inverting to obtain the E_b that yields the desired P_b. This numerical solution and the approximation based on the Chernoff bound are shown in Fig. 3.6. We see from this figure that the upper bound we obtained in (8) is quite loose: cross all distances the bound leads to roughly double the required E_b. Therefore, for the best accuracy, the numerical method should be used to find the required E_b, then substitute E_b into (3) and proceed through (1)-(4) to obtain E_{bt}. The value of E_{bt} over transmission distance d obtained in this manner is plotted in Fig. 3.7, where we see that the SISO system outperforms the MISO system when $d \leq 62$ m. In other words, the critical distance below which SISO beats MISO in terms of energy efficiency is 62 m in this particular example. If we plot the transmission energy only, we see that the MISO system deploying the Alamouti code always beats the SISO system due to the diversity gain, as shown in Fig. 3.8. The crossover in Fig. 3.7 indicates where the transmission energy savings in MISO exceeds the extra circuit energy consumption in comparison with SISO. In Fig. 3.9, we show that if we use the bound approximation, the crossover point will be dramatically different from the numerical solution due to the looseness of the bound.

Alamouti 2 × 2: We now consider a 2 × 2 MIMO system based on the Alamouti code. This MIMO system can achieve a diversity order of 4 and an array gain of 2, which means that even less transmission energy is required compared with the 2 × 1 MISO system under the same performance requirement. However, since the circuit energy consumption dominates the transmission energy when d is small, and the extra receiver branch in the 2 × 2 MIMO adds more circuit energy consumption than in the 2 × 1 MISO, as shown in Fig. 3.10 the critical distance below which SISO is more energy-efficient is even larger than the MISO case.

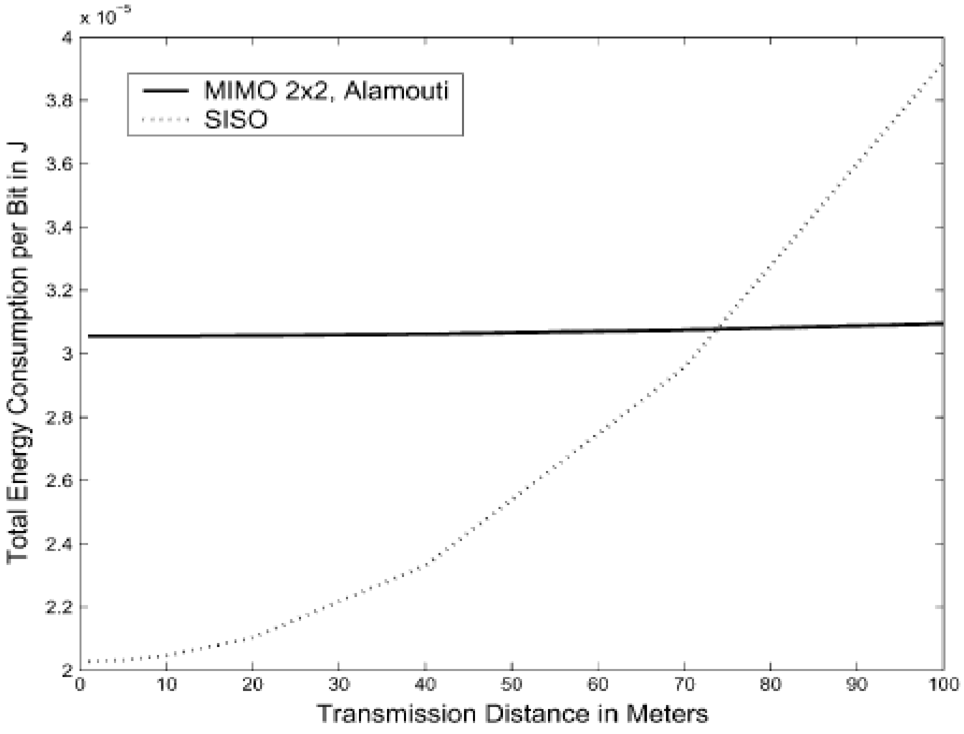

Figure 3.10: Total energy consumption over d, MIMO versus SISO.

We have seen that SISO can beat MIMO in terms of energy efficiency for short-range applications. However, for a data net-work the traffic is usually bulky and the data is communicated on a packet-by-packet basis. Suppose we have L bits in the transmitter buffer, and we have a deadline T to finish the transmission of these L bits. It has been shown that the optimal strategy to minimize the total energy consumption is to operate on a multimode basis, which provides a significant savings of energy when the sleep mode is deployed. The transceiver spends time $T_{\mathrm{on}} \leq T$ to transmit and receive these bits, where T_{on} is a parameter to optimize, and then returns to the sleep mode where all the circuits in the signal path are shut down to save energy. The optimized T_{on} corresponds to an optimal constellation size b (bits per symbol). Since multi quadrature amplitude modulation (MQAM) is assumed in the example, so $b = (L/\mathrm{B}T_{\mathrm{on}})$, where B is the modulation bandwidth for the MIMO system.

In the previous section, the energy efficiency of MISO and MIMO systems using BPSK was compared. It is well-known that MISO or MIMO systems support higher data rates than SISO in Rayleigh-fading channels. Thus, it may be possible to deploy higher constellation sizes for MISO and MIMO systems without violating the BER requirement. These larger constellation sizes will allow us to decrease the transmission time T_{on} to reduce the circuit energy consumption E_c, where $E_c = P_c T_{\mathrm{on}}$. Since the energy consumption in the sleep and transient modes is usually much less than that in the active mode when the circuits are properly designed for the multimode operation, energy consumption in these modes is neglected in our model for simplicity. However, this model can be easily modified to incorporate the energy consumption values in the sleep and transient modes when they are not negligible (e.g., when deep sub-micron CMOS technology is used). As a result, for transmitters with one or two antennas, the total energy consumption per bit is given as,

$$E_{\mathrm{bt}} = (1+\alpha)\,\bar{E}_b \times \frac{(4\pi d)^2}{G_t G_r \lambda^2} M_l N_f + P_c T_{\mathrm{on}}/L \tag{10}$$

Where E_b is defined by the target BER and the underlying constellation size b according to the following relationship:

$$\bar{P}_b \approx \mathcal{E}_{\mathbf{H}} \left\{ \frac{4}{b}\left(1-\frac{1}{2^{\frac{b}{2}}}\right) Q\left(\sqrt{\frac{3b}{M-1}\gamma_b}\right)\right\} \tag{11}$$

For b>2.

So we can finalize our discussion by saying that as the distance an increase, MIMO proves to be more and more energy efficient compared to SISO system.

Chapter 4

Important Protocols for Wireless Sensor Network

4.1 LOW ENERGY ADAPTIVE CLUSTERING HIERERCHY:

Many research activities have been carried out on the area of energy-efficient data gathering in WSN, since the basic task of the WSN is to effectively collect the data with lesser resource consumption. Most of the data gathering algorithms are aimed to minimize the energy consumption problem.

LEACH is a hierarchical protocol, in which the node details are handled by CHs [4,5]. The CHs gather the data and compress them and forward to the base station (sink). Every node uses the stochastic algorithm to find out the CH. Figure 1 shows the architecture of the standard LEACH Protocol. During the setup phase, each node creates a random number between 0 and 1. If the random number is smaller than the threshold value, then the node becomes a CH for the present round. The threshold value is calculated based on the following equation:

$$K(s) = \begin{pmatrix} \dfrac{p}{1-p\left(r \bmod \dfrac{1}{p}\right)} & if \;\; s \in G \\ 0 & Otherwise \end{pmatrix}$$

Here, p is the desired percentage of CH, r denotes the count of present round, and G is the group of sensor nodes that are not CHs in the previous 1/p rounds. The schematic structure of the proposed LEACH Protocol is shown in Figure 1.

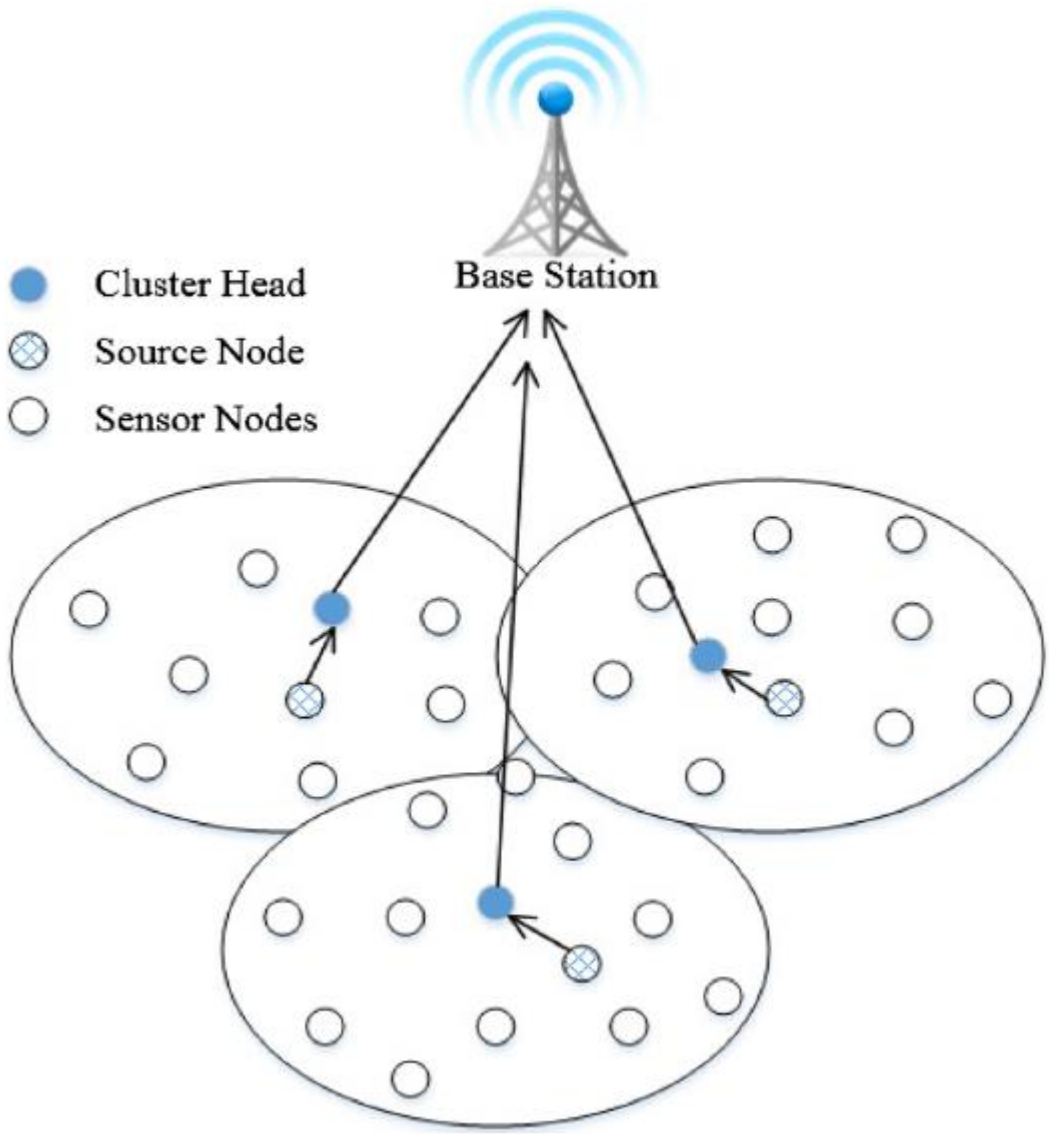

Figure 4.1: Schematic structure of the LEACH Protocol.

4.1.1 The drawbacks of this protocol:

- A sensor node is selected as the CH-using distributed probabilistic approach; whereas the non- cluster nodes calculate which cluster to join based on the signal strength. This approach assures lower message overhead, but cannot assure that CHs are uniformly distributed over the network. The entire network is divided into clusters and load imbalance among the CHs may lead to minimum network lifetime.

- It is assumed that all nodes are isomorphic and all nodes have similar amount of energy capacity in each election round. Such a supposition is impractical in most application circumstances. Hence, LEACH should be enhanced to report for node heterogeneity.
- LEACH involves source nodes to send data to CHs directly. However, if the CH is extremely far away from the source nodes, they might expend excessive energy in data transmission. Further, LEACH requires CHs to transfer their aggregated data to the sink node over a single-hop link. Nevertheless, single-hop transmission may be quite costly when the sink appears far away from the CHs.
- LEACH also holds an assumption that all sensor nodes have sufficient power to reach the sink node if necessary, which might be resistant for energy constrained sensor nodes.

To overcome these problems energy efficient LEACH protocol has been proposed.

4.2 EE-LEACH: energy-efficient LEACH Protocol

An efficient-energy-aware routing protocol is mandatory for data gathering. All the sensor nodes have similar significance and equal capabilities. This motivates the need for improving the lifetime of the sensor nodes and sensor network. The objective of the proposed EE-LEACH Protocol is to reduce the energy consumption and increase the network longevity. Here, Gaussian distribution model is used for effective coverage of the sensing network area.

Also, conditional probability theorem is used for node aggregation. The flow of the EE-LEACH Protocol is depicted in Figure 2.

4.2.1 Topology construction

Consider a sensor network of N nodes and base station BS is distributed over an area. The position of the sensor nodes and the base station are known beforehand. Let us consider a network in 2D plane with N nodes and it is deployed on the sensing field by 2D Gaussian distribution. It is described as:

$$f(m,n) = \frac{1}{2\pi\sigma_m\sigma_n} e^{-\left(\frac{(m-m_i)^2}{2\sigma_m^2} + \frac{(n-n_i)^2}{2\sigma_n^2}\right)}$$

Where, (mi,ni) denotes the deployment point, σm and σn are the standard deviation for m and n dimensions, respectively. The deployment point is taken as the central point of the disk. (mi = ni = 0). The Gaussian distribution is given as:

$$f(m,n) = \frac{1}{2\pi\sigma_m\sigma_n} e^{-\left(\frac{m^2}{2\sigma_m^2} + \frac{n^2}{2\sigma_n^2}\right)}$$

Each node senses the traffic pattern about its data, and a BS is responsible for gathering the data periodically.

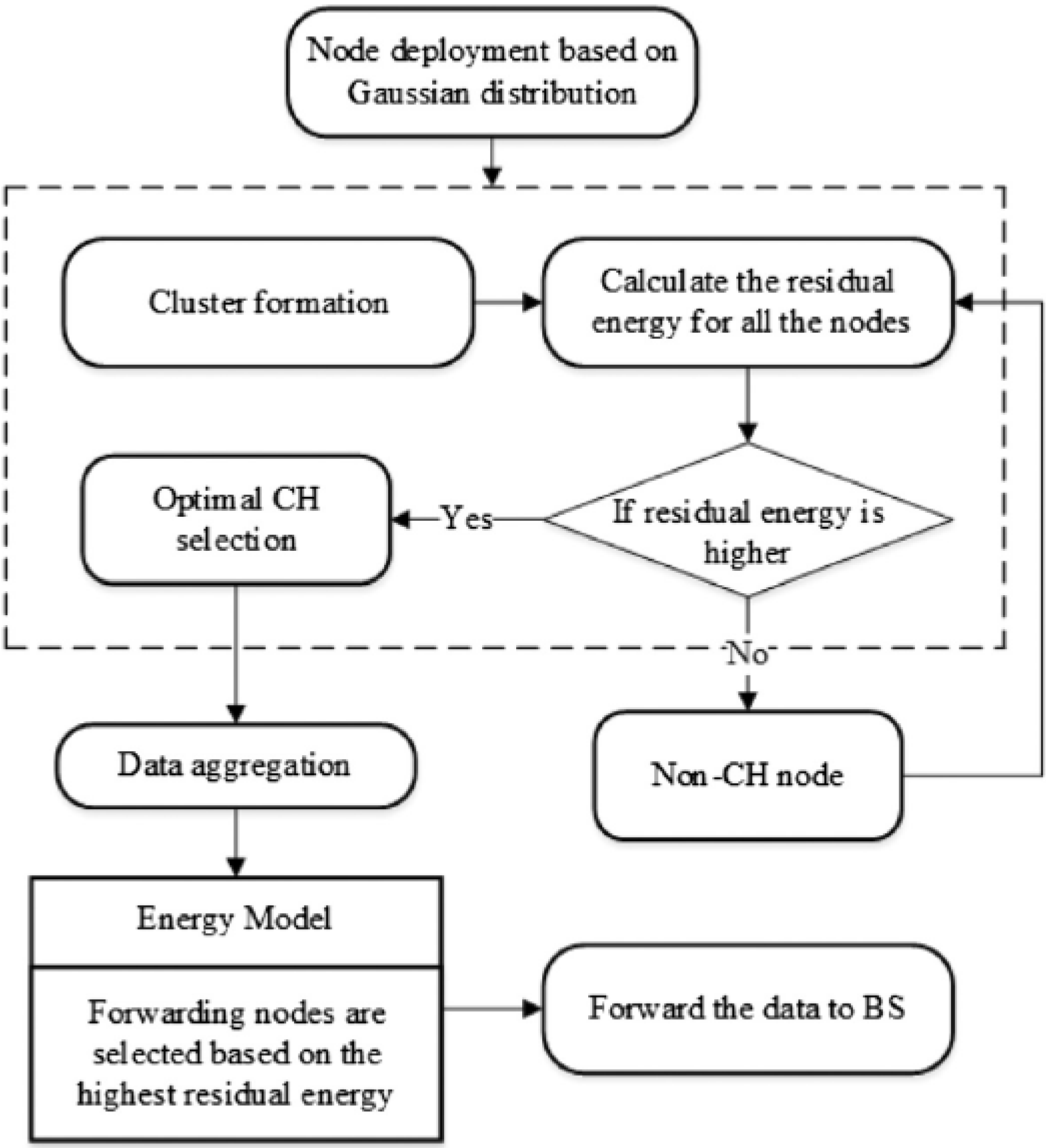

Figure 4.2: Flow of the proposed EE-LEACH Protocol.

4.2.2 Optimal cluster formulation:

The formation of clusters in sensor networks highly depends on the time taken to receive the neighbor node message and the residual energy. The protocol is divided into rounds, and each round is triggered to find out the optimal CH. The clusters are formed based on the following steps:

Step 1: neighbor information retrieval:

The neighbor node information are sensed by broadcasting the beacon messages throughout the network.

Step 2: perform sorting algorithm:

The sorting algorithm is performed to retrieve the list of all neighbor nodes about its hop distance. The list is sorted into descending order.

Step 3: candidate for cluster:

When its two- hop neighbor node is not enclosed, analyze all the members of stage 2 one-by-one and crown any one two-hop neighbor for being as a candidate for the cluster.

Step 4: calculate the residual energy of neighbor node:

Finally, the sorting algorithm is executed based on the residual energy of the neighbor nodes.

4.2.3 CH selection

The computations are based on the following simplifications:

Assume that the intra cluster transmission stage is long. Hence all the data nodes can forward the data to their CH and inter cluster transmission is long enough; hence, all CH having data can forward their data to the BS. The CH needs to perform the data aggregation and compression before forwarding the data to the BS. The optimal probability of a sensor node is elected as a CH based on the function of spatial density. The clustering approach is optimal in the sense that overall energy utilization is minimum. Such optimal clustering is greatly dependent on the energy model.

4.2.4 Energy consumption model

If the signal-to-noise ratio forwards the M bit message across l distance, then the energy expanded can be defined

$$E_T(M,l) = \begin{cases} M * E_g + M * \varepsilon_f * l^2 & if \;\; l \leq l_0 \\ M * E_g + M * \varepsilon_h * l^4 & if \;\; l \geq l_0 \end{cases}$$

Where, Eg denotes the energy dissipated per bit, εf and εh are the transmission ability and l is the distance from the sender to BS. To retrieve the M bit message, the system expends

$$E_R = M.E_g.$$

Moreover, the energy dissipated in the CH is defined as:

$$E_{CH} = \left(\frac{n}{k} - 1\right) * M * E_g + \frac{n}{k} * M * E_D + M * E_g + M * \varepsilon_f * l_{BS}^2$$

Here, k is defined as the number of clusters, ED denotes the processing cost for a bit report to the BS, and lBS represents the average distance between the CH and BS. The energy dissipated for normal nodes is:

$$E_{normal} = M * E_g + M * \varepsilon_f * l_{CH}^2$$

Where lCH denotes the average distance between the normal sensor nodes and the CH. Consider that the nodes are uniformly distributed, which is defined as:

$$l_{CH}^2 = \int_0^{X_{max}} \int_0^{Y_{max}} \left((x^2 + y^2) * \rho(x, y) \right) dxdy = \frac{A^2}{2\pi k}$$

ρ(x,y) is the node distribution. The overall energy dissipated in the network is given as follows:

$$E_O = M * \left(2 * n * E_g + n * E_D + \left(k * l_{BS}^2 + n * l_{CH}^2 \right) \right)$$

The optimal probability for a normal node to become a CH can be calculated based on the following equation:

$$P_{Otm} = \frac{k_{Otm}}{n}$$

4.2.5 Benefits for optimal CH selection:

The selection of CH nodes in the sensor networks can provide the following three benefits:

Prolonging network lifetime - In the form of heterogeneous networks,

1. The average energy utilization for transmitting the data from the sensor node to the BS will be much lesser than the energy utilized for homogenous networks.

2. Improving reliability of data forwarding:

It is generally known that the links tend to be low reliability. Each hop significantly minimizes the packet delivery rate. In heterogeneous nodes, there will be lesser hops between the nodes and the BS. Hence, the heterogeneous sensor networks can achieve a much better packet delivery ratio than the homogenous networks.

3. Decreasing latency for data transmission:

Computational heterogeneity can minimize the latency in immediate nodes. The heterogeneity among the links can minimize the waiting time in the forwarding queue. Choosing lesser hops among the nodes to BS will reduce the forwarding latency.

4.3 SIMULATION AND RESULTS

Here some simulation results are shown for LEACH and EE-LEACH protocol

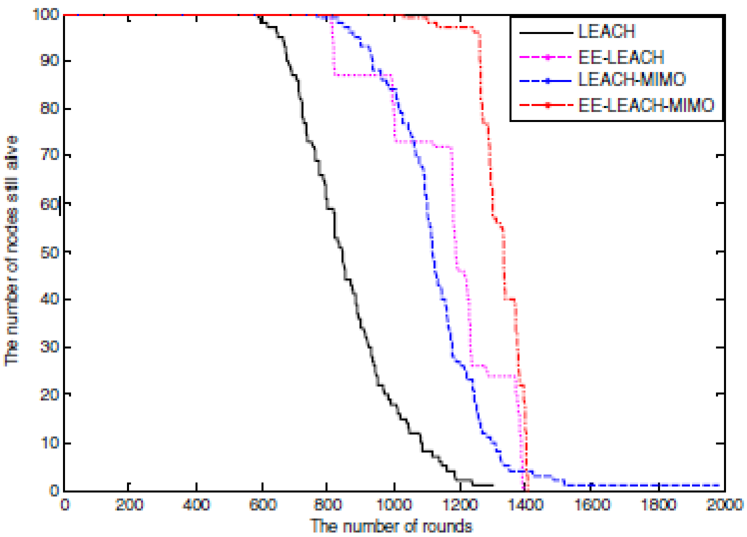

Figure 4.3: comparison between different protocol

The lifetime of network for LEACH is shortest among them. Meanwhile, its corresponding curve declines slowly and smoothly. It means that energy consumption among nodes in the network has not well balanced. LEACH-MIMO scheme has the same problem. For EE-LEACH scheme, its curve shows that a few of nodes die at almost the same time. It results from the even distribution of cluster heads in the observed area with one cluster head in each sector. However, the energy of cluster head is consumed much in the round so that its curve descends with clear steps. Apparently, EE-LEACH-MIMO scheme solves the problem in EE-LEACH with the application of cooperative MIMO, which decreases the energy consumption of cluster head for data transmission in the round. Its curve is extremely steep. All of its nodes use out at almost a moment. That means the energy consumption among nodes in the network is well balanced. EE-LEACHMIMO scheme has the longest network lifetime among the four schemes.

Chapter 5

Proposed EEBCDA Co-Operative MIMO Scheme

5.1 Introduction

We proposed a model based on unequal clustering and used cooperative MIMO to balance energy and enhance the network lifetime. Data aggregation is also important to reduce energy consumption by eliminating redundant data. So energy efficient and balanced cluster based data aggregation algorithm is proposed in this chapter.

We name it EEBCDA CO MIMO scheme.

5.2 EEBCDA SCHEME

Energy efficient and balanced cluster based data aggregation algorithm is proposed to balance the energy dissipation. The network is divided into unequal grids. The grid's CH is selected on the basis of residual energy, a node having maximum residual energy is chosen as CH of that grid. In first round, CHs are selected by the member nodes of the grids. After first round, CHs are selected by the last round cluster heads (LRCHs) not by the member nodes as LRCHs have the residual energy information of every nodes of the grids. CHs are regularly scattered in the network. The further away grid from BS has more member nodes as CH of that grid consumes more energy in a round. So, to balance energy load more nodes are deployed in that grid which take part in CHs rotation. If the grid far away from BS has less number of nodes then the CH dies faster than other grid's CH which leads to earlier failure of the network. In EEBCDA scheme, data aggregation algorithm is introduced to eliminate the redundant data. So by setting the size of each grid properly and aggregating the data, excellent performance of balancing the energy dissipation can be obtained by EEBCDA protocol.

5.3 THE PROPOSED ENERGY EFFICIENT AND BALANCED CLUSTER BASED DATA AGGREGATION COOPERATIVE MIMO SCHEME

The sensor nodes in WSNs are powered by battery with limited energy. So that, WSNs are commonly designed to be energy efficient. In WSNs, clustering algorithm is verified to be an energy efficient method. The clustering based network is divided into many clusters or grids, each of the clusters consists of many member nodes. In this section, we propose an energy efficient and balanced cooperative MIMO scheme, which combines an improved clustering algorithm with cooperative MIMO. We name it EEBCDA MIMO scheme. The EEBCDA is one of the clustering algorithms.

The operation of EEBCDA MIMO is divided into two phases: cluster setup and steady data transmission.

In EEBCDA MIMO, each round consists of the above mentioned phases. In the phase of cluster setup, cluster heads are regularly scattered in the network based on the maximum residual energy to form clusters. In the phase of steady data transmission, each CH collects sensed data from the other sensors in the cluster, fuses them, transmits the fused data to the selected cooperative nodes, and then CH and cooperative nodes send the fused data to the BS. In EEBCDA MIMO scheme, the network is divided into grids having unequal number of nodes based on the distance from BS, where the residual energy of each node is considered for generating CH and both the location and residual energy are considered for cooperative nodes selection. A brief overview of EEBCDA MIMO is shown in Fig. 1, where different sections (swim lanes, grids, clusters) are shown. Every cluster has a CH and many member nodes. A few nodes are also chosen as cooperative nodes. The BS is far away from the monitoring area. In our scheme, the network is firstly partitioned by BS, and all operations are organized in rounds. Each round contains four stages: cluster head generation, cooperative nodes selection, data aggregation and data transmission.

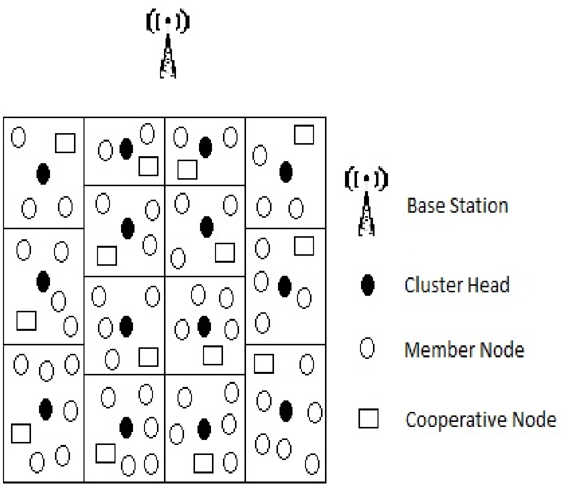

Figure 5.1: Network Model

5.3.1 Network Partition

We assume that the sink is above the network area along Y- axis. At first, the monitoring area is divided into rectangular swim lanes along X-axis. The width of each swim lane is equal, and the length of each swim lane is equal to the border of deployment area. Each swim lane is divided into several rectangular grids along Y-axis. The width of each grid is same to that of swim lane. For different swim lanes, the further it is away from BS, the fewer grids it has. But for same swim lane, the grids further away from BS have longer length. So, it is adjusted that a grid locating far away from BS, has larger size. That means it has more number of nodes. This type of partition prolongs the lifetime of network as faraway grids have more nodes. CH consumes more energy in a round but there are more nodes to take part in CH rotation. Hence, the energy dissipation is balanced in different grids by this network division. The BS broadcasts a message to all nodes in the network and receives data packet from every node, which include the ID, location and residual energy of the node. From BS message, each node calculates the id of the grid where it belongs to.

5.3.2 Cluster Head Generation:

In a clustering based network, a CH is the main unit which coordinates the operation among member nodes in a cluster, collecting and fusing data and then sending the aggregated data to the BS. The energy consumption in CH is more compared to other member nodes in the round. Thus in CH selection, the residual energy of node is taken into account so that, it can balance the energy consumption of all nodes in every cluster for prolonging the lifetime of the network.

In the first round, the CH of a grid is selected by the cooperative work of all nodes within a grid. At First, all nodes send a NODE_MSG (H, (u, v),E_r, (x, y)) to other nodes of the same grid. Where His node ID, (u, v) is node's grid ID, E_r is the node's residual energy and (x, y) is the location of the node, which includes the location and the residual energy information of the node. NODE_MSG has to cover the node's grid only, as a result additional overheads energy is saved.

After the first round, the CH is selected by the LRCHs (Last round Cluster Head) as it receives the residual energy information of all member nodes with data at the last time of data gathering. In our scheme, the CHs are selected by LRCHS based on the maximum residual energy of the node. So the cluster head selection strategy is:

$$\max_{node\ i \subset cluster} E_r(i)$$

Where $E_r(i)$ is the residual energy of member node in a grid. When CHs are selected, each CH broadcasts a message to other nodes of its own grid. By this way, every node is not only covered by at least one message but also saves energy.

5.3.3 Cooperative Nodes Selection:

In order to implement cooperative MIMO communication, cooperative nodes are selected from member nodes based on their location and residual energy. For M_t-cooperative sensors, M_t-1 cooperative nodes are chosen in each cluster. Since the CH holds the information of residual energy and location of each node in the cluster, it is in charge of the selection of the cooperative nodes according to the following strategy

$$\max_{node\ i \subset cluster} \frac{E_r(i)}{d_i^2}$$

$$d_{min} \leq d_i \leq d_{max}$$

Where d_{min} and d_{max} are calculated by the carrier wavelength and the synchronization necessity respectively [ ]. Where d_i is the distance between CH and member node i in the cluster.

5.3.4 Data Aggregation and Transmission:

For data transmission, each CH sets up a TDMA schedule for its members and broadcasts the schedule to the members in its cluster. Each cluster includes time slots for data transmission from member nodes to the CH, from the CH to the cooperative nodes, and from the CH and cooperative nodes to the

BS. Then every member node sends data to CH during its allocated transmission slot according to the TDMA schedule. To save energy, they fall asleep during the rest time. After this, every CH aggregates the collected data and then sends the fused data to cooperative node and then M_t sensors (CHs and cooperative nodes) send the aggregated data to BS with space-time block codes (STBC).

5.3.5 Energy Consumption Model

In our model, we introduce the energy consumption model in [ ]. The multipath model is used if the distance between the transmitter and receiver is greater than a threshold value d_o, otherwise, the free space path model is used. The energy consumption for transmitting and receiving l-bit message over distance d are respectively:

$$E_{SISO-Tx}(l,d) = \begin{cases} lE_{Tx-elec} + l\varepsilon_{fs}d^2, & d < do \\ lE_{Tx-elec} + l\varepsilon_{mp}d^4, & d \geq do \end{cases}$$

$$E_{SISO-Rx}(l) = lE_{Rx-elec}$$

For the cooperative transmission,

$$E_{MIMO-Tx}(l,d) = \begin{cases} M_t lE_{Tx-elec} + l\varepsilon_{M_t}d^2, & d < do \\ M_t lE_{Tx-elec} + l\varepsilon_{M_t}d^4, & d \geq do \end{cases}$$

$$E_{MIMO-Rx}(l) = M_t\, lE_{Rx-elec}$$

Where $E_{Tx-elec}$ and $E_{Rx-elec}$ represent the transmitter and receiver circuit energy consumption per bit respectively. ε_{fs} and ε_{mp} are the energy dissipated per bit to run the transmitamplifier. M_t is the number of transmitting antennas. ε_{M_t} is taken into account for the number of transmitting antenna based on$\varepsilon_{mp}$and ε_{fs}. The energy consumption to aggregate n messages with l-bit is:

$$E_A(n,l) = n \times l \times E_{DA}$$

Where E_{DA} is the energy consumed per bit to aggregate data. The total energy of network is mainly consumed by these operations: 1) data transmission from member nodes to the CH, then from CH to the cooperative nodes, and from the CH and cooperative nodes to the BS; 2) circuit energy consumptions corresponding to the above data transmission; 3) data aggregation in the cluster head; 4) the additional overheads to generate cluster head and cooperative nodes selection.

5.4 SIMULATION AND ANALYSIS

In this section, EEBCDA and EEBCDA MIMO are simulated by MATLAB. For comparison, we use EEBCDA and EEBCDA MIMO with different number of cooperative nodes. To evaluate the performance of the network lifetime, the number of rounds before the first node dies (FND), half nodes die (HND) and last node dies (LND) are considered. The parameters of our simulation are listed in Table 1. For different number of M_t, the value of ε_{M_t} is similar as those in [ ].

Table 5.1: SYSTEM PARAMETERS

Parameter	Value	Parameter	Value
Area of network	(0,0)-(200,200)m	Packet size	800 bit
Number of nodes	400	ε_{fs}	10 pJ/(bit-m^2)
Location of BS	(100,250)m	ε_{mp}	0.0013 pJ/(bit-m^4)
Initial energy	0.5 J	do	87m
$E_{Tx-elec}$	50 nJ/bit	E_{DA}	5 nJ/bit
$E_{Rx-elec}$	50 nJ/bit	Frequency	2.5GHz

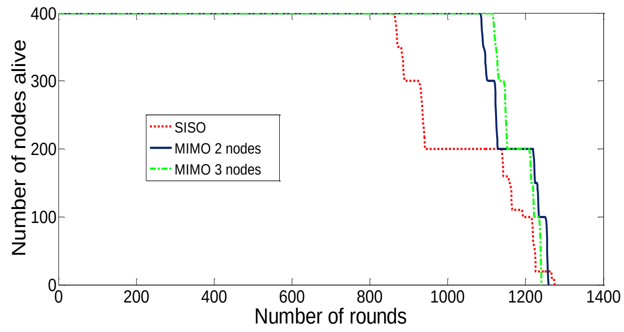

Figure 5.2: Number of nodes alive over rounds

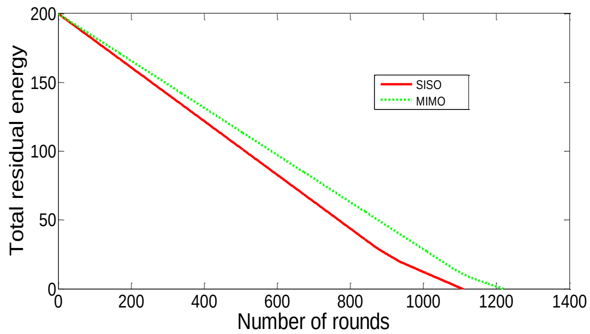

Figure 5.3: Total residual energy of the network over rounds

In our simulation, we consider the additional overheads for CH generation and cooperative nodes selection. Every member node in a cluster adds 50 more bits in its data packet and sends to the CH in each round, which contains its location and residual energy information. CH dissipates 100 more bits of electronic energy for broadcasting message to the member nodes about the CH and cooperative nodes of the next round.

For data aggregation, the sensed data are highly correlated in the same cluster. So cluster head aggregates some l- bit data message into one l- bit data message.

Simulation results are shown in Fig. 2, 3 and Table 2. Table 2 shows the comparison between EEBCDA and EEBCDA MIMO on FND, HND, and LND. Fig. 2 and Fig.3 show that, our proposed EEBCDA MIMO scheme shows its advantages over EEBCDA on FND by 26% for one cooperative node and 29.61 % for two cooperative nodes.

Table 5.2: FND, HND, LND For each scheme

	FND	HND	LND
EEBCDA	861	1138	1275
EEBCDA MIMO with one cooperative node	1085	1220	1259
EEBCDA MIMO with two cooperative nodes	1116	1211	1241

The lifetime of the network for EEBCDA MIMO scheme is longer than EEBCDA scheme. In EEBCDA scheme, CH consumes more energy in the round than member nodes. So that, its curve inclines with clear steps. EEBCDA MIMO scheme solves the problem in EEBCDA with the application of cooperative MIMO technique, which decreases the energy consumption of CH for transmitting data to the BS in the round. EEBCDA MIMO scheme with one cooperative nodes curve is tremendously steep. EEBCDA MIMO scheme with three cooperative nodes curve is steeper than EEBCDA MIMO scheme with one cooperative node. Its lifetime is longer than EEBCDA MIMO scheme with one cooperative node. All of its nodes die out at almost at the same time. In Fig. 3, we compare the total residual energy of the network over rounds for both EEBCDA MIMO and EEBCDA scheme. Fig. 3 shows that, EEBCDA MIMO has more residual energy than EEBCDA in every same round.

So the energy consumption among the nodes in the network is well balanced. The results show that, EEBCDA MIMO scheme has the longer lifetime than EEBCDA scheme.

Chapter 6
Conclusion

6.1 Summery

We focus on the problem of unbalanced energy dissipation in cluster-based and homogeneous WSNs in which CHs transmit data to BS by one-hop communication, and propose a novel cluster-based data aggregation protocol named EEBCDA CO MIMO. It divides network into grids with unequal size, the grid further away from BS has bigger size and more nodes. The CHs rotation is performed in each grid. Although the CHs in the grids which are further away from BS consume more energy in each round, these grids have more nodes to participate in CHs rotation and share energy load, so that EEBCDA CO MIMO is able to balance energy dissipation on a long view. To improve energy efficiency, EEBCDA CO MIMO adopts some measures to save energy. The simulation results show that EEBCDA CO MIMO outperforms EEBCDA SISO in aspects of network lifetime, energy efficiency and balanced extent of energy dissipation.

6.2 Contributions

Our developed EEBCDA CO MIMO protocol outperforms the other traditional protocol with better performance.

Contributions are summarizes as follows:

- Cooperative MIMO technique applied to balance the energy dissipation and to increase the energy efficiency.
- Performance analysis shows that, EEBCDA CO MIMO can balance the energy well and sends terrific amount of rounds.

- In case of energy efficiency and energy balancing, EEBCDA CO MIMO outperforms traditional SISO by 29%.
- Application of cooperative MIMO technique increases the energy efficiency by consuming less transmission energy than SISO with fixed bit error rate (BER).

6.3 Future work

As a future work, we will formulate the parameters of EEBCDA CO MIMO to maximize the performance of algorithm. In addition, we will address the problem of unbalanced energy dissipation in cluster-based WSNs in which CHs transmit data to BS by multi-hop communication.

References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A survey on sensor networks,” IEEE Commun

[2] S. Cui, A. J. Goldsmith, and A. Bahai, “Energy-efficiency of MIMO and cooperative MIMO in sensor networks,” IEEE JSAC, vol. 22, no. 6, pp. 1089–1098, Aug. 2004.

[3] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior,” IEEE Trans. on Info. Theory, vol. 22, Dec. 2004.

[4] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, “Energyefficient communication protocol for wireless sensor networks”, in: Proceeding of the Hawaii International Conference System Sciences, Hawaii, January 2000.

[5] H. Gou and Y. Yoo, “An Energy Balancing LEACH Algorithm for Wireless Sensor Networks,” Proc. International Conference on Information Technology (ITNG 10), IEEE Press, Dec, 2010, pp. 822-827, doi: 10.1109/ITNG.2010.12

[6] X. Li, N. Li, L. Chen, Y. Shen, Z. Wang, and Z. Zhu, “An Improved LEACH for Clustering Protocols in Wireless Sensor Networks,” Proc.International Conference. Measuring Technology and Mechatronics Automation (ICMTMA 10), IEEE Press, May, 2010, pp. 496-499,doi: 10.1109/ICMTMA.2010.710

[7] S. Lindsey, C.S. Raghavendra, "PEGASIS: power efficient gathering in sensor information systems", in: Proceedings of the IEEE Aerospace Conference, Big Sky, Montana, March 2002.

[8] D Kumar, TC Aseri, R Patel, EECDA: energy efficient clustering and data aggregation protocol for heterogeneous wireless sensor networks. Int. J. Comput. Commun. Control **6**, 113–124 (2011)

[9] D Wei, Y Jin, S Vural, K Moessner, R Tafazolli, An energy-efficient clustering solution for wireless sensor networks. Wirel. Commun. IEEE Transac. **10**, 3973–3983 (2011)

[10] X Min, S Wei-Ren, J Chang-Jiang, Z Ying, Energy efficient clustering algorithm for maximizing lifetime of wireless sensor networks. AEU-Int J. Electron. Commun. **64**, 289–298 (2010)

[11]R Fengyuan, Z Jiao, H Tao, L Chuang, SKD Ren, EBRP: energy-balanced routing protocol for data gathering in wireless sensor networks. IEEE Transac. Parallel. Distrib. Syst. **22**, 2108–2125 (2011)

[12]D Karaboga, S Okdem, C Ozturk, Cluster based wireless sensor network routing using artificial bee colony algorithm. Wirel. Netw. **18**, 847–860 (2012)

[13]J Yuea, W Zhang, W Xiao, D Tang, J Tang, Energy efficient and balanced cluster-based data aggregation algorithm for wireless sensor networks. Procedia. Eng. **29**, 2009–2015 (2012)CrossRefGoogle Scholar

[14]RR Rout, SK Ghosh, Adaptive data aggregation and energy efficiency using network coding in a clustered wireless sensor network: an analytical approach. Comput. Commun. **40**, 65–75 (2014). 3/1

[15]L Hui, H Uster, Exact and heuristic algorithms for data-gathering cluster-based wireless sensor network design problem. Netw. IEEE/ACM Transac **22**, 903–916 (2014)

[16]BS Mathapati, SR Patil, VD Mytri, Energy efficient reliable data aggregation technique for wireless sensor networks, in *2012 International Conference on Computing Sciences (ICCS),* (Reykjavík, Iceland, 2012), pp. 153-158

[17]JP Sheu, PK Sahoo, CH Su, WK Hu, Efficient path planning and data gathering protocols for the wireless sensor network. Comput. Commun. **33**, 398–408 (2010). 2/26

[18]D Ebrahimi, C Assi, Compressive data gathering using random projection for energy efficient wireless sensor networks. Ad Hoc Netw. **16**, 105–119 (2014)

[19]JK Min, CW Chung, EDGES: Efficient data gathering in sensor networks using temporal and spatial correlations. J. Syst. Softw. **83**, 271–282 (2010). 2//

[20]W Jin, T Shaojie, Y Baocai, L Xiang-Yang, Data gathering in wireless sensor networks through intelligent compressive sensing, in *2012 Proceedings IEEE INFOCOM,* (Toronto, Canada), pp. 603-611, 2012

[21]Y Song, L Liu, H Ma, AV Vasilako, A biology-based algorithm to minimal exposure problem of wireless sensor networks. IEEE Trans. Netw. Serv. Manag. **11**, 417–430 (2014)

[22]L Liu, Y Song, H Zhang, H Ma, A Vasilakos, Physarum optimization: a biology-inspired algorithm for the Steiner tree problem in networks. IEEE Trans. Comput. **64**(3), 819–832 (2013)

[23]P Li, S Guo, S Yu, AV Vasilakos, CodePipe: an opportunistic feeding and routing protocol for reliable multicast with pipelined network coding, in *2012 Proceedings IEEE INFOCOM*, (2012), pp. 100-108.

[24]Y Zeng, K Xiang, D Li, A Vasilakos, Directional routing and scheduling for green vehicular delay tolerant networks. Wire. Net. **19**, 161–173 (2013). /02/01 2013

[25]Y Yao, Q Cao, AV Vasilakos, EDAL: an energy-efficient, delay-aware, and lifetime-balancing data collection protocol for wireless sensor networks, in *2013 IEEE 10th International Conference on Mobile Ad-Hoc and Sensor Systems (MASS),* (China, 2013), pp. 182-190

[26]K Han, J Luo, Y Liu, AV Vasilakos, Algorithm design for data communications in duty-cycled wireless sensor networks: a survey. IEEE Commun. Mag. **51**, 107–113 (2013)

[27]L Xiang, J Luo, A Vasilakos, Compressed data aggregation for energy efficient wireless sensor networks, in *2011 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON),* (Seattle, 2011), pp. 46-54

[28] Jun Yuea, Weiming Zhang, Weidong Xiao, Daquan Tang, Jiuyang Tang ‘’Energy Efficient and Balanced Cluster-Based Data Aggregation Algorithm for Wireless Sensor Networks,’’ProcediaEngineeringVolume 29, 2012, Pages 2009-2015. 2012 International Workshop on Information and Electronics Engineering

[29] X. Li, M. Chen and W. Liu, “Application of STBC-Encoded Cooperative Transmissions in Wireless Sensor Networks,” IEEE Signal Processing Letters, vol. 12, Feb, 2005, pp. 134-137, doi: 10.1109/LSP.2004.840870(410) 12