OPTIMAL ENERGY EFFICIENT SENSOR NETWORK DESIGN

RAED S.M. DARAGHMA

(Doctorate Thesis)

Eskişehir, 2016

OPTIMAL ENERGY EFFICIENT SENSOR NETWORK DESIGN

RAED S.M. DARAGHMA

DOCTORATE THESIS
Department of Electrical and Electronics Engineering
Supervisor: Assoc. Prof. Dr. Nuray AT

Eskişehir
Anadolu University
Graduate School of Science
May, 2016

JÜRİ VE ENSTİTÜ ONAYI

(APPROVAL OF JURY AND INSTITUTE)

Raed DARAGHMA'nın"Optimal Energy Efficient Sensor Network Design"başlıklı tezi 24/5/2016 tarihinde aşağıdaki jüri tarafından değerlendirilerek "Anadolu Üniversitesi Lisanüstü Eğitim-Öğretim ve Sınav Yönetmeliği"nin ilgili maddeleri uyarınca, Elektrik-Elektronik Mühendisliği Anabilim dalında Doktora tezi olarak kabul edilmiştir.

	Unvanı- Adı Soyadı	İmza
Üye (Tez Danışmanı)	: Doç. Dr.Nuray AT	……….
Üye	:Prof. Dr.Yalçın KÜÇÜK	……….
Üye	:Doç. Dr. Hakan ŞENEL	……….
Üye	: Yrd. Doç. Dr. Mustafa ATANAK	………
Üye	: Yrd. Doç. Dr. Mehmet KOÇ	……….

……………………..

Enstitü Müdürü

ABSTRACT

OPTIMAL ENERGY EFFICIENT SENSOR NETWORK DESIGN

Raed S. M. Daraghma

Department of Electrical and Electronics Engineering

Anadolu University, Graduate School of Science, May, 2016

Supervisor: Assoc. Prof. Dr. Nuray AT

Wireless sensor network is made up of very tiny motes called as sensor nodes and a fixed or mobile base station. For making the network reliable many routing algorithms are proposed. Due to the presence of sensor nodes in harsh environment it is not possible to provide unlimited power source so, energy efficiency is a major issues in WSN. Multi-objective Approach for Energy Efficiency and Multi objective Cluster Based Approach protocols are proposed to increase the lifetime of the network.

The first study develops a new energy efficient (EE) clustering-based protocol for single-hop, heterogeneous WSNs. An architecture for microsensor networks that combine the ideas of using channel state information (CSI) and minimum residual energy (MRE) in the selection process of Cluster Heads (CHs). The proposed protocol shows better results as compared with LEACH, SEP and DEEC protocols. In cooperative communication a relay node overhears and repeats a source nodes message to the BS. Where the two independently faded signals are combined. The resulting of cooperative communication of achieving reliable communication at much lower transmission energy cost reduces the energy consumption of the sensor nodes when are compared with non-cooperative communication case. In order to save energy data must aggregated to reduce the amount of traffic in the network. Data aggregation has done with the help of clustering schemes. Clusters reduce the localized traffic by means of grouping sensor nodes and compress the data together and then transmit only compact data to the base station. Therefore optimal cluster head selection is important to maximize the lifetime of the network by utilizing the limited energy in an efficient manner. In this thesis, clustering approach is proposed to determine the optimal number of clusters in WSN. Cluster heads are chosen based on their residual energies, distances and optimal number of clusters in the network. Also this thesis presents an analysis of IEEE 802.15.4 implementations available for typical sensor node systems, such as the Bluetooth Low Energy (BLE) node CC 2450 chip, AP2 transceiver modules were used for ANT, and other transceiver is ZigBee (Texas Instrument). Results show that our proposed protocol maximizes the network lifetime and nodes stay alive for longer period using the same transmitted power, radio frequency, packet size and data rate for three protocols, ZigBee is shown to consume less energy and offers longer network lifetime.

Keywords: wireless sensor network, optimal cluster head, energy consumption, network lifetime, LEACH protocol.

ÖZET

ALGILAYICI AĞ TASARIMI

Raed S. M. Daraghma

Anadolu Üniversitesi, Fen Bilimleri Enstitüsü

Elektrik-Elektronik Mühendisliği Anabilim Dalı

Danışman: Doç. Dr. Nuray At

2016

Kablosuz algılayıcı ağlar çok sayıda kaynak-kısıtlı algılayıcı düğüm ve sabit (veya mobil) baz istasyonundan oluşur. Bu algılayıcı düğümler genelde küçük pillerle çalışırlar ve pillerin değiştirilmeleri zordur; dolayısıyla, algılayıcıların sahip olduğu enerjinin mümkün olduğunca verimli bir şekilde kullanılması esastır. Enerjiyi tasarruflu kullanmanın bir yolu, kümeleme kullanarak ağdaki trafik miktarınıazaltmaktır. Kümelemede,bazı algılayıcı düğümler gruplanır; gruplanan bu algılayıcı düğümlerden gelen bilgiler birleştirilir, sıkıştırılır ve kompakt hale getirilen bu veri artık baz istasyonuna gönderilir.Ancak bu yaklaşım, optimum küme sayısının belirlenmesi ve kümeler içinde küme başkanlarının seçilmesi gibi bazı sorunları da beraberinde getirmektedir.Bu tezde, kablosuz algılayıcı ağların eylemsel yaşam sürelerini uzatmak için bazı enerji tasarruf teknikleri önerilmektedir.

İlk olarak, tek atlamalı çoktürel (heterojen) kablosuz algılayıcı ağlar için, kümeleme-tabanlı yeni bir enerji verimli protokol önerilmiştir. Bu protokolde, küme başkanları kanal durum bilgisi ve minimum kalan enerji kullanılarak seçilmiştir. İkinci olarak, enerji-kısıtlı kablosuz algılayıcı ağlar için özgün bir işbirliği stratejisi sunulmuştur. Üçüncü olarak, enerji verimli kablosuz algılayıcı ağlar için gelişmiş küme başkanı seçme tekniği incelenmiştir. Bu teknikte, küme başkanları kalan enerji, mesafe ve optimum küme sayıları dikkate alınarak seçilmektedir. Son olarak, kablosuz algılayıcı ağların pratik yönleriCC2450 yongalı düşük enerjili bluetooth düğümü, AP2 alıcı-verici modülüne sahip ANT ve Texas Instrument'ın ZigBee modüllerinin mevcut bulunan IEEE 802.15.4 gerçeklemeleri analizi yoluyla çalışılmıştır.

Anahtar kelimeler: Kablosuz algılayıcı ağ, kümeleme, enerji verimliliği, ağ yaşam süresi, işbirlikli çeşitleme, kalan enerji

ACKNOWLEDGMENTS

First of all, without the enlightenment of ALLAH, this work would not have been done successfully. I would like to express my sincere thankfulness to my thesis advisors, Dr. Nuray At for her guidance, patience, encouragement and support during my stay at Anadolu University. I would also like to thank the committee members: Dr. Yalçın Küçük, Dr. Hakan Şenel, Dr. Mustafa Müjdat Atanak and Dr. Mehmet Koç for their time in reviewing my thesis. Most importantly, I would like to thank all my friends who helped me through four years of graduate school. Special thanks to my friends. I send my greetings to my teachers, department, faculty, and my dear university anadolu university, and there who helped me to achieve the doctorate degree. Now, time has come to express full gratefulness to persons who educate me to be in this position, and continually doing this work; thanks to my parents, who first taught me how to think and reason, encouraged me to learn and excel, and planted in me ethics, principles and standards. Many thanks to my brothers and my wife who continually encourage me.

RAED DARAGHMA

2016

ETİK İLKE VE KURALLARA UYGUNLUK BEYANNAMESİ

Bu tezin bana ait, özgün bir çalışma olduğunu; çalışmamın hazırlık, veri toplama, analiz ve bilgilerin sunumu olmak üzere tüm aşamalardan bilimsel etik ilke ve kurallara uygun davrandığımı; bu çalışma kapsamında elde edilemeyen tüm veri ve bilgiler için kaynak gösterdiğimi ve bu kaynaklara kaynakçada yer verdiğimi; bu çalışmanın Anadolu Üniversitesi tarafından kullanılan "bilimsel intihal tespit programı"yla tarandığını ve hiçbir şekilde "intihal içermediğini" beyan ederim. Herhangi bir zamanda, çalışmamla ilgili yaptığım bu beyana aykırı bir durumun saptanması durumunda, ortaya çıkacak tüm ahlaki ve hukuki sonuçlara razı olduğumu bildiririm.

....

(İmza)

....

(Adı-Soyadı)

Contents

List of Figures

List of Tables

Glossary

List of Abbreviations

ACW:	Adaptive Connection Window
ADC:	Analog-to-Digital Converter
AF:	Amplifies and Forward
BER:	Bit Error Rate
BS:	Base Station
CDMA:	Code Division Multiple Accesses
CH:	Cluster Head
CIPRA:	Clustering In network Processing Routing Algorithm
CSI:	Channel State Information
CN:	Complex Additive Noise
CRC:	Cyclic redundancy check
CSP:	Current State Probability
CTS:	Clear To Send
DEEC:	Distributed Energy Efficient Clustering
DDEEC:	Developed Distributed Energy Efficient Clustering
DEBC:	Distributed Energy Balanced Clustering
DCHE:	Distributed Cluster Head Election
DF:	Decodes and Forward
EE:	Energy Efficient
EEG:	Electro Encephala Gram
EEHC:	Energy Efficient Hierarchical Clustering

EEHCA: Energy Efficient Hierarchical Clustering Algorithm

E-LEACH: Enhanced Low-Energy Adaptive Clustering Hierarchy

EHEED: Extended hybrid Energy Efficient Distributed

ERA: Energy Residue Aware Algorithm

EECHSSDA: Efficient Cluster Head Selection Scheme for Data Aggregation

FDMA: Frequency Division Multiple Access

FCM: Fuzzy C-Means

GPS: Global Position System

GP: General Probability

HEED: Hybrid Energy Efficient Distributed

HEF: High Energy First Algorithm

HTS: Helper Ready to Send

ID: Identity

LEACH: Low- Energy Adaptive Clustering Hierarchy

LEACH-B: Low-Energy Adaptive Clustering Hierarchy Balanced

LE LEACH-C: Low- Energy Adaptive Clustering Hierarchy- Centralized

LEACH-F: Low-Energy Adaptive Clustering Hierarchy–Fixed cluster

LEACH-HPR: Low-Energy Adaptive Clustering hierarchy- Heterogeneous Prim routing

MAC: Media Access Control

MEMS: Micro Electro-Mechanical System

M-QAM: M-array Quadrate Amplitude Modulation

MRC: Maximum- Ratio Combining

MH-LEACH: Multi-hop Low-Energy Adaptive Clustering Hierarchy

MTE: Minimum Transmission Energy

M-PSK: M-Array Phase Shift Keying

OCEA: Optimal Cluster Energy Aware

PEGASIS: Power Efficient Gathering in Sensor Information Systems

REI: Residual Energy Information

RTS: Ready To Send

SEP: Stable Election Protocol

SDEEC: Stochastic Distributed Energy Efficient Clustering

TEEN: Threshold Sensitive Energy Efficient Sensor Network Protocol

TDEEC: Threshold Distributed Energy Efficient Clustering

TDMA: Time Division Multiple Access

WSN: Wireless Sensor Network

WEP: Weighted Election Protocol

Symbols

d_0 Threshold distance

d The distance between the transmitter and receiver

d^2 The distance between the transmitter and receiver when free space model is used

d^4 The distance between the transmitter and receiver when multipath model is used

d_{BS}^2 The average distance between a CH and the BS

d_{CH}^2 The average distance between a cluster member and its Corresponding CH

$d(i)$ The distance from node to BS

D_{iBS} The distance between CH node i and the BS

D_{pt} The time of the power data

E_{av} The average energy

$E_{beschanel}$ The largest variance (or, energy) of channel gains σ_{iBS}^2

E_c Circuit energy consumption of transmitting a data packet

E_{CH} Energy dissipated in a CH

E_{coop} The cooperative energy

E_{co1}, E_{co2} The most two energies in each cluster takes both CSI and REI

E_{cs} Energy consumption of a control packet at the transmitter

E_{DA} The data aggregation processing cost

E_{elec} Energy of electronics transmitter

E_{es} the receiving and computing energy consumption of a data packet

E_{fs} Energy of transmit amplifier in free space model

E_i The initial energy of node i

$E(i)$ The residual energy

E_{MRE} The maximum of minimum residual energy

E_{non-CH} The energy used by a non-CH node

$\bar{E}_r$ The estimated of the average energy

E_{Ra} The energy of random node

E_{Re} The minimum residual energy of the node

E_{round} The total energy dissipated during one round

E_{rx} Energy of receiver

E_{Tx} The average transmission energy

E_w The average wasted energy

f	Frequency of the carrier
G	A set of sensor nodes that have not been selected as CHs
G_t	The gain of transmitter antenna
G_r	The gain of receiver antenna
$h_{iBS}(n)$	The channel gain between the CH node i and the BS
$h_{sr}(n)$	The channel gain of the source-relay
$h_{sd}(n)$	The channel gain of source-BS
$h_{rd}(n)$	The channel gain of the relay-BS
h_t	the height of transmitting antenna above the ground
h_r	the height of receiving antenna above the ground
K_{opt}	The optimal number of clusters
L	The system factor
N_0	The power spectral density of the additive noise
P_i	The transmission power of the CH node i
$P_{\max}$	The maximum transmission power
p_{opt}	The optimal probability of a node being selected as a CH
P_{r-th}	This receive power threshold to determine the minimum transmit
$P_r(d)$	The receiver power given a transmitter-receiver separation of d
P_t	The transmitter power
T_X	Transmitter

R	The network lifetime r^{th} current round
R_b	The data rate
R_X	Receiver
T(s)	The threshold value which the node becomes a CH for that round
$y_{iBS}(n)$	The received signal at the BS due to the CH i
ε_{fs}	The amplifier energy per bit per square meter (m^2) when free space model is used
ε_{mp}	The amplifier energy per bit per m^4 when multipath Propagation model is used
α	The path loss exponent
σ^2_{iBS}	Variance
β	Constant whose value depends on the propagation environment
λ	the wavelength of the carrier signal
$\sigma^2{}_{sr}$	The channel variance between source and relay
$\sigma^2{}_{rd}$	The channel variance between relay and destination
$\sigma^2{}_{sd}$	The channel variance between source and destination
η_{sr}	Additive noise between source-relay
η_{sd}	Additive noise between source-BS
η_{rd}	Additive noise between relay-BS

1.INTRODUCTION

1.1 Wireless Microsensor Networks

In general, sensor networks can contain hundreds to thousands sensing nodes. The most important part of these networks is to make these nodes as cheap and energy-efficient as possible and rely on their large numbers to obtain superior quality outcomes. Wireless Sensor Networks (WSNs) are used for a large numbers of duties such as detection, localization and tracking objects of interest. In [1], a proper estimate of a source location can be achieved by using energy readings of sensors.

In the recent years, the advances in MEMS (Micro Electro-Mechanical Systems) as well as in wireless communications have motivated the growth of millions of small size and low cost wireless devices as well as different types of wireless networks which connect these devices with or without any existing ground work. Wireless sensor network (WSN) [2-11] is one of the most important parts of the advanced wireless communication networks. The network can be studied as a network forming of hundreds or thousands of wireless sensor nodes which collect the data from their surrounding environment and send their sensed data to remote control center which is called Base Station (BS) or sink node in a organize themselves manner. WSNs can be viewed as a big data base which stores information about the environment to be monitored or detected. Each sensor node will perform sensing, processing and communication functions inside the network. WSNs are interesting from an engineer perspective, because they show important key design difficulties.

1.2 Challenges and Research Issues in WSNs

In this part we will explain the most important characteristics in WSNs which are different from classic wired or wireless networks. First, there is no rigid infrastructure and sensors will self-organize via cooperation. Second, sensors are strained to limited resources such as energy, bandwidth, processing and memory. Third, sensors may breakdown due to reasons like energy consumption, interference, movement or obstacles. Because of the above characteristics for WSNs, the network topology may change fatly and dynamically. Also, WSNs have the following difficulties and research topics to deal.

- Energy conservation.

From the previous literature, it is known that WSNs may have a lifetime of at least several months to years depending on the specific application. The extending of the lifetime of the network is the basic challenge for researchers since most sensor nodes are powered by restricted batteries. There are many basic factors which can affect the energy consumption in WSNs. Since the sensor nodes are formed of sensing, communication and processing units, the energy consumption can also be divided into 3 parts correspondingly. First, during sensing phase or also can be called set-up phase some low power hardware components can be loaded on the sensor board to reduce energy consumed. Second, the choosing of various protocols on different layers can affect the energy consumption very much. For instance, the node sleeping and wakeup mechanism [12, 13, and 14] can be inserted in the MAC layer to decrease energy consumption. If we want adopt better processing efficiency of different types of data messages we can use advanced signal processing techniques [15]. Also we can combine the clustering and data mining mechanism whilst routing process in order to obtain energy efficiency. On the other hand we can adopt power control and power management, when we using this techniques not only energy efficient but also network capacity and interference performance can have developed. Lastly, in some cases we can decrease the amount of data or the number of transmission by using smart signal processing or data mining methods then will cause decreased in energy consumption.

- Topology design.

  In WSNS, [16, 17, and 18] the topology design is one of the most significance important factors in network stability, connectivity besides energy consumption. The sensor nodes can be stationed either previously with a certain pattern or urgently in a random distribution. How to balance the energy workload with the help of topology design is one of a practical challenge to the accomplished application of WSNs.

- Architecture design.

The processing, memory and energy are parameters dynamically changed in the WSNS, The system should work autonomously, variable its configurations as needed by each application. So, the node's inside architecture needs to be attentively designed according to hardware platform [19]. besides, the interconnection between WSNs and other networks needs be acceptable [20]. Other function modules also must be considered as localization, synchronization, signal processing and the storage and taking bake of data information under the whole architecture.

- Collaborative signal processing.

When the collaboration of nodes are considered in WSNs, each node can send data to other sensor node (forward) using multi-hop communication or direct communication (single-hop communication) to the BS. Collaborative signal processing [21] in WSNs is a hot research area. Major research topic contains the rate of information sharing between nodes and how nodes reject information from other nodes. Processing data from more sensors normally results in better performance but also requires more communication resources. Thus, the tradeoff between performance and resource access in collaborative signal processing should be considered. Data fusion [22-29] is one representative approach of collaborative signal processing, which can much decrease energy consumption.

- Security.

With the inclusion of research topic as security infrastructure, switch management, authentication, robustness to DoS (Denial of Service) attacks, secure routing, privacy etc. [30, 31, and 32]. Security is not insignificant problem for WSNs. To obtain a secure system, security must be integrated into each component module rather than each separate module since components designed without security maybe a point of attack in WSNs.

1.3 Literature Review

One of the disadvantages of a single-hop dynamic clustering protocols like LEACH [33] is the cluster head rotation overhead in each round. LEACH works as following: selects cluster heads based on randomly generated value between 0 and 1. If this randomly generated value is less than the threshold value, then the node become cluster head for the current round. Advanced LEACH [34] was developed to enhance the performance of LEACH by choosing the best suitable node for CH and enhances the threshold equation of LEACH by introducing two terms: General Probability (GP) and Current State Probability (CSP). It is known that in a LEACH, nodes make self-governing decision without any central intervention taking into account residual energy. In [35], an energy-efficient hierarchical clustering algorithm (EEHCA) is suggested for WSNs. In this protocol a new adopts method for CH selection along using the concept of backup CHs to enhance the performance of the WSNs. Besides, after the data aggregation has been done by CHs, the CHs transmit this data to the BS node by a multi-hop communication technique. Results were shown that the EEHCA achieves a good performance in terms of network lifetime and stability period by minimizing energy consumption for communication and balancing the energy load among all the nodes. Re-cluster-LEACH [36] an algorithm is depending on nodes density, which takes into account the density of nodes inside the cluster for CH formation. LEACH-F [37] is protocol consider that the number of clusters will be not changed during the network lifetime and the cluster heads are rotated within its clusters, in LEACH-F one of the similarities to other protocol is steady state phase which is identical to that of LEACH. LEACH-B [38] is a decentralized protocol in which consider a sensor node only knows about its own position and position of final receiver and not the position of all sensor nodes. E-LEACH [39] supplies improvement in selection of CHs of LEACH protocol. This protocol takes into account the residual energy of the nodes as the basic factor whether these sensor nodes turn into the CH or not in the next round. LEACH-HIR [40] is an energy efficient CH selection method and using the developed Prim algorithm to build an inter-cluster routing in the heterogeneous WSN.

Generally, the cooperative communication system consists of three parts: a source s, it is destination d, and r relay, as shown in Figure 1.1. In the conventional code and forward cooperative communications [41], relay receives the transmitted signal from the source and previous relay, then applies maximal–ratio combining technique (MRC) [42] on the received signals and retransmits the decoded signals if they have been correctly decoded. The main idea of the cooperative depends on the choosing one relay from the multi relays to cooperate with the source, if the cooperation needs cooperation. We consider a cooperation scheme with two phases in wireless network (WN) which can be mobile ad hoc networks or mobile networks. During the phase 1, each node in a WN sends information to its destination, and the information is also received by other users simultaneously. While during phase 2, each user helps others by forwarding the information that it receives in phase 1. Each user may decode the received information and forward it (corresponding to the DF protocol), or exclusively amplify and forward data (corresponding to the AF protocol). It is noticed that in both phases, all users transmit signals through orthogonal channels by using TDMA, FDMA or CDMA approach [43]. If we want understanding the cooperation concept better, we focus on a two-user cooperation approach. Particularly, node s sends information to its destination in phase 1, while node r receives the data. Node r helps node s to forward the information in phase 2. At the same time, when node s sends its information to its destination in phase 1, node r receives the information and forwards it to node d destination in phase 2. Because the two users are similar to each other's, we will discuss only the node s performance. Without loss of generality, we consider the following model shown in Figure 1.1.

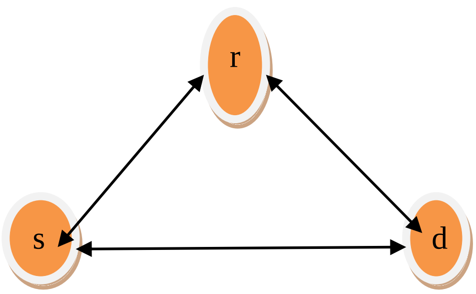


Figure 1.1. Cooperative communication.

It is known that clustering in WSNs was first considered in LEACH which contains a distributed cluster formation technique that enabling self-organization of large numbers of nodes. In [37] this protocol was adapted clusters, and rotating cluster head positions to evenly distribute the energy load among all the nodes in the network. On the other hand this protocol has some drawbacks: *i*) if network size increases, implementing the dynamic clustering may become frustrating difficult. *ii*) The number of clusters to be formed is random. In some cases a small number of clusters and sometimes a large number of clusters are formed. In another saying, LEACH protocol does not make sure that the optimal numbers of clusters are formed at each and every round in the network. Modified Rumor [44], TEEN [45], and PEGASIS [46] are other very famous clustering-based protocols which also do not find the optimal number of clusters. while, [47] supposes the optimal number of clusters in the network with mobile base station in which the BS can move very close to the CH resulting trivial path loss. In LEACH-G [48], the optimal number of cluster heads is proposed depended on the energy model for LEACH algorithm. Randomized selection of clusters is centralized in OCEA [49] in which cluster heads are chosen depended on their available energies. In [50], the optimal number of clusters is founded using of a Fuzzy C-Means (FCM) clustering approach.

The most important characteristics in the design of WSNs are energy consumption and network lifetime. In this thesis we present clustering based routing for WSNs. There are many clustering based protocols called homogenous (each node has the same energy), such as LEACH [37], PEGASIS [46] and HEED [51]. [37] Is one of the most well-known and nominee hierarchical routing protocols for WSNs. It can extend network lifetime 8 times longer than other usually routing protocols such as direction transmission and minimum transmission energy routing protocols. However, the cluster head nodes are randomly selected and they only use direct transmission to the BS under their small measure sensor network. Power Efficient Gathering in Sensor Information Systems (PEGASIS) [46] is a chain protocol using routing scheme which performs better than LEACH protocol in energy consumption and extend the lifetime. It works as following: after data can get aggregated along the chain then it will be sent to the BS using direct transmission by one of the node on the chain. The major drawback is that PEGASIS needs a global knowledge of whole network, and this situation makes this network practically very hard to be succeeded. .

In PEGASIS nodes consist of a chain to send data from source to the BS. Each node on the chain formation process connects with next node. The chain formation process needs global knowledge of sensor nodes; hence, it is not easy to present this topology. The main function of the CH in the network is to collect data from its members or slave nodes, aggregate and then forward or transmit data to the BS. Normally, this method excessive load to the CH and it costs a lot of energy consumption. In LEACH, the CHs are selected periodically and consume uniform energy by choosing a new CH in each round. The probability P decides if a node becomes CH in current round or not. It is noticed that LEACH considers well in a homogenous network however, this protocol is not suitable for heterogeneous networks. From previous results, we can say that the main drawbacks of LEACH protocol are uneven distribution of cluster heads, also it is needed to high transmission power when the size of the network is increased, also this protocol has lower stability region due to the early death of its nodes. LEACH-C [52] uses a centralized CH selection technique; in this algorithm the BS is responsible for the selection of CHs. In each round, the current location of all nodes in the network is known and is updated by the BS also the remaining energy. Depending on the remaining energy information, the base station can decide a number of nodes for the CH selection in each round. The BS accounts the average node energy of the network. Then if the remaining energy of a node is larger or equal to the average node energy, the node will be chosen in the candidate number for the CH. After deciding the candidate number of the CHs, the BS finds the optimal number of CHSs by using an approximation approach such as simulated annealing [53]. The simulated annealing approach runs on the candidate CHs number to find the best CHS. Once the optimal CHs are known, the BS broadcasts the cluster heads IDs, cluster member node IDs, and transmission schedule for each cluster to all nodes in the network. The next step is each node compares its ID with the cluster head ID, and if it analogous, then it behaviors as the CH. Otherwise the node decides its slot in the transmission schedule and sends data to CH in its slot. In LEACH-C [52] one of the major shortages is repeated cluster formation overhead. There is also data and energy wastage because of fixed round time. A hybrid Protocol Energy Efficient Reactive Protocol for WSN is developed in [54]. In this protocol, CH is selected based on the residual energy of node and average energy of network. In [55] Sharma have adjusted the value of the threshold, according to which a node decides to be CH or not, based on the ratio of residual energy and average energy. In [56] H-HEED is proposed, the authors introduced different level of heterogeneity : 2 level and multi-level in terms of node energy. Xuegong et al. [57] proposed a new protocol of the cluster multi-hop transmission for heterogeneous sensor networks, the algorithm selects the CH nodes by calculating weight-value and transfer data by using nodes in cluster and cluster head multi-hop transmission manner.

Generally the BS can received data from the sensor nodes with two different ways. Single-hop communication [58] and multi-hop communication [59, 60]. When we are using single-hop communication every sensor node can arrive to the BS directly (using one hop), also called Direct Transmission Mode. While when we are using multi-hop communication sensor networks route the message using specific routing protocols (using more than one hop). One of protocols that are used multi-hop for routing data messages to the BS is Minimum Transmission Energy (MTE) protocol. A two-hop is a special case of multi-hop network. The first hop is from member sensor nodes to CHs and the second is from the CHs to the BS. On the other hand, these two categories have main problem which is the creation of energy holes [61, 62]. It is know that in a single-hop protocols the energy utilization increases as the distance from the BS increases. While in a multi-hop networks the energy usage increases as the distance to the BS decreases. One of the drawbacks of a multi-hop protocol creates hot-spots [61, 63] in the surrounding of BS. Generally, wireless sensor networks can be widely categorized into two main parts. Homogeneous and heterogeneous sensor networks [64]. In homogeneous networks, sensor nodes have similar abilities in terms of energy, hardware and processing abilities. CHs are flipped periodically in order to balance energy usage. However, periodic rotation of cluster heads does not figure out the problem of unbalanced distribution of energy utilization in cluster heads with consideration of distance from Base Station. While heterogeneous sensor networks comprise of sensor nodes have different energies, processing and transmission abilities. It is noticed that cluster heads have higher initial energies and can communicate over longer distances. However, main problem in heterogeneous sensor networks is a fault tolerance. By the way, failure of cluster heads may lead to disconnection in sensor network. Homogeneous networks select cluster heads from a large number of suitable cluster heads and have a higher tolerance towards failure of sensor nodes. Hierarchical routing protocols [37,46] are very convenient for WSNs since they not only supplied scalability for hundreds or thousands of sensors, but also the cluster head can execute data gathering and coordination within each cluster.

It is well-known that location-based routing protocols [65, 66] normally need sensor location information which can be wined either through global positioning system (GPS) devices or through specific estimation algorithms depend on received signal strength. Minimum Energy Communication Network (MECN) supplies a minimum energy network for WSNs with the help of low power GPS. In [54] this protocol was developed to extend the protocol in [65] which accounts the possible number of obstacles between any two nodes. In [67], the author suggests energy-LEACH and multi-hop-LEACH protocols named LEACH-M. Energy- LEACH protocol makes better the selection process of the CH; in this protocol some nodes have been taken which have extra residual energy as CHs in the next round. Multi-hop LEACH protocol makes better communication mode from single hop to multi-hop between CH and the BS. From the result we can see that energy-LEACH and multi-hop LEACH protocols perform better than LEACH protocols in lifetime and energy consumption. In [68], the problem of clustering in WSNs was suggested by the author, governed to upper bounds on the maximum latency, also the energy consumed by intermediate nodes, and clusters size were discussed. Those limitations are important for the stability of the system and for prolonging its lifetime. In [69], an Energy-Efficient uneven Clustering is developed for multi hop sensor network. Simulation results prove that the uneven clustering mechanism balances the energy consumption well across all sensor nodes and reach to a clear enhancement on the network lifetime.

In [70, 71] two protocols were developed in the case of heterogeneous sensor networks, authors denotes that nodes with high initial energy will be chosen as CHs. While in [72, 73, and 74] authors were suggested that any node in the network can be chosen as a CH but with some restrictions. According to the Stable Election Protocol (SEP) [72] allows weighted probability for each node to becomes a CH. While according to DEEC [73] available energy of the node is considered to be choosing as CH. LEACH [37], TEEN [75], DEEC [73] and PEGASIS [46] are distinctive routing techniques for wireless sensor networks. Primary process of choosing a CH was given by LEACH and that is also improved by SEP and DEEC. The main advantage of TEEN [75] that it was introduced the concept of thresholds that gives well results in network lifetime and the energy consumption. These thresholds can be applied in any routing protocol to enhance its performance according to their applications. Depending on theses protocols (LEACH, SEP and DEEC) many protocols are proposed. According to protocol Q-LEACH [76] network lifetime of homogeneous wireless sensor network was optimized. In [77] protocol gives a specific comparison analysis on distinct variants of LEACH as A-LEACH, S-LEACH and M-LEACH in terms of energy efficiency, lifetimes and their applications. In [78] a big exciting comparison analysis between LEACH, Multi-level Hierarchy LEACH and Multi-hop LEACH is assumed. Authors of [79] improve SEP in terms of heterogeneity. They develop a model that gives three level heterogeneity. Whereas [80] gives a new protocol that works better than SEP in terms of network stability and life time having two level heterogeneity. T.N. Qureshi et.al [81] modified DEEC protocol in terms of network stability, throughput as well as network life time.

1.4 Contributions

Generally, we have many ways to minimize energy and prolong the lifetime in WSNs; we will mention some of them:

- The way which sensor nodes are been deployed.
- Selection of CH with the best of energy efficient.
- Energy Efficient Scheduling.
- Using efficient ways for data aggregation.
- Design of energy efficient routing protocols.

Energy efficient routing for WSNs is a significant research topic and maximization of lifetime plays a major part on many networks. In this thesis, we want study and develop routing protocols for WSNs by study their effect on energy consumption, network lifetime in addition to the packet received to the BS (throughput). We propose a new energy routing algorithms for WSNs which can assign the transmission manner, the optimal number of cluster heads as well as fit cooperative nodes while multi-hop routing process under practical sensor networks. While the selection of next hop node, the factor of optimal hop number is handled as main problem rather than other factors as maximal residual energy, shortest path or minimum cost function. We find the optimal number of cluster head nodes by solving an optimization problem of minimizing the total energy consumption during single and multi-hop routing cases under limitation conditions.

The contributions in this thesis lie in the following aspects:

- We specify the transmission manner under the cooperative methods in WSNs, for example sending data from source to relay and to the BS.
- We take into account both residual energy and the channel state information in the selection process of Cluster Heads (CHs)
- We find the optimal number of nodes under both one dimensional practical sensor network environment and hardware circuit parameters.
- We propose and evaluate a new distributed energy-efficient clustering scheme for heterogeneous wireless sensor network with new cooperative protocol.
- Our effort has been done to propose a protocol in heterogeneous environment in which the randomized selection of clusters is tried to be centralized and to avoid the redundancy cluster heads tried to keep well separated with the region. Unlike other protocols, cluster heads are chosen based on their residual energies, distance and the optimal number of cluster head which results in better distributions of cluster heads within the region.
- We make a lot of theoretical and experimental simulations to confirm the performance of our proposed energy routing algorithms.

1.5 Structure of the Thesis

This thesis is structured as follows: Chapter 2 presents the background material underlying the work presented in the reminder of the thesis. The original research presented in Chapters 3-6. **In chapter 3**, is considered with a new clustering-based energy-efficient (EE) protocol for single-hop, heterogeneous WSNs. CHs are selected by using weighted probabilities. These weighted probabilities are evaluated based on the ratio between residual energy and the best channel of each node and average energy of the network.

Chapter 4 investigates the problem of optimality energy efficient transmit power allocation for the cooperative scheme, the CHs are selected based on the following parameters: energy remaining in the nodes (minimum residual energy) and channel state information. The node that offers the highest channel gain and minimum residual energy is selected to be CH (source), and then the node that offers the next highest channel gain and next highest minimum residual energy is selected to be relay in each cluster. By making use of the above parameters, the lifetime of the entire WSN was enhanced.

Chapter 5 presents the improvement in selection of cluster head, residual energy, distance, heterogeneous and optimal number of cluster head parameters are incorporated in the determination of single- hop routing paths between CHs and the BS to balance the load among CHs. We propose and evaluate a new distributed energy-efficient clustering scheme for heterogeneous wireless sensor network with new cost function protocol by modifying the selection of cluster head. Simulation results show that proposed protocol consumes less energy and performs better as compared to others

In Chapter 6, we propose a multi-hop protocol for wireless personal area networks. In particular, both distance and residual energy taken into consideration to select the primary node or forwarder. The cost function selects a parent node which has high residual energy and minimum distance to the base station. We a comparison of energy consumption of Bluetooth Low Energy (BLE), ZigBee and ANT protocols in which a specific range and low power wireless sensor node periodically sends a data packet to the base station.

Chapter 7 concludes the thesis by summarizing research presented in the previous chapters , highlighting key analysis results, and suggestion future research directions.

2. SENSOR NETWORK

2.1 Main Aspects of Wireless Sensor Networks

In this section we will define important related to our study :

Lifetime: Sensor nodes are battery driven so they work with a limited energy resource. In dense sensor networks, it may not be possible to change batteries of sensors when a sensor dies. Practically, in many applications it is necessary to supply assurances that a network with uncontrollable wireless sensors should keep working without any changes for several years. For example, in large and unreachable fields, such as the deepest zones of the Atlantic Ocean, sensors can be spread in order to form a large-dense sensor network to sense seismic waves, temperature or other parameters. In this type of scenarios, changing the battery of a sensor node would be highly expensive and difficult. So protocols prolong the lifetime of sensor networks are utmost important.

Deployment: The networks are deployed by taking into account two aspects. Size of the area to be covered and connectivity [82] . Both define the stability of having always a path between every couple of nodes. The sensor nodes can be easily controlled if the deployment is performed with careful hand placement of network nodes. This technique is called structured deployment approach. Another technique is known as randomized deployment scheme that can be used in applications where, for example, the aircraft drops the nodes. Another aspects of the deployment is the heterogeneity or homogeneity of the deployment. Some applications need nodes with different performance entered due to the characteristics of the network topology. In a single-hop topology, for example the sink or the base station has a higher traffic load than the sensing nodes. Therefore, the sink node must be better equipped in order to achieve assigned duties.

Self-configuration: The wireless sensor networks contain sensor nodes. These nodes configure synchronize, regulate and localize themselves, at their own network topology, also sensor nodes have to coordinate the communication between CH and CH member nodes and the communication between CH and BS. Nodes can define other significant operating parameters [82]. Sometimes they need to adapt themselves to the environmental circumstances and unforeseen conditions in order to keep the performance contracted and have a powerful network. It is common in wireless sensor networks that topology of the network changes after the deployment due to the changes in sensor nodes location, position, reachability, the remained energy, and device failure or energy consumption [83].

Since the above-mentioned arguments and to avoid collisions in the network, a lot of routing protocols providing auto-management schemes are adapted in the wireless sensor network environments. Some of these protocols replace the dropped nodes and other aspects. Some of these protocols are described in the thesis.

Figure 2.1 depicts a typical sensor network. In general, sensor nodes are deployed randomly (e.g., they are dropped from an airplane) in an environment and these nodes take a "snapshot" of their surrounding environment like light, temperature, humidity, sound or motion detection information. After that, this information is further gathered and then sent to the BS through direct transmission (single-hop) or multi-hop transmission. Finally analyzing the collected information from sensors, the BS takes decisions and makes reasonable deduction or prediction about the event, according to these decisions the BS may change some parameters in the sensor network.

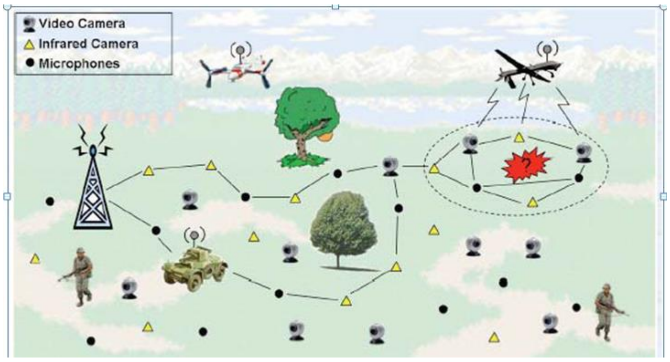


Figure 2.1. A typical sensor network [84]

2.2 Application of WSNs

Even though, the wireless sensor networks are first suggested, used and supported by U.S. Military Department; they have many applications [85-92]. As presented below:

- Military observation: in a battle field, there is no rigid infrastructure and sensor nodes can be stationed in a self-organized manner to gather dynamic information like sniper's position, solder and tank's movement etc.
- Agriculture and industry monitoring.
- Healthcare: Small sensor devices are attached to a person to measure his/her physical condition like EEG (electroencephalogram), heart and pulse rate etc. Some high level information like a person’s gesture, motion and feeling can also be inferred or used through WSNs. Body area sensor networks cam provide a different way of treatment and care for the disabled or old people.
- Other applications: in the wireless personal area networks (WPANs), the pressure sensors can be used to monitor the level of stress in a building so as to avoid the building from collapsing [85]. WSNs can also be used to monitor the traffic on the motor way and provide traffic control so as to enhance transportation quality.

2.3 Sensor Node Architecture

Figure 2.2 depicts the sensor node architecture on a sensor board [93, 99]. Each sensor has four basic components, namely: sensing unit, processing unit, transmission unit and power unit.

Sensor node architecture has two further elements position finding system and mobilizer. Unfortunately each sensor has limited resource in terms of energy, bandwidth, processing and memory capabilities which bring research challenges in routing, localization etc.

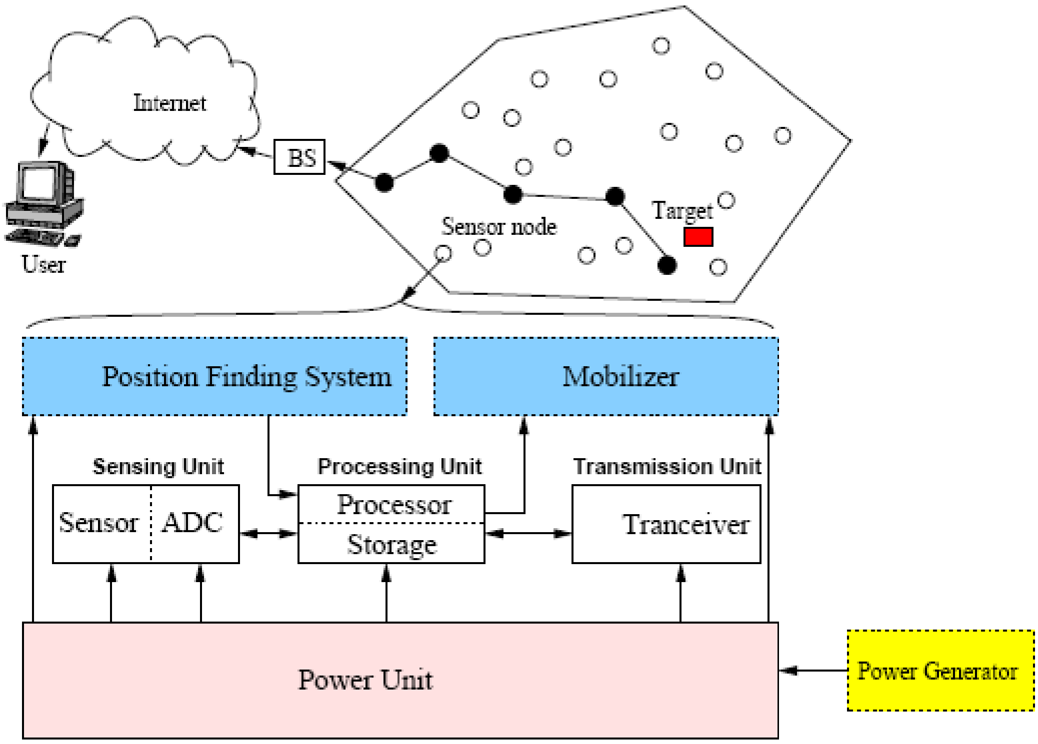


Figure 2.2. Sensor Node Architecture [99]

- Sensing unit: this part of the sensor node architecture comprises of two sub-units: sensor and ADC (Analog-to-Digital Converter) units. Since the observed information is usually an analogous signal, it needs to be transformed into digital signal for processing with purposes.
- Processing unit: The processor and the storage units are the two sub-units which comprises the processing units. When we are choosing this part of sensor node, we should take into consideration many factors like power consumption, available memory etc. The type and the size of information to be stored, processed and buffered for transmission is dependent on the memory so the memory is an important part in this unit.
- Transmission unit (transceiver): the transceiver is the most power greedy component on a sensor board. It is well known that to transmit one bit message over 100 meters consumes about 1000 times energy than to process the message. To minimize energy consumption, other technologies such as coding, data fusion and wake-up techniques need to be adopted to reduce the length of a message or in general to reduce

the energy consumption in this unit and in the network. [100, and 101].

- Power unit: Any electronic device needs a power unit to supply energy to all components on board for each sensor node is the energy consumption or conservation, since the battery cannot re-charged easily once they are deployed, in WSNs two AA batteries are used, so our attention is focusing to minimize energy.
- Two further components: The position finding system and mobilizer are the two furthers components. In most cases, WSNs use a position finding system (like GPS device), the location of each node and the location of other nodes respect to each other or to the BS are known, when this information of hard they can change their power level based on the relative distance. With this way, large amount of energy can be saved. Moreover, the static sensor node can become mobile if it is supplied with mobilizer. If the BS is supplied with mobilizer, the whole network lifetime can be prolonged since the load in the network may be balanced.

2.4 Challenges of Sensor Networks

The power management issue is the main challenge in WSNs. Generally sensor node has limited energy; the main goal is to used this energy intelligently so that a WSN has longer lifetime. Clustering [102-105] is one of the successful techniques to improve the lifetime of a WSN. In this approach, a network field is divided into sub regions, called clusters. Each cluster has a Cluster Head (CH) which is responsible for collecting data from member nodes within its cluster and transmitting the data to the Base Station (BS). However, this method comes with some problems such as deciding the number of clusters and CH to member ratio, selection and rotation process of CH(s).

Two types of networks exist in the literature: homogenous and heterogeneous. If all sensor nodes in the network have equal energy, these networks are called homogeneous networks. On the other hand, if some nodes in the network have different energies, these networks are called heterogeneous networks. Heterogeneous networks can be constructed by adding more nodes. These newly added nodes will be equipped with more energy than nodes that are already in use which will cause heterogeneity in the network. The communications between elements on a network, that is, from CH to CH members and from CH to BS are governed by protocols. These protocols should be designed to achieve minimum fault tolerance in the presence of individual node failure(s) and to achieve minimum energy consumption. Moreover, since the limited wireless channel bandwidth is shared among all sensors in the network, routing protocols should be able to perform a local collaboration to reduce bandwidth requirements.

2.5 The LEACH Protocol Architecture

LEACH (Low-Energy Adaptive Clustering Hierarchy) is proposed in [33], [106]. The main feature of this protocol is minimized the energy consumption in a sensor networks by using clustering techniques. From the results, it is shown that LEACH outperforms classical clustering algorithms since it uses adaptive(dynamic) clusters, rotates CHs, and allows energy requirements of the system to be distributed among all sensors in the network. But one of the main drawback of this protocol is when a CH dies in LEACH that cluster will become useless since data gathered at the CH will never reach to the base station.

Wireless sensor networks are spatially distributed autonomous system of sensor networks that are deployed for environment, health monitoring, military surveillance, etc. they consist of several wireless sensors that collect information from their soundings and route it to the base station. One of the primary restrictive factors that affect the performance of WSNs is limited energy of sensors. Consideration of life time of networks becomes essential for any deployment strategy because a sensor network can remain effective as long as it is a live [33]. In the mathematical model which was proposed in [33], total energy consumption in the sensor network is calculated against the transmission of only one frame. In the mathematical model which was suggested in [107] total energy consumption in the sensor network is calculated during a single round. Energy consumption during a single round or a frame transmission does not represent the practical true energy consumption of the sensor nodes in their life time. The long run or expected rate of energy consumption truly reflects the energy consumption of the sensor nodes in their life times as the life time is inversely related to the long run rate of energy consumption. From the previous literature, none of the mathematical models [33] and [107] has computed long run rate of energy consumption by the sensor nodes, which made them incomplete and not useful. Therefore, it is necessary to derive a mathematical model based on long run rate of energy consumption in the sensor nodes in order to make it complete and useful to complete the parameters, such as the percentage of cluster head, optimal number of hops. Inefficiencies in the selection of optimal number of cluster heads in existing schemes [108] and [109] are analyzed.

2.5.1 LEACH Algorithm Details

The operation of LEACH is working as follow : the sensor nodes organize themselves into clusters, one of them acting as cluster head (CH). Non-cluster head sensor nodes transmit their information to the CH, while the CH node receives the information from all the cluster members, perform signal processing function on the information, then this CH node transmits information to the BS. CH node is much more energy than other sensor nodes. If CHs were chosen a priori and fixed throughout the system lifetime, these sensor nodes would use up their limited energy. Once the CH runs out of energy, it will be useless, then all node members that belong to the cluster lose communication ability. According to the above-mentioned, the LEACH protocol incorporates randomized rotation of the high energy CH position among the nodes to avoid draining the battery of any nodes in the network.

The operation of LEACH is broken up into rounds, where each round begins with a set-up phase, when the clusters are organized, followed by a steady-state when data are transferred from the sensor nodes to the CH and on the BS. The following section describe the cluster head selection and distributed cluster formation algorithms and the steady-state operation of LEACH.

2.5.1.1 Advertisement Phase

Initially, when clusters are being created, each node decides whether or not be become a CH for the current round. This decision is based on the suggested percentage of the CHs for the network and the number of times the node has been a CH so far. Let r represent the number of rounds to be a CH for the node s. each node select itself as a CH once every $r = 1/p$ rounds. It is noticed that at the start of first round all nodes in both regions has equal energy level and has equal opportunity to become CH. In each round, the node is selected to be CH on the basis of reaming energy and with probability p.

A node can become CH only once in an epoch and the nodes not selected as CH in the current round feel right to the set G. The probability of a node to select as CH increases in each round. It is required to support balanced number of CHs. At the start of each round, a node s belongs to set G and self-governing select a random number between 0 to 1. If the created random number for node s is less than a specific threshold T(s) value then the node becomes CH in the current round.

The threshold value can be found as:

$$T(s) = \begin{cases} \dfrac{p}{1 - p*(r \bmod \left(\dfrac{1}{p}\right)} & if \;\; s \;\varepsilon\; G \\ 0 & otherwise \end{cases} \qquad (2.1)$$

Where p = the desired percentage of CHs (e.g., p = 0.05), r = the current round, G = set of nodes not selected as CH in current round. In this way CHs selection have been completed, next step starts and CHs declare their work to all nodes in the network. CHs broadcast a control packet using a CSMA MAC protocol. According to the received control packet from CH, each node sends acknowledge packet. Node, who finds nearest CH, decides to be one of the members of that CH.

2.5.1.2 Cluster Set-Up Phase

After each sensor node has decided to which cluster it belongs, this node should inform the CH node that it will be one of the member of the cluster. Every node in the network transmits this information back to the CH again using CSMA MAC protocol. During this phase, all CH nodes should keep their receiver on.

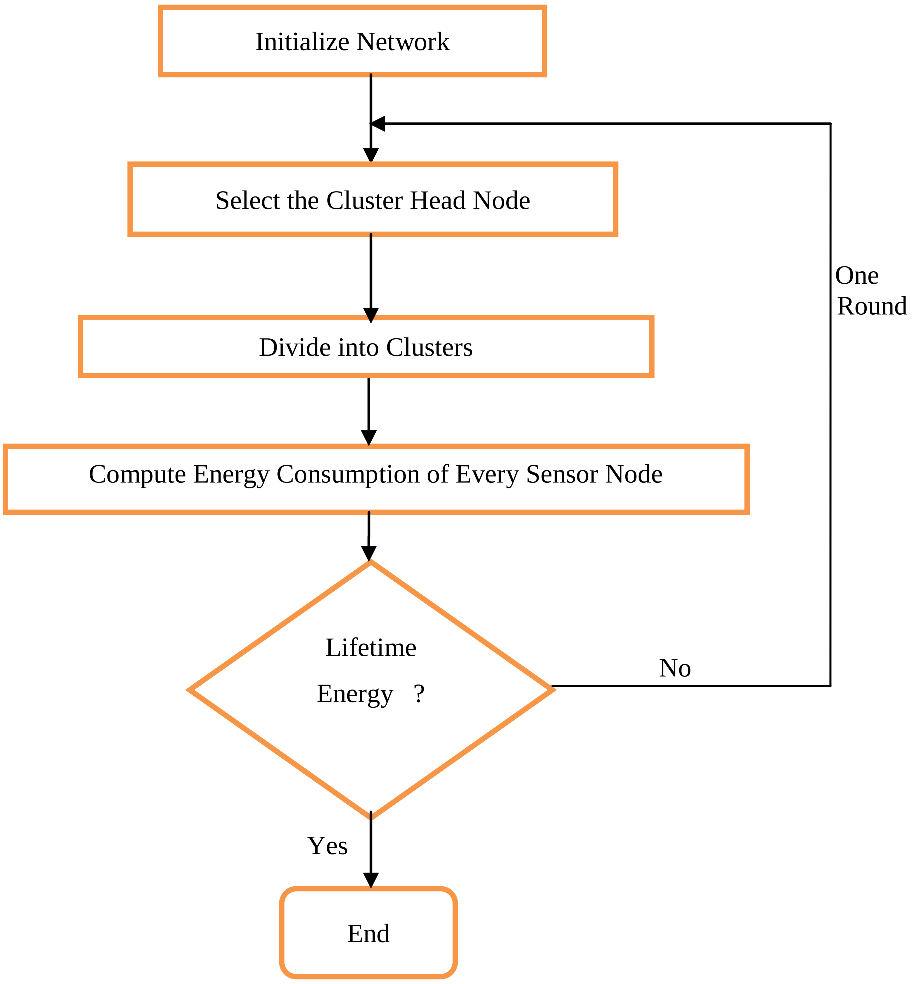
2.5.1.3 Schedule Creation

The CH node receives all the messages for sensor nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the CH node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster.

2.5.1.4 Data Transmission

This phase begins after the clusters are created and the TDMA schedule is fixed. Sensor nodes send data during their allocated time to the CH. If the radio of every non-cluster head node can be turned off until the nodes allocated transmission time then this transmission uses minimum energy dissipation in these nodes. While the CH node should keep its receiver on to receive the data from all nodes in the cluster. Once all sensor nodes send data and data has been received, the CH node performs signal processing functions and aggregate the data, this data is sent to the base station. During this phase high energy transmission is used, since the BS is far away. This is also called steady state operation, after a certain time, the next round begins with each node determining if it should be a CH for this round and advertising this information as described in section 2.5.1.1. A flowchart of schematic diagram for implementation of LEACH is shown in Fig. 2.3.

Figure 2.3. Flowchart of LEACH Protocol



3. A NEW ENERGY EFFICIENT CLUSTERING PROTOCOL USING CSI AND RE IN WIRELESS SENSOR NETWORKS

3.1 Motivation

In this study, we assume that the BS is not energy limited, the dimensions of the field and the coordinates of the BS are known. We propose a new clustering-based energy-efficient (EE) protocol for single-hop, heterogeneous WSNs. In EE-Heterogeneous LEACH, CHs are selected by using weighted probabilities. These weighted probabilities are evaluated based on the ratio between residual energy and the best channel of each node and average energy of the network. The rotating epoch (time interval) for each node is different according to its initial and residual energy. Nodes with high initial and residual energy will be more likely to become CHs per round per epoch. CHs collect data from member nodes in their respective clusters, aggregate the received data and send it to the BS using single-hop communication. Simulation results show that the proposed protocol extends network lifetime and improves energy consumption compared to other well-known protocols including LEACH, DEEC, and SEP.

3.2 Network Model

It is known that the electromagnet wave propogation in a wireless channel can be modeled as a drop power low function of the distance between the transmitter and receiver. In addition, if there is no direct, line of sight path between the transmitter and receiver, the electromagnetic wave will bounce off objects in the envirenment and arrive at the receiver from different paths at different times (two round ground) this cause multipath fading.

The distance between the transmitter and receiver is important, if the distance between the transmitter and receiver is less than a certain thresold distance (d_0), the Friss free space model is used, and if the distance is greater than d_0 , the multipath fading propogation model is used. The threshold distance is defined as follows:

$$d_0 = \frac{4\pi\sqrt{L}h_t h_r}{\lambda} \tag{3.1}$$

Where

$L \geq 1$ is the system loss factor not related to propagation,

h_r is the height of the receiving the antenna above ground,

h_t is the height of the transmitting the antenna above the ground, and

λ is the wavelength of the carrier signal.

If the distance is less than d_0, the transmit power is attenuated according to the Friss free apace equation as follows:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2 L} \tag{3.2}$$

Where

$P_r(d)$ is the receive power given a transmitter- receiver separation of d,

P_t is the transmitter power,

G_t is the gain of transmitter antenna,

G_r is the gain of receiving antenna,

λ is the wavelength of the carrier signal,

d is the distance between the transmitter and the receiver, and

$L \geq 1$ is the system loss factor not related to propagation,

This equation models the attenuation when the transmitter and receiver have direct, line of sight communication, which will only occur if the transmitter and the receiver are close to each other (i.e., $d < d_0$). If the distance is greater than d_0, the transmit power is attenuated according to the multipath propagation equation as follows:

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \tag{3.3}$$

Where

$P_r(d)$ is the receive power given a transmitter receiver separation of d,

P_t is the transmitter power,

G_t is the gain of transmitter antenna,

G_r is the gain of receiving antenna,

h_r is the height of the receiving the antenna above ground,

h_t is the height of the transmitting the antenna above the ground, and

d is the distance between the transmitter and the receiver.

We can conclude that, the received signal comes from both the direct path and a ground reflection path. Generally, if we have one path destructive interference will happened to the arrived signal, and then the signal is attenuated as d^4.

In this dissertation, we assume that an Omni directional antenna was used with the following parameters: $G_t = G_r = 1$, $h_t = h_r = 1.5$, (L=1) no loss system, f = 914 MHz , and $\lambda = 0.328$ m. using these values, $d_0 = 86.2$ m.

In this study, we use a radio energy dissipation model given in Figure 3.1. Here, L bit data packets are transmitted to a receiver (Rx) located at a distance d from the transmitter (Tx). E_{elec} is the amount of energy needed in Tx or Rx hardware to send or receive data. Because there is path loss and multipath fading phenomena happened in wireless channels, Tx is supplied with an amplifier. The amplifier has a gain of $\varepsilon L d^{\alpha}$ where α denotes the path loss exponent. It is noticed that the value of the path loss exponent is between 2 and 4 in general.

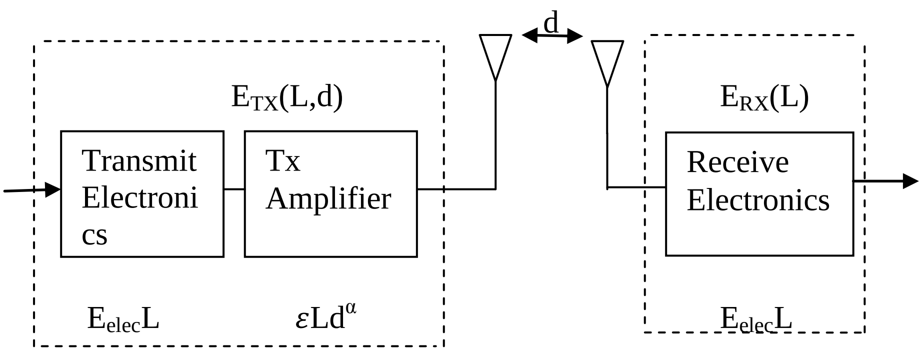


Figure 3.1. Radio Energy Dissipation Model.

We need the following energy to transmit L-bit message to a distance d:

$$E_{Tx}(L,d) = \begin{cases} LE_{elec} + L\varepsilon_{fs} d^2, & d \le d_0 \\ LE_{elec} + L\varepsilon_{mp} d^4, & d \ge d_0 \end{cases} \quad (3.4)$$

where ε_{fs} is the amplifier energy per bit per square meter (m^2) when free space model is used for the channel and ε_{mp} is the amplifier energy per bit per m^4 when multipath propagation model is used.

For the experiments described in this dissertation, we set the energy dissipated per bit in the transceiver electronics to be E_{elec} = 50 nJ/bit for a 1 Mbps transceiver. This means that the radio electronics dissipates 50 m W when in operation.

The threshold distance d_0 in (1) is given by

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{3.5}$$

and it is value is set to 86.2 m in this study. Similarly, at the Rx side:

$$E_{Rx} = LE_{elec} \tag{3.6}$$

When we design protocols in WSNs, these protocols should try to minimize not only the transmit distances but also the number of transmit and receive operations for each message because transmitting a message is consumed a lot of energy in wireless channels.

The parameters ε_{fs} and ε_{mp} normally depend on the required received sensitivity and the receiver noise figure, to make the power at the receiver above a certain threshold, transmit power needs to be adjusted, $P_{r\text{-}th}$. To determine the minimum transmit power, we can start from the backwards. If the radio bit rate is R_b, the transmit power, P_t is given by:

$$P_t = E_{TX-amp}(1,d)\, R_b \tag{3.7}$$

Put the value of $E_{TX-amp}(1,d)$ gives:

$$P_t = \begin{cases} \varepsilon_{fs}\, R_b\, d^2 & d < d_0 \\ \varepsilon_{mp}\, R_b\, d^4 & d \ge d_0 \end{cases} \tag{3.8}$$

If we using the channel model described in the previous, the received power is:

$$P_r = \begin{cases} \dfrac{\varepsilon_{fs}\, R_b\, G_t\, G_r\, \lambda^2}{(4\pi)^2} & d < d_0 \\ \varepsilon_{mp}\, R_b\, G_t\, G_r h_t^2 h_r^2 & d \ge d_0 \end{cases} \tag{3.9}$$

The parameters ε_{fs} and ε_{mp} can be determined by setting equation (3.9) equal to

$P_{r\text{-}th}$:

$$\varepsilon_{fs} = \frac{P_{r-th}(4\pi)^2}{R_b\, G_t\, G_r \lambda^2} \tag{3.10}$$

$$\varepsilon_{mp} = \frac{P_{r-th}}{R_b\ G_t\ G_r h_t^2 h_r^2} \tag{3.11}$$

Because of the transmit power is the function of both the received power and the distance between the transmitter and receiver, so we can write the P_t as:

$$P_t = \begin{cases} \alpha P_{r-th}\ d^2 & d < d_0 \\ \beta P_{r-th}\ d^4 & d \geq d_0 \end{cases} \tag{3.12}$$

Where $\alpha = \frac{(4\pi)^2}{G_t\ G_r \lambda^2}$ and $\beta = \frac{1}{G_t\ G_r h_t^2 h_r^2}$

Finally, we can determine the receiver threshold P_{r-th} using estimates for the noise at receiver.

In this dissertation the value of P_{r-th} will be used -52 dBm, therefore the received power must be at least -52 dBm or 6.3 nW for successful reception of the packet.

put the values that will be used in this study ($G_t = G_r$ = 1, $h_t = h_r$ = 1.5 m, λ =0.328 m and R_b = 1 Mbps) into equations (3.10), (3.11) gives:

ε_{fs} = 10 pJ/bit/m^2, ε_{mp} = 0.0013 pJ/bit/m^4

These are the radio energy parameters will be used for the simulation described in this thesis.

3.3 Proposed Protocol

Our proposed protocol has two phases like LEACH, setup phase and steady phase. During the setup phase, the BS broadcasts a message at a particular power including its identification information. This message makes each node know the location of the BS. The BS makes a decision about the number of and optimal size of clusters according as the size of a network area and density of nodes. The BS then transmits control packets to each node telling about which protocol is to be used. These control packets are formed from all essential information required for steady state working of the protocol including threshold energy value for a CH change, using TDMA slots for intra-cluster communication, CDMA code for communication with the BS along with node identities makes each node knows location the other members of its cluster, current round CH, and CH rotation sequence, most protocol uses sleep and wake-up techniques to reduce collision and to save energy in the network. The least amount of energy to have for a CH node is called threshold energy.

While the steady phase works as follows: non-CH nodes collect data and transmit to its CH (inter-cluster communication). At the same time, each CH sends data to the BS (intra-cluster communication). When each round is finished, a CH inspects its remaining energy to see if it is arrived to the threshold value (E_{th}) for a CH change. If so, it creates a beep signal and permits its cluster members know a CH is about to change. Subsequently, it acts same a non-CH node, i.e., it gathers data and sends to the new CH. The process of CH rotation progress until each node within the cluster becomes a chance to be a CH. After the last node is arrived to the threshold value, the algorithm starts over and runs the same CH schedule.

In short,

- The BS is fixed and located far from sensor nodes.
- In the network, all sensor nodes are uniformly distributed over a square field.
- After the deployment of sensor nodes and the BS are left unattended.
- Heterogeneous nodes in terms of energy are used in the network.
- sensor nodes are the same of importance’s.
- The battery of the BS is rechargeable.

It is known that LEACH is are cursive algorithm and each iteration in the algorithm is called a 'round'. The round r is referred to a time interval where all cluster members send to the CH. In LEACH, when the setup phase is working, each node creates a random number between 0 and 1. If this random number is less than a certain value, known as threshold value T(s), then the node becomes a CH for that round. The threshold value is selected as:

$$T(s)=\begin{cases}\dfrac{p_{opt}}{1-p_{opt}\left(r \bmod \left(\dfrac{1}{p_{opt}}\right)\right)}, & \text{if } s\in G\\ 0, & \text{otherwise}\end{cases} \tag{3.13}$$

where p_{opt} is the desired percentage of CHs among all nodes, r is the current round number, G is a set of sensor nodes that have not been chosen as CHs in the last $\left(\frac{1}{p_{opt}}\right)$ rounds, and s is the current CH node.

From literature it is noticed that most energy-efficient schemes intent to minimize the average wasted energy E_w. To this affect, they only take into account the residual energy. On the other hand, other energy-efficient schemes focus on minimizing the average transmission energy E_{Tx} and take into account the CSI. It is a well-known fact that network lifetime depends on both the average wasted energy E_w and the average transmission energy E_{Tx}. Since the ultimate goal is to maximize the network lifetime and to increase the stability period, we need to balance the both schemes. In this study, we consider the case where the CSI is available.

The received signal at the BS due to the CH i is:

$$y_{iBS}(n)=\sqrt{P_i}\,h_{iBS}(n)x_i(n)+\eta_{iBS}(n) \tag{3.14}$$

where P_i is the transmission power of the CH node i, $h_{iBS}(n)$ is the channel gain between the CH node i and the BS (circularly-symmetric Gaussian random variable with zero mean and variance σ_{iBS}^2), and $x_i(n)$ is the M-PSK modulated transmitted signal ($M=2^k$ with k positive integer) with unit average power, and $\eta_{iBS}(n)$ is an additive noise term, circularly-symmetric Gaussian random variable with zero mean. The variance of $h_{iBS}(n)$ is given by

$$\sigma_{iBS}^2=\beta D_{iBS}^{-\alpha} \tag{3.15}$$

where D_{iBS} is the distance between CH node i and the BS, α is the path loss exponent, and β is a constant whose value depends on the propagation environment [110].

We propose a new threshold value T(s), an improvement to (3.13), as follows:

$$T(s) = \left\{ \frac{p_{opt}}{1 - p_{opt}\left(r \bmod \left(\frac{1}{p_{opt}} \right) \right)} \left(\frac{E_{MRE} E_{bestchannel}}{E_{av}} \right) \right. \tag{3.16}$$

where E_{MRE} denotes the maximum of minimum residual energies, $E_{bestchannel}$ is the largest variance (or, energy) of channel gains σ^2_{iBS}, and E_{av} is the average energy of the network.

The average energy E_{av} of the network at the rth round is given by

$$E_{av}(r) = \frac{1}{N} E \left(1 - \frac{r}{R} \right) \tag{3.17}$$

where R is the lifetime of the network, it is noticed that it assumes that every node consumes the same amount of energy in each round. We assume also all nodes die at the same time; hence, R is the total number of rounds in which the network is alive. Let E_{round} denote the energy consumed by the WSN in each round. Then R is given by

$$R = \frac{E_{total}}{E_{round}} \tag{3.18}$$

In this study, we consider a WSN that uses a single-hop communication. An illustrative example of a single-hop communication with four clusters is depicted in Figure 3.2 where each non-CH node communicates directly (single-hop) with its CH and each CH communicates directly with the BS.

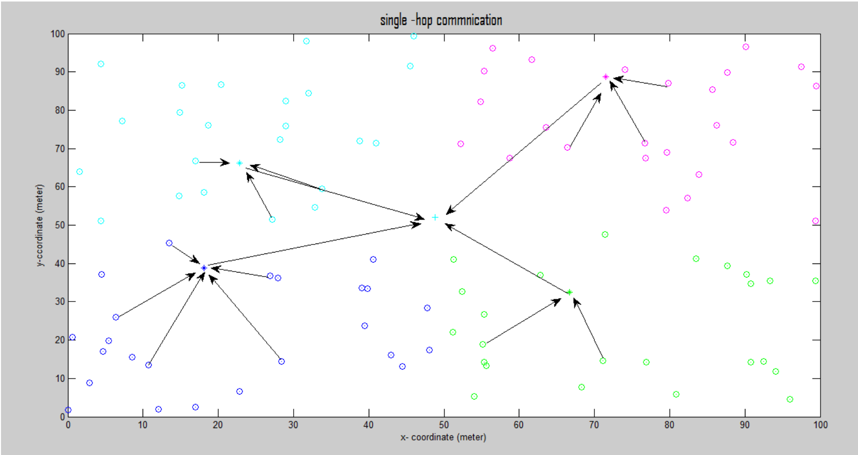


Figure 3.2. Single-hop communication with four clusters

The BS is responsible for the data retrieval operation, the BS broadcasts the request to send (RTS) message to activate sensor nodes. CHs are enabled and data packets are transmitted to the BS through the wireless channel. Only sensor nodes that have received RTS will deal for the data channel by using the non-cooperative schemes as presented in [110]. At any time instant, only one CH occupies the channel to transmit a data packet to the BS. When one transmission is being activated, other CH nodes are in a sleeping mode in the network.

The average BER performance for a non-cooperative node with M-PSK modulation is upper-bounded by [111]:

$$BER \leq \frac{AN_0}{bP_i\sigma_{iBS}^2 \log_2 M} \tag{3.19}$$

where N_0 is the power spectral density of the additive noise term η_{iBS}, A and b are defined as

$$A = \frac{(M-1)}{2M} + \sin\left(\frac{\frac{2\pi}{M}}{4\pi}\right), \qquad b = \sin^2\left(\frac{\pi}{M}\right) \tag{3.20}$$

If the average BER is needed to be less than or equal to a given value ζ, that is, $BER_{iBS} \leq \zeta$, the minimum transmission power is:

$$P_{\min} = \frac{AN_0}{b\zeta\sigma_{iBS}^2 \log_2 M}. \tag{3.21}$$

Thus $P_i \in [P_{min}, P_{max}]$, where P_{max} denotes the maximum transmission power.

3.4 SIMULATION RESULTS

The performance of the proposed clustering-based protocol is evaluated using MATLAB both for homogeneous and heterogeneous networks. In the network, 100 nodes are randomly deployed in a 100m x 100m region where the BS is located at the center as illustrated in Figure 3.3.

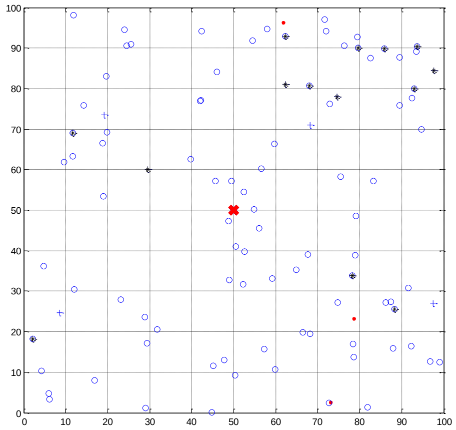


Figure 3.3. An illustration of the network

The performance evaluation of the proposed network is done with respect to the following parameters:

Stability period: The time interval between the start of the network operation and the death of the first sensor node also known as stable region.

Instability period: The time interval between the death of the first sensor node and of the last sensor node.

Network lifetime: The time interval between the start of the network operation and the death of the last sensor node.

Number of alive nodes: The number of sensor nodes that have not yet depleted their energy.

Number of dead nodes: The number of sensor nodes that have consumed all of their energy and are not able to do any kind of functionality.

Throughput: The rate of data sent from cluster heads to the base station.

The proposed algorithm is compared with LEACH, DEEC, and SEP in terms of dead and alive nodes per round, energy consumption of the network, and overall throughput. The total number of rounds used in our experiments is 8000.

Case I: Homogeneous Networks

Network model parameters are summarized in Table 3.1.

Table 3.1. Network model parameters

Parameter name	**Value**
E_0	0.5 J
Packet size	4000 bits
E_{elec}	50 nJ/bit
$E_{tx} = E_{rx}$	50 nJ/bit
E_{fs}	10 pJ/bits/m^2
E_{mp}	0.0013 pJ/bits/m^2
E_{DA}	5 nJ
F_c	1 GH
N_0	-40 dBm
BER	10^{-3}
η	1
α	2
$P_{\max}$	0.2
Data rate R	10^4
Modulation type	BPSK
E_c	$2x10^{-4}$
E_{cs}	$2x10^{-4}$
E_{es}	10^{-4}

Figure 3.4.shows the number of dead nodes per round indicating stability time of the networks. The death of the first node occurs at the round 1270 in the proposed protocol whereas the death of the first node occurs at rounds 984, 1140, and 912 in LEACH, DEEC, and SEP, respectively. The death of the last node occurs at the round 2529 in the proposed protocol whereas the death of the last node occurs at rounds 1450, 1554, and 2115 in LEACH, DEEC and SEP, respectively. Hence, the proposed protocol has better stability time and network lifetime as compared to the other networks.

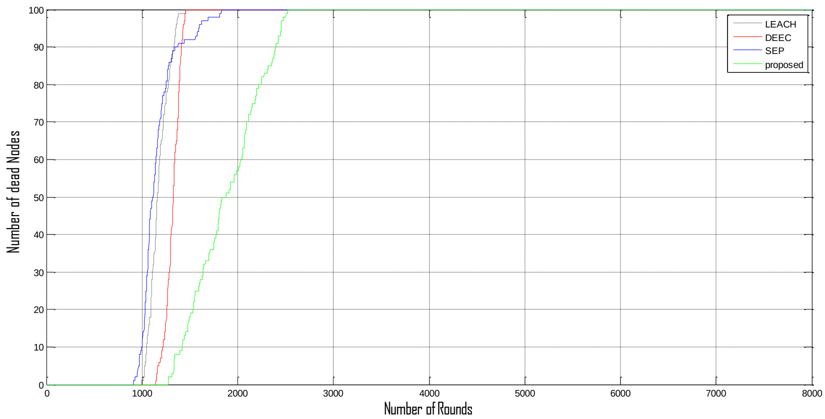


Figure 3.4. Number of dead nodes per round

The proposed protocol has also better energy comsumption and higher throughput than the other protocols considered which can be seen from the Figure 3.5 and Figure 3.6. Initial energy E_0 of the network is consumed at the round 2100 in the proposed protocol whereas the initial energy E_0 of the network is consumed at rounds 1100, 1200 and 1300 in LEACH, DEEC and SEP, respectively (Figure 3.5). Similarly, Figure 3.6 shows the superiority of the proposed algorithm in terms of the throughput thanks to the wiser selection of CHs.

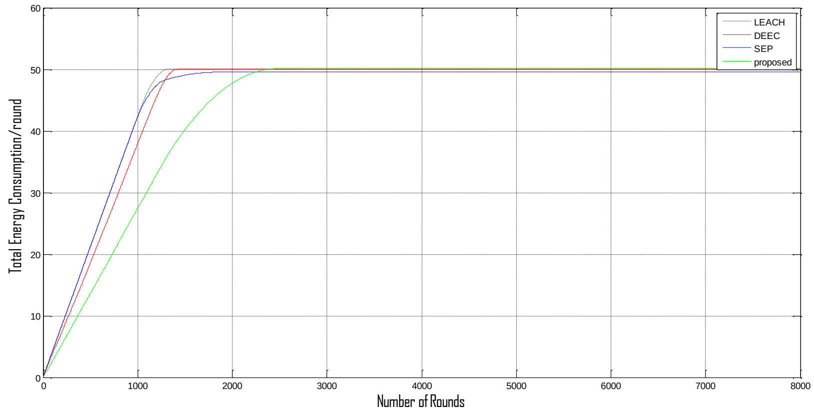


Figure 3.5. Energy consumption

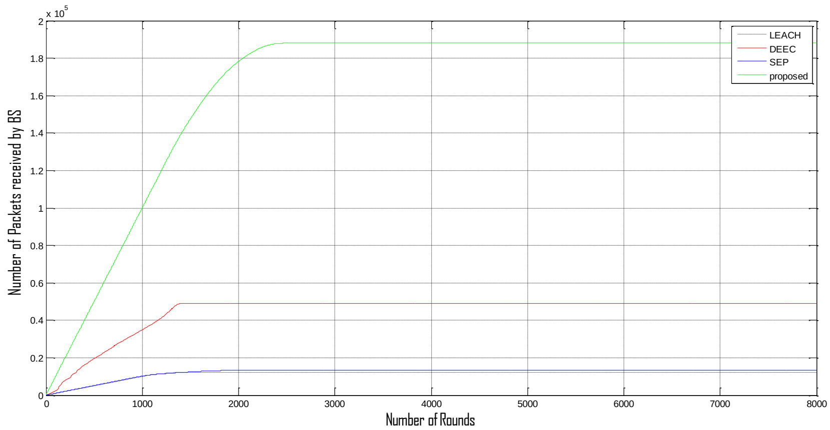


Figure 3.6. Throughput

Case II: Heterogeneous Networks

Here all nodes have different amount of initial energies. The initial energies are uniformly distributed on [0.5, 1] resulting the average initial energy of 0.75 J. Several experiments are conducted, the average stability periods are calculated, and the results are shown in Figures 3.7, 3.8 and 3.9. The results show that on the average the proposed algorithm has 1.62 to 1.89 times better stability period compared to other protocols considered. Figure 3.7 shows the number of dead nodes per round indicating stability time of the networks. The death of the first node occurs at the round 1894 in the proposed protocol whereas the death of the first node occurs at rounds 1036, 1322, and 1243 in LEACH, DEEC, and SEP, respectively. Hence, the proposed protocol has better stability time and network lifetime as compared to the other networks. The proposed protocol has also better energy comsumption and higher throughput than the other protocols considered which can be seen from the Figure 3.8 and Figure 3.9.

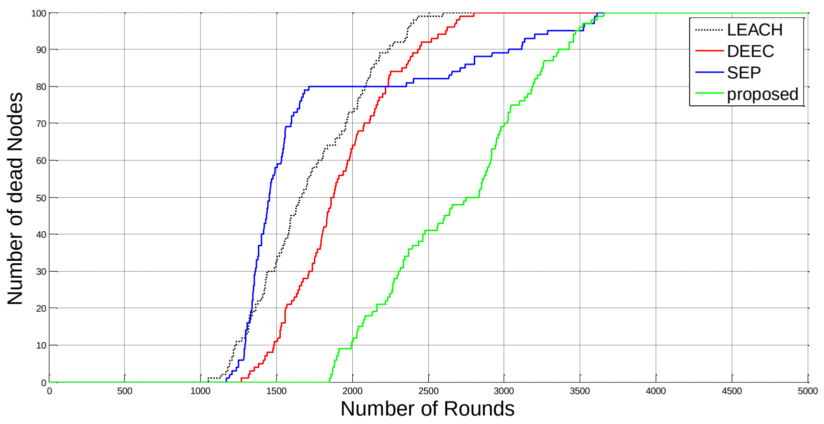


Figure 3.7. Number of dead nodes per round

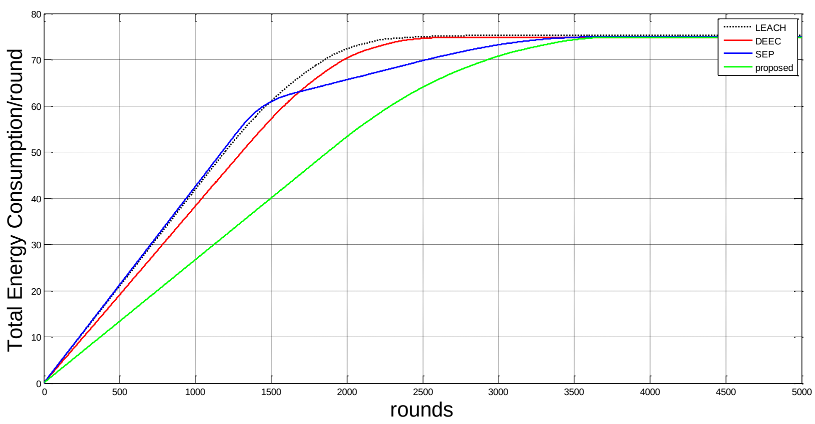


Figure 3.8. Energy consumption

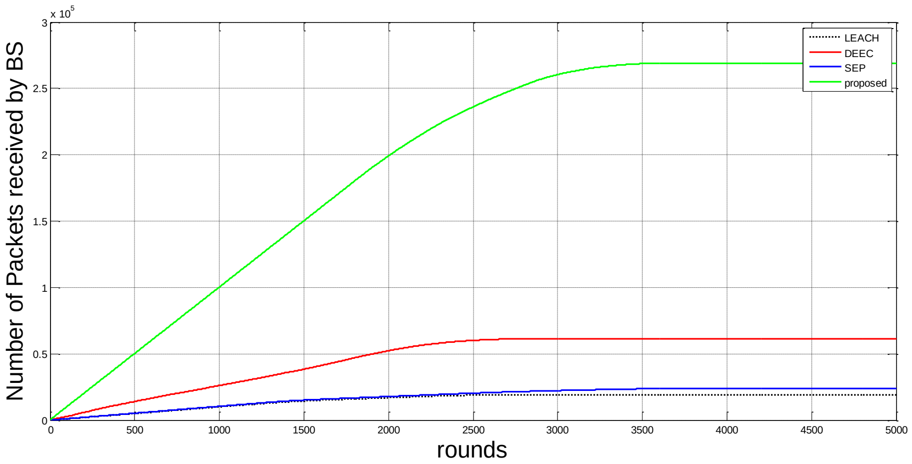


Figure 3.9. Throughput

3.5 Results and Discussion

This paper presents a new clustering-based protocol, EE-Heterogeneous LEACH, for WSNs. In the proposed protocol, nodes with different energy levels are considered causing heterogeneity in the network. Moreover, a single-hop transmission approach is adopted for intra-cluster and inter-cluster communication. We proposed an optimized routing scheme where the main focus is to enhance cluster head selection process. CHs are selected in each cluster on the basis of residual node energy and the best channel.

From the conducted experiments, it is seen that:

Stability period of the network is enhanced compared to the other protocols LEACH, DEEC, and SEP. Superior network lifetime is obtained for different scenarios. Last but not least, the throughput of the proposed protocol is significantly better than the other protocols considered. Thus, we claim that the proposed protocol has improved energy efficiency and effective in prolonging the network lifetime.

4.ENERGY EFFICIENT CLUSTERING PROTOCOL FOR WIRELESS SENSOR NETWORKS USING NEW COOPERATIVE PROTOCOL

4.1 Motivation

Most of previous studies in the network of a WSN employ non-cooperative transmissions. However, some studies have shown that considerable potential exists of cooperative transmission is used, conventionally most of the previous studies focus on improving physical layer performance by minimizing energy consumption of a network. In WSNs, on the other hand, many algorithms recently proposed aim at increasing stability and lifetime of heterogeneous WSNs. An algorithm proposed for a specific network will not perform well for other types of networks. A major challenge is how to provide efficient communication between sensor nodes to save energy. Cooperative communication and network clustering ideas have been shown to be effective to treat this challenge in WSNs. In the literature, most studies focus on the performance of the two schemes separately. In our study, we investigate the performance of a system that combines these ideas. Namely, we apply cooperative transmission to reduces energy consumption and decrease the differences of energy consumption among sensor nodes. To further balance energy consumption among sensor nodes, we apply clustering approach. In this study, we propose the source and relay which has not previously considered for broadcast cooperative networks. The CHs are selected based on the following parameters: remaining energy of the nodes (minimum residual energy) and channel state information. The node that offers the highest channel gain with the BS and minimum residual energy is selected to be a CH (source), and the node that offers the next highest channel gain and next highest minimum residual energy is selected to be a relay for each cluster. With this way, nodes with more residual energy, high channel gain are likely to be selected as CH (source) and relay, preventing the network die early and enhancing the lifetime of the WSN. We also evaluate this scheme in the following. Simulation results show the super performer of the proposed protocol.

4.2 Network Model :

In this study, we use a radio energy dissipation model given in Figure 3.1.

4.3 Proposed Protocol

We define a new three threshold values T(s), an improvement to (3.14) as follows:

$$T(s)=\begin{cases}\dfrac{P_i}{1-P_i\left[r \bmod\left(\dfrac{1}{P_i}\right)\right]} & , \quad if \quad s\in G\\ 0 & , \quad otherwise\end{cases} \tag{4.1}$$

$$P_i=\left\{\frac{p_{opt}E_{Ra}}{E_{avg}}\right. \tag{4.2}$$

$$P_i=\left\{\frac{p_{opt}E_{\mathrm{Re}}}{E_{avg}}\right. \tag{4.3}$$

$$P_i=\left\{\frac{p_{opt}E_{coop}}{E_{avg}}\right. \tag{4.4}$$

where (4.2) defines RaEnegery protocol, (4.3) defines ReEnergy protocol, and both of them define the probabilities of non-cooperative cases, E_{Ra} is the energy of a random node, E_{Re} is the minimum residual energy of node, and (4.4) is the probability of cooperative nodes, E_{coop} is the cooperative energy and E_{avg} is the average energy of the network. The answer of how the source node **s** and relay node **r** are selected (cooperative mode) is be given as follows: specifically, these nodes are selected with respect to other maximal energies, these energies are called E_{coop} which takes into account both the best channel state and minimum residual energy information. Flowchart of the proposed algorithm is shown in Figure 4.1.

1. BS need to initiate a data transmission process, it sends a Request To Send (RTS) packet. If it doesn't receive the Clear To Send (CTS) packet in a certain time it will retransmit RTS. The network is considered dead when the maximum number of repetition is reached. If the CTS packet is successfully received by BS, the repetition counter will be cleared. Then BS waits for the Helper ready To Send (HTS) packets for a certain time. if HTS packet is received, then BS enters into cooperative mode, and

receives packets transmitted from source and relay nodes. Otherwise, it receives a data packet from the source node in non-cooperative mode.

Figure 4.1. Flowchart of the proposed algorithm

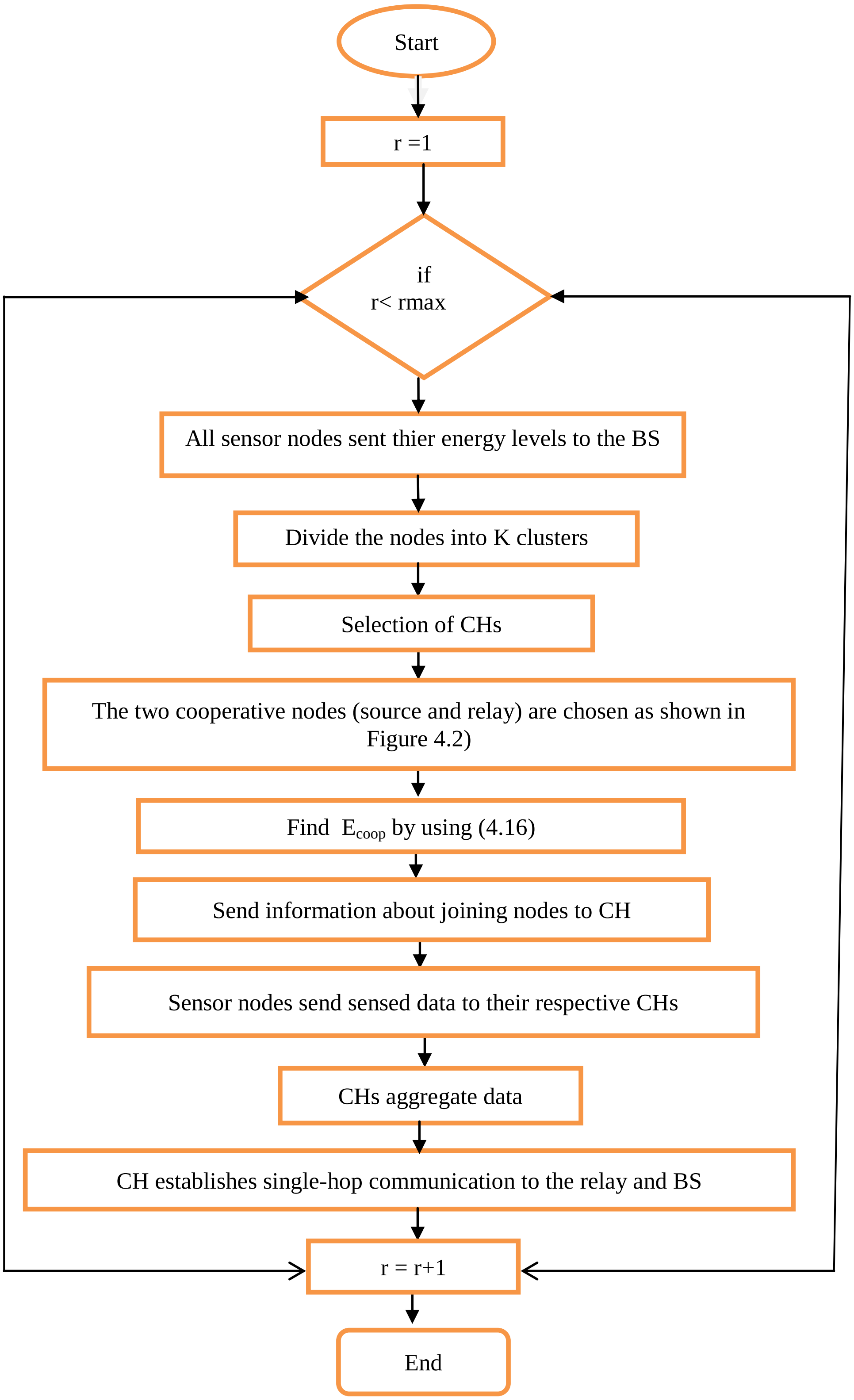
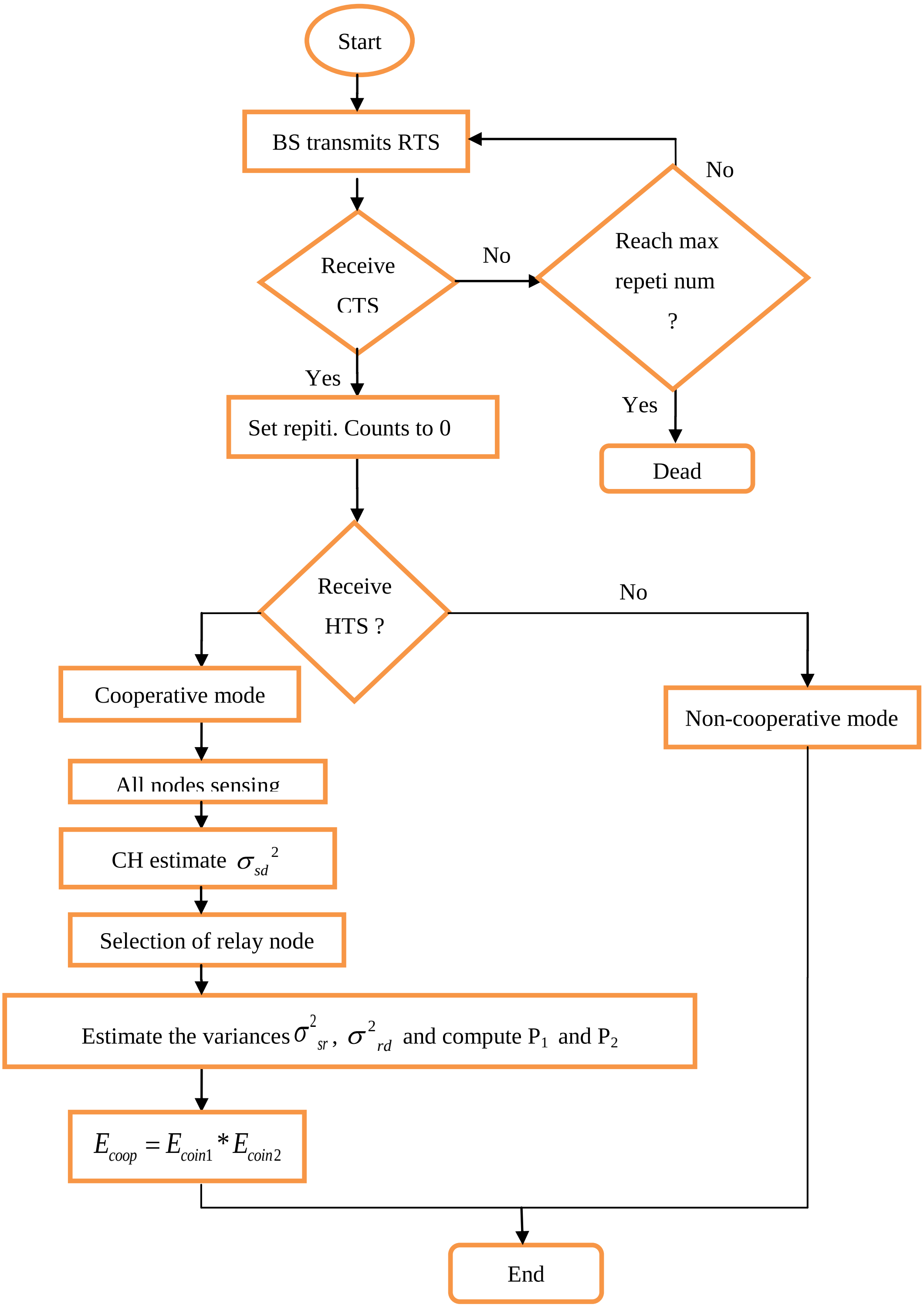


Figure 4.2. Flowchart illustrating actions of BS in cooperative mode.



2. All sensor nodes in the network listen for RTS, CTS and HTS sent by BS, when the sensor node hears the RTS packet, it will estimate the variance of the channel (σ^2_{sd}).

3. After relay node is chosen (the node that offers the second highest channel gain and second highest minimum residual energy is selected to be a relay for each cluster) the channel variance between source and relay σ^2_{sr} and the channel variance between relay and BS σ^2_{rd} are determined. The transmission power P_1 and P_2 are computed according to (4.13) appended the value P_1 to the HTS and send out.

4. Source node waits for the HTS packet after transmitting the CTS packet. If it receives the HTS packet then the cooperative relationship between source and relay node is established. Otherwise source node sends data to the BS directly.

All nodes in the network need to know the total energy initially. The average energy E_{av} of the network at the rth round is given by

$$E_{av}(r) = \frac{1}{N} E\left(1 - \frac{r}{R}\right) \tag{4.5}$$

where R is the network lifetime, it is noticed that we assume that every node consumes the same amount of energy at each round (E). We further assume that all nodes die at the same time; hence, R is the number of rounds in which the network is alive. Let E_{round} denote the energy consumed by the WSN at each round. Then R is given by

$$R = \frac{E_{total}}{E_{round}} \tag{4.6}$$

Let signals received by the relay node and base station at time n be denoted as $y_{sr}(n)$ and $y_{sd}(n)$, respectively. Signals received by the BS $y_{rd}(n)$ and $y_{sd}(n)$ are combined via (Maximum Ratio Combining) MRC technique to yield y(n), received signal formula are given in the following:

$$y_{sr}(n) = \sqrt{P_1} h_{sr}(n) x(n) + \eta_{sr}(n) \tag{4.7}$$

$$y_{sd}(n)=\sqrt{P_1}h_{sd}(n)x(n)+\eta_{sd}(n) \tag{4.8}$$

$$y_{rd}(n)=\sqrt{\tilde{P}_2}h_{rd}(n)x(n)+\eta_{rd}(n) \tag{4.9}$$

$$y(n)=(\sqrt{P_1}h^*_{sd}/N_0)y_{sd}(n)+(\sqrt{\tilde{P}_2}h^*_{rd}(n)/N_0)y_{rd}(n) \tag{4.10}$$

where P_1 is the transmission power of the source node, and $x(n)$ is the transmitted symbol with unit average power. $h_{sr}(n)$, $h_{sd}(n)$ and $h_{rd}(n)$ are channel gains of the source-relay, source-BS and relay-BS channels distributed according to CN (0, σ^2_{sr}), CN $(0,\sigma^2_{sd})$ and CN $(0,\sigma^2_{rd})$, respectively, here CN stands for Complex Gaussian (normal) and the instantaneous gains of different links are assumed to be mutually independent. σ^2_{sr}, σ^2_{sd}, σ^2_{rd} are variances of the channel gains, η_{sr}, η_{sd} and η_{rd} are additive noise terms modeled as CN $(0,N_0)$. If Cyclic Redundancy Check (CRC) code is appended to the end of data packets, the relay node and BS will know whether the decoded packet is received without error. When the relay node decodes the received packet correctly, $\tilde{P}_2=P_2$, otherwise $\tilde{P}_2=0$. If the channel gains remain constant in a time slot that happens for slow fading channels, then the subscript n can be omitted. In the following, an optimal power allocation strategy that minimizes the total transmission power subject to Bit Error Rate (BER) constraint is derived at the base station. we assume that all channel links are available ($\sigma^2_{sr}\neq 0,\sigma^2_{sd}\neq 0,\sigma^2_{rd}\neq 0$). Note that the average BER performance for cooperative communication with M-PSK or M-QAM modulation is upper-bounded by [111] :

$$BER_{coop}\leq\frac{A^2N_0^{\ 2}}{b^2P_1^2\sigma^2_{sd}\sigma^2_{sr}\log_2 M}+\frac{BN_0^{\ 2}}{b^2P_1P_2\sigma^2_{sd}\sigma^2_{rd}\log_2 M} \tag{4.11}$$

M-PSK, values of b and A are as follows :

$B=3(M-1)/2M+\sin(2\pi/M)/4\pi-\sin(4\pi/M)/32\pi$.

If the average BER requirement is $BER_{coop}\leq\zeta$, to determine the minimum value P_1 and P_2, according to the BER upper bound in (4.11), P_1 and P_2 must satisfy [112]:

$$\frac{A^2 N_0^{\ 2}}{b^2 P_1^2 \sigma^2_{\ sd} \sigma^2_{\ sr} \log_2 M} + \frac{B N_0^{\ 2}}{b^2 P_1 P_2 \sigma^2_{\ sd} \sigma^2_{\ rd} \log_2 M} = \zeta \tag{4.12}$$

Then power P_2 can be expressed in term of P_1 as:

$$P_2 = f(P_1) = \frac{B N_0^{\ 2} \sigma^2_{\ sr} P_1}{\zeta b^2 P_1^2 \sigma_{sd}^{\ 2} \sigma_{sr}^{\ 2} \sigma_{rd}^{\ 2} \log_2 M - A^2 N_0^{\ 2} \sigma_{rd}^{\ 2}} \tag{4.13}$$

$$= \frac{P_1}{C P_1^{\ 2} - D}$$

Where $C = \left(\zeta b^2 \sigma_{sd}^{\ 2} \sigma_{rd}^{\ 2} \log_2 M \right) / B N_0^{\ 2}$ and $D = A^2 \sigma_{rd}^{\ 2} / B \sigma_{sr}^{\ 2}$. Minimizing the total transmission power of the source and relay nodes under the constraint of the maximum transmission power $P_{\max}$, the optimization problem can be formulated as [112]:

$$\begin{aligned} &\min && y = P_1 + f(P_1) \\ &: s.t && P_2 = f(P_1) \\ & && 0 < P_1 \le P_{\max}, 0 < P_2 \le P_{\max} \end{aligned} \tag{4.14}$$

The minimum transmission power can be got by setting the derivative of the objective function to be 0, thus the value of P_1 is derived, and P_2 can be got through expression (4.14):

$$P_1 = \left\{ \sqrt{t/C}, P_{\max} \right)_{\min}, P_2 = \left\{ f(P_1), P_{\max} \right)_{\min} \tag{4.15}$$

Where $t = C P_1^{\ 2} = \left(2D + 1 + \sqrt{8D + 1} \right) / 2.$

$$E_{coop} = E_{coin1} * E_{coin2} \tag{4.16}$$

$$E_{coin1} = E_{co1} - P_1 * D_{pt} - E_{es} - E_{cs} - E_c$$

$$D_{pt} = \frac{packetsize}{R_b}$$

$$E_{coin2} = E_{co2} - P_2 * D_{pt} - E_{es} - E_{cs} - E_c$$

Where E_{co1}, E_{co2} are the most two energies in each cluster takes both CSI and REI into account to prolong the network lifetime while meeting the average BER requirement, D_{pt} it is the time of the power data, R_b it is the data rate.

4.4 SIMULATION RESULTS

The proposed algorithm is compared with LEACH and DEEC in terms of dead and alive nodes per round, energy consumption of the network, and overall throughput. The total number of rounds used in our experiments is 4000.

Network model parameters are summarized in Table 4.1.

Where E_c is the circuit energy of transmitting a data packet, E_{cs} is the energy consumption of a control packet at the transmitter, E_{es} is the receiving and computing energy consumption of a data packet.

We assume all nodes have different amount of initial energies. The initial energies are uniformly distributed on [0.5, 1] resulting the average initial energy of 0.75 J. Several experiments are conducted, the average stability periods are calculated, and the results are shown in the following figures.

Table 4.1. Network model parameters

Parameter name	**Value**
E_0	0.5 J
Packet size	4000 bits
E_{elec}	50 nJ/bit
$E_{tx} = E_{rx}$	50 nJ/bit
E_{fs}	10 pJ/bits/m^2
E_{mp}	0.0013 pJ/bits/m^2
E_{DA}	5 nJ
F_c	1 GH
N_0	-40 dBm
BER	10^{-3}
η	1
α	2
$P_{\max}$	0.2
Data rate R_b	10^4

Modulation type	BPSK
E_c	$2x10^{-4}$
E_{cs}	$2x10^{-4}$
E_{es}	10^{-4}

Figure 4.3 shows that our proposed protocol has greater stability time as compared to LEACH and DEE. The first node of our proposed protocol is dead after approximately 1867 rounds whereas the first node of LEACH and DEEC is dead after approximately 1059 and 1040 rounds respectively. The proposed protocol provides the better stability time and overall network life time is longest than the others as shown in Figure 4. 3.

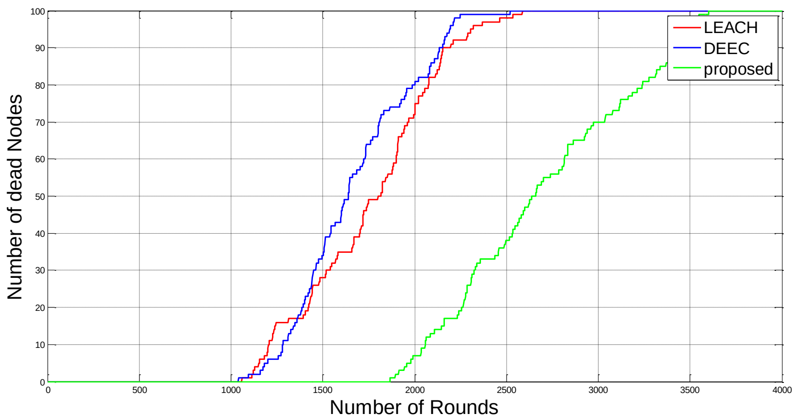


Figure 4.3. Total number of live nodes in each round.

Figure 4.4 shows that the throughput of proposed protocol is signifiantly greater as compared to LEACH and DEEC in stable and unstable regions. From this graph we see that our proposed protocol guarantees more pakets to the base station in comparison with LEACH and DEEC.

The throughput of proposed protocol is more than the other two protocols because the efficiency selection of cluster head.

Figure 4.5 shows total remaining energy over time i.e, number of rounds. Here total initial energy is 75 J which decreases linearly up to around 2000 rounds for three protocols. Energy per round is more in our proposed protocol as compared to LEACH and DEEC.

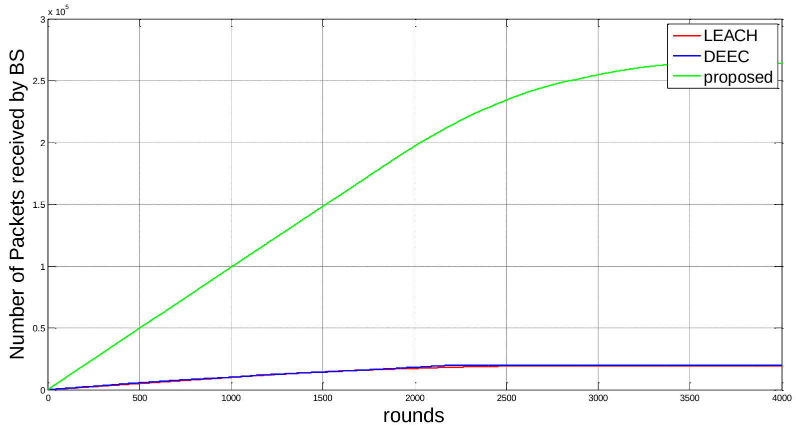


Figure 4.4. Comparative throughput.

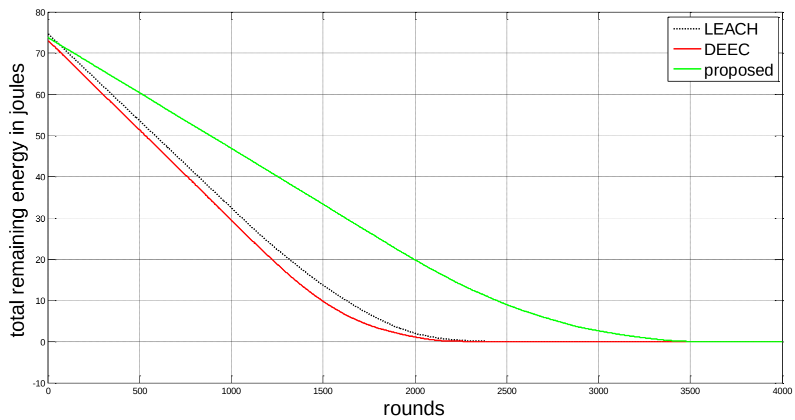


Figure 4.5. Total remaining energy over rounds.

Figure 4.6 shows that our proposed protocol has greater stability time as compared to (RaEnergy) energy of random selection and (ReEnergy) residual energy. The first node of our proposed protocol is dead after approimately 1853 rounds whereas the first node of random selection and residual energy is dead after approximately 1196 and 1601 rounds respectively. The proposed protocol provides the better stability time and overall network life time is the longest the others.

Figure 4.7 shows that the throughput of proposed protocol is signifiantly greater as compared to random selection and residual energy selection in stable and unstable regions. From this graph we see that our proposed protocol guarantees more pakets to the base station in comparison with random selection and residual energy selection.

The throughput of proposed protocol is more than the other two protocols because of the efficient number of cluster head selection.

The proposed protocol reaches the threshold level of 75 joules approximately at 3000 rounds, while random selection and residual energy selection consumes 75 joules of energy in 2000 and 2700 rounds respectively. This show that our proposed is better energy consumption than the two protocols as shown in Figure 4.8 .

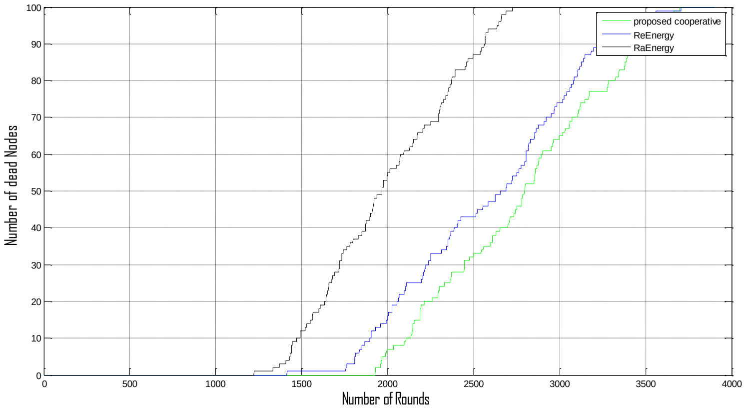


Figure 4.6. Total number of live nodes in each round.

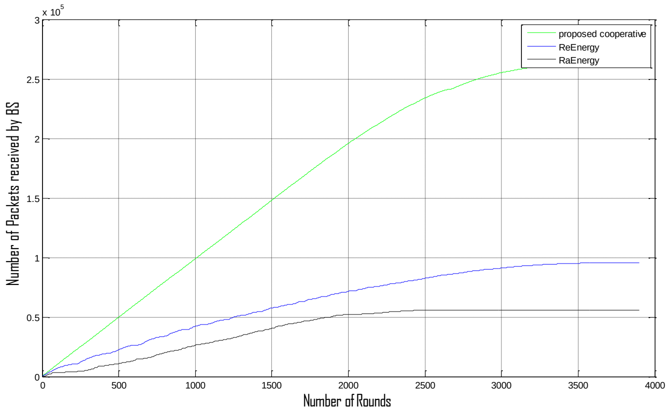


Figure 4.7. Comparative throughput**.**

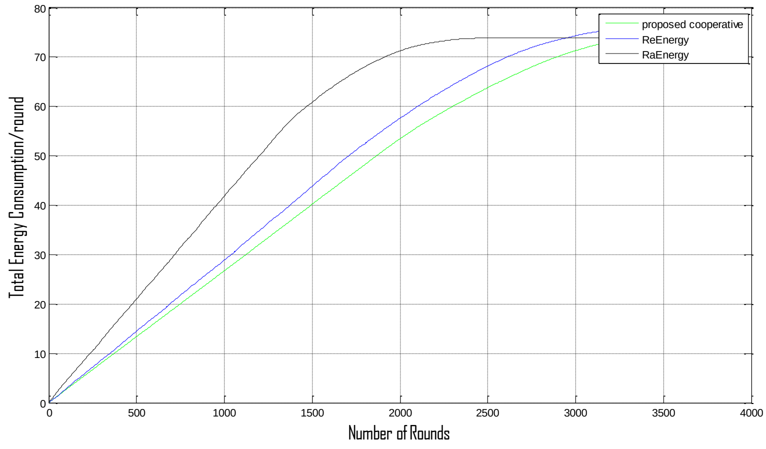


Figure 4.8.Network energy consumption per round.

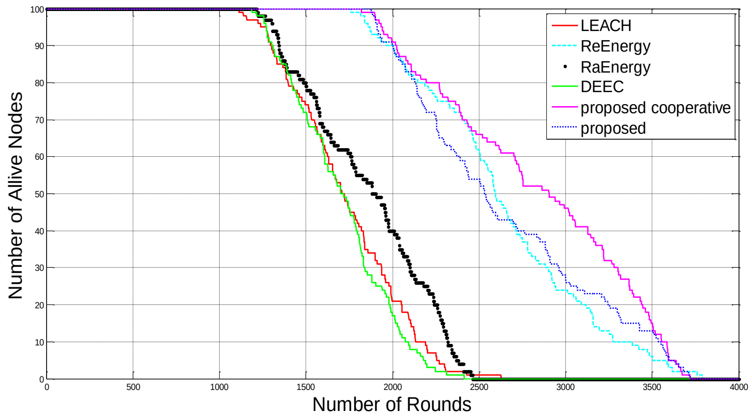


Figure 4.9. Totalnumber of live nodes in each round.

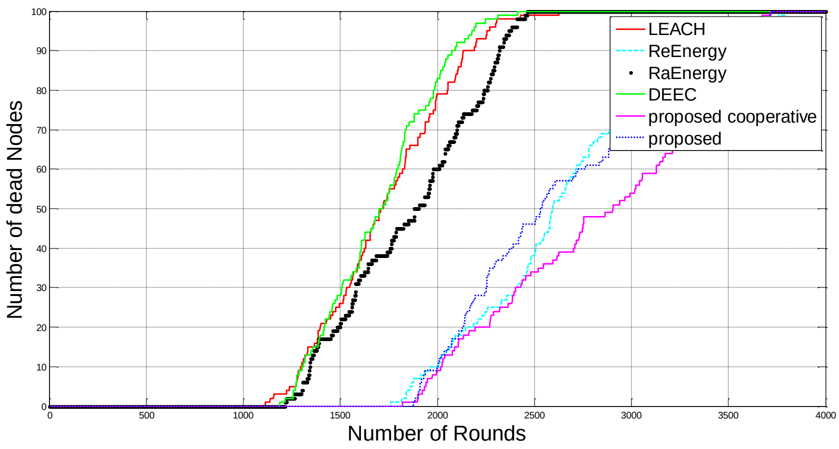


Figure 4.10. Total number of dead nodes in each round.

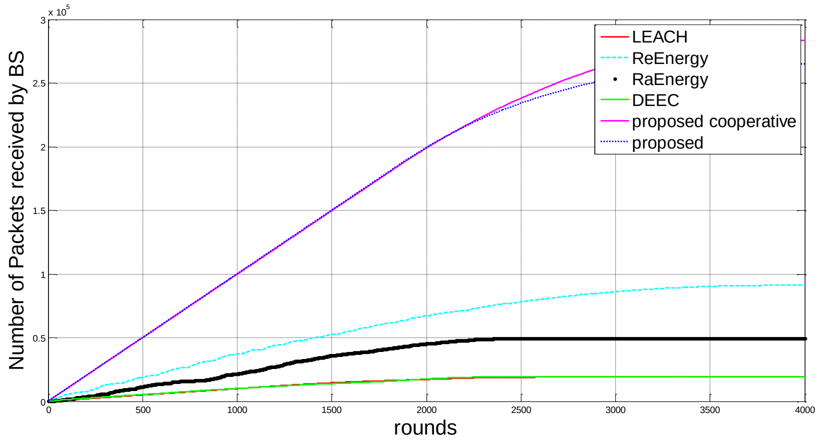


Figure 4.11. Comparative throughput.

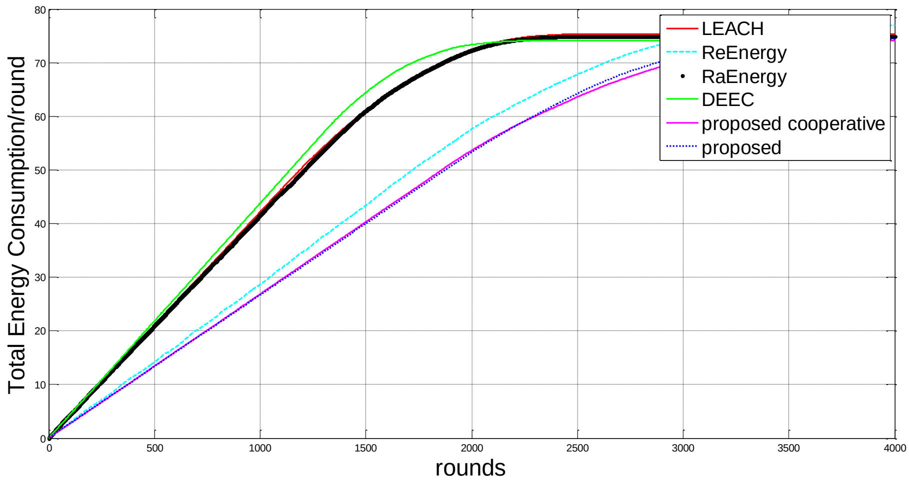


Figure 4.12. Total remaining energy over rounds.

Figures. 4.13-15 compare the network life time of WSN employing cooperative protocol under different modulation schemes. We can see from the figures that compared with other M-PSK or M-QAM modulation. BPSK has much better life time performance. The reason can be explained with the following aspect: as the M parameter increase, the minimum Euclidean distance of the constellation diagram is becoming shorter which means more transmission power should be allocated to satisfy the average BER constraint. In BPSK the increased energy consumption maybe lower than the energy saved in QPSK. For higher order modulation such as 8-PSK or 16-QAM the energy saved can't even compensate for the additional energy consumption to meet the BER requirement compared with BPSK. Thus, WSN with BPSK modulation has the longest lifetime. When M becomes bigger, the network life time changes slightly.

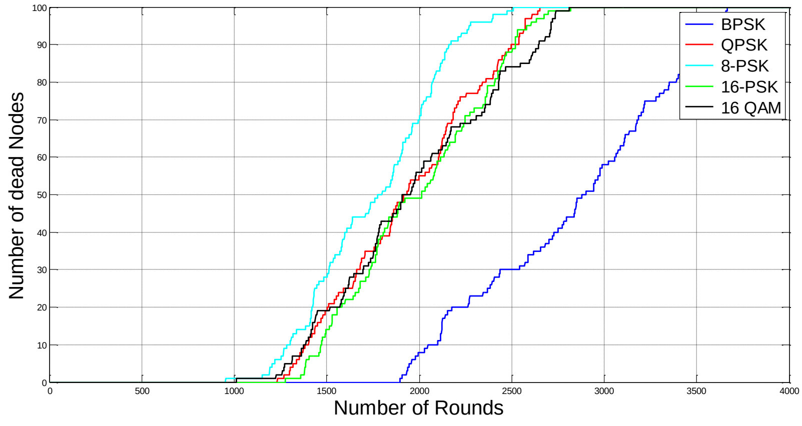


Figure 4.13.Total number of live nodes in each round.

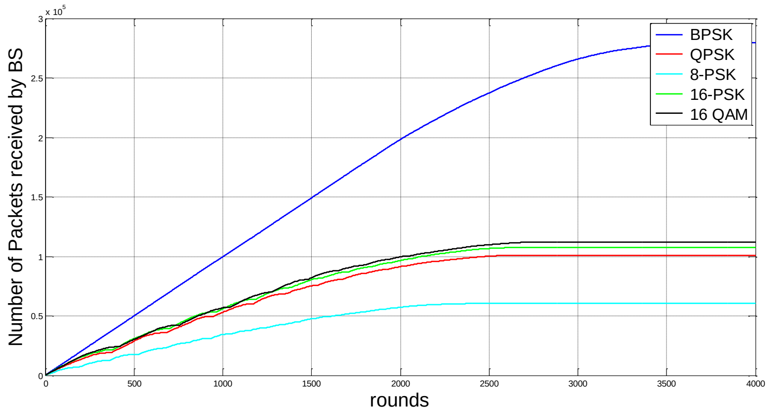


Figure 4.14. Comparative throughput.

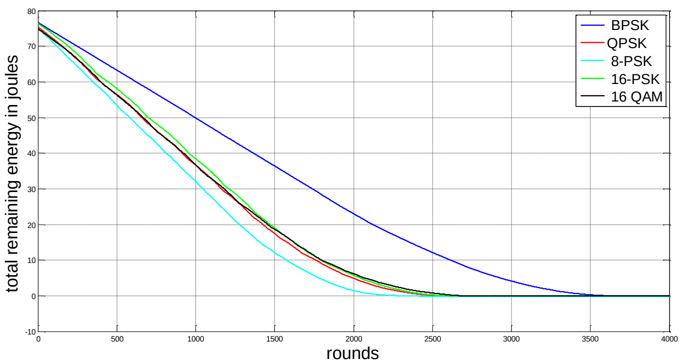


Figure 4.15. Total remaining energy over rounds.

4.5 Results and Discussion

This chapter presents a new clustering based cooperative protocol for heterogeneous WSNs. In the protocol we consider nodes with different battery energy which is a source of heterogeneity. We proposed an optimized routing scheme for WSNs. The main focus was to enhance cluster head selection process. In proposed protocol, cluster heads are selected in each cluster by a probability based on the ratio between cooperative energy (takes both CSI and REI into account) of node and the average energy of the network. From the simulation results, following conclusions can be drawn:

- There is less number of dead nodes compared to the other routing protocols.
- Number of live nodes is enhanced.
- The throughput of the proposed protocol is significantly greater as compared to other protocols, the proposed clustering approach is more energy efficient and hence effective in prolonging the network life time and balance energy consumption compared to other protocols.

5. IMPROVED CLUSTER HEAD SELECTION FOR ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS

5.1 Motivation

Most of pervious works on extending lifetime, protocols concentrate on distributed energy-efficient clustering algorithm for homogenous and heterogeneous wireless sensor networks which are based on clustering, most of them the cluster- heads are selected depend on one of the following: random probability and it is does not consider about energy consumption of nodes, maximum residual energy, the current location of the node, the distance vector from the base station (BS). The optimal construction of clusters is very important. However, the previous research works have proved significant potential of showing that if the clusters are not constructed in an optimal way, the total consumed energy of the sensor network per round is increased exponentially either when the number of clusters that are created is greater or especially when the number of the constructed clusters is less than the optimal number of clusters. It is noticed that using distance limit determination in WSNs should not be too low neither too much. If it is too low, then each node would be associated with a small number of neighbors. In this case, the node is more likely to have the highest level of residual energy compared to all of its neighbors and thus it is more likely to be selected as a CH. This could eventually result in a large number of CHs which can cause collisions and redundancy when CHs aggregate the collected data and forward it towards the BS. On the other hand if the distance too high, then each node would be associated with many neighbors and this gives the node a lower chance to be selected as a CH. Therefore, the value of the distance which produces a desired number of CHs should be selected. In our proposed protocol, two scenarios should be taken into account, the data transmission between nodes, and that between the node and the BS. The energy dissipation due to channel transmission is remarkably affected by the distance, and the network lifetime is strongly related to the nodes residual energy level and the optimal number of cluster head in the network. In the other hand, many algorithms are recently proposed to increase stability and lifetime of heterogeneous WSNs. Every algorithm does not work efficiently for different networks having different heterogeneity levels and fails to maintain the same stability period and lifetime as in previous heterogeneous WSNs. In literature most existing studies focus on the performance of the above schemes taking into account one or two parameters. Thus, on the design of cost functions, all of these factors should be taken into account and reflected in the expressions. In our study, we investigate the performance of system that combines tightly to gather. In particular, we introduce a new method in determining the neighbors of each node to be used in CH selection while ensuring that the network has a desired optimal number of CHs. Moreover, we propose to use the number of members that belong to a CH to balance the sizes of clusters and hence, the loads and energy consumptions among CHs, besides residual energy, distance, heterogeneous and optimal number of cluster head parameters are also incorporated in the determination of single- hop routing paths between CHs and the BS to balance the load among CHs. We propose and evaluate a new distributed energy-efficient clustering scheme for heterogeneous wireless sensor network with new cost function protocol by modifying the selection of cluster head. Simulation results show that proposed protocol consumes less energy and performs better as compared to others.

Table 5.1 compares several clustering-based schemes proposed for heterogeneous WSNs with respect to their cluster head selection process. As seen from the table, most of the studies take at most two parameters into account.

Table 5.2. Compares the various clustering protocols on discussed on pervious literatures on various points, clustering method, CH rotation, energy factor. As shown in table 5.2, each of these protocols uses one of cluster head selection criteria and considers some properties for its cluster. All of these protocols use single-hop communication. It is observed that, clustering algorithms without energy awareness, CH cannot be rotated, and loads cannot be shared. Therefore it is difficult for sensors to choose the most appropriate cluster heads to maximize their network lifetime.

Table 5.1. Comparison of CH selection in WSN protocols

Clustering approach	Clustering method	CH selection based on		
		Initial Energy	**Residual Energy**	**Average Energy of Network**
EEHC	Distributed	□	√	□
DEBC	Distributed	□	√	√
WEP	Distributed	√	□	□
DEEC	Distributed	□	√	√
DDEEC	Distributed	√	√	□
SDEEC	Distributed	√	√	□
TDEEC	Distributed	□	√	□
DCHE	Distributed	√	□	□

5.2 System Model

In this study, we use a radio energy dissipation model given in Figure 3.1. Here, L bit data packets are transmitted to a receiver (Rx) located at a distance d from the transmitter (Tx). E_{elec} is the amount of energy needed in Tx or Rx hardware to send or receive data. Due to path loss and multipath fading phenomena that occur in wireless channels, Tx is equipped with an amplifier. The amplifier has a gain of $\varepsilon L d^{\alpha}$ where α denotes the path loss exponent. Note that the value of the path loss exponent is between 2 and 4 in general.

To transmit L-bit message to a distance d:

$$E_{Tx}(L,d) = \begin{cases} LE_{elec} + L\varepsilon_{fs} d^2, & d \le d_0 \\ LE_{elec} + L\varepsilon_{mp} d^4, & d \ge d_0 \end{cases} \tag{5.1}$$

where ε_{fs} is the amplifier energy per bit per square meter (m^2) when free space model is used for the channel and ε_{mp} is the amplifier energy per bit per m^4 when multipath propagation model is used. The threshold distance d_0 in (5.1) is given by

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (5.2)$$

Table 5.2. Comparison of Cluster Head Selection Algorithms:

Clustering Approach	CHs Selection	CH Rotation	Energy Factor	Prolong Network Lifetime	Predictability
LEACH	Prob/random	Yes	No	Yes	No
ACW	Back off	Yes	No	Yes	No
CIPRA	ID-Based	Yes	No	Yes	No
ERA	Prob/random	Yes	Yes	Yes	No
C-LEACH	Average Energy	Yes	Yes	Yes	No
EECHSSDA	Average Energy	Yes	Yes	Yes	No
HEED	Prob/Energy	Yes	Yes	Yes	No
Extended HEED	Prob/Energy	Yes	Yes	Yes	No
HEF	Residual Energy	Yes	Yes	Yes	Yes

and is set to 87m in this study. Similarly, at the Rx side:

$$E_{Rx} = LE_{elec} \quad (5.3)$$

Since transmitting a message is a costly operation in wireless channels, protocols used in WSNs should try to minimize not only the transmit distances but also the number of transmit and receive operations for each message.

5.3 Optimal Clustering:

We assume that N nodes are uniformly distributed over a square field (D x D). The square field has an area of D^2 square meters and the BS is located at the center of the field for simplicity. The field is divided into K sub regions, clusters. For each cluster, one node is assigned as the cluster head. During transmission, each non-cluster head (non-CH) node sends L bit data to the CH node within its cluster. Thus, the energy used by a non-CH node is [113]:

$$E_{non-CH} = LE_{elec} + L\varepsilon_{fs} d_{CH}^2 \tag{5.4}$$

where d_{CH} is the average distance between a cluster member and its corresponding CH [72]:

$$d_{CH}^2 = \frac{D^2}{2\pi K} \tag{5.5}$$

Similarly, the energy dissipated in a CH is given by

$$E_{CH} = \left(\frac{N}{K} - 1\right) LE_{elec} + \frac{N}{K} LE_{DA} + LE_{elec} + L\varepsilon_{fs} d_{BS}^2 \tag{5.6}$$

where E_{DA} is the data aggregation processing cost and d_{BS} is the average distance between a CH and the BS given by [113]:

$$d_{BS} = 0.765 \frac{D}{2}$$

The total energy dissipated during one round is

$$E_{round} = L(2NE_{elec} + NE_{DA} + \varepsilon_{fs}(Kd_{BS}^2 + Nd_{CH}^2)) \tag{5.7}$$

If we know E_{round} , we may estimate the average energy

$$\bar{E}_r = \frac{E_{total} - rE_{round}}{N} \tag{5.8}$$

Where $E_{total} = \sum_{i=1}^{N} E_i$ is the initial energy of all the nodes E_i is the i^{th} node energy. E_{round} is the single round energy consumed, let single round energy consumed to be uniform. On above condition, we may estimate $\bar{E}_r$.

By differentiating E_{round} with respect to K and equating to zero, the optimal number of clusters is found to be [113], [72]:

$$K_{opt} = \sqrt{\frac{N}{2\pi}}\frac{D}{d_{BS}} = \sqrt{\frac{N}{2\pi}}\frac{2}{0.765} \tag{5.9}$$

If a significant percentage of nodes are farther away from the BS (a distance greater than d_0), then the optimal number of clusters is given by [113]

$$K_{opt} = \sqrt{\frac{N}{2\pi}}\sqrt{\frac{\varepsilon_{fs} D}{\varepsilon_{mp} d_{BS}^2}} \tag{5.10}$$

The optimal probability of a node being selected as a CH is computed as [113]

$$p_{opt} = \frac{K_{opt}}{N} = \frac{1}{0.765}\sqrt{\frac{2}{N\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{5.11}$$

The quantity p_{opt} plays an important role in the operations of WSNs. If the clusters are not constructed in an optimal way, the total energy consumed during a round will increase in a nonlinear fashion.

5.4 Proposed Protocol:

It is noticed that in LEACH the selection strategy of cluster head nodes does not take into account the residual energy factor, distance from base station and therefore easily results in the cluster head nodes deactivate. Additional parameters should be considered to optimize the process of cluster-head selection and to enhance energy load distribution over the whole network. Our attention is focusing to improve the selection of cluster head by adjusting the threshold T(n) denoted in [13], relative to the nodes remaining energy, distance of the nodes from the base station and the number of consecutive rounds in which a node has not been a cluster head and the cluster formation algorithm is created to ensure that the expected number of clusters per round is K_{opt}. As has been discussed before, the energy dissipation due to channel transmission is remarkably affected by the distance, and the network life time is strongly related to the nodes residual energy level. The cluster head consumes more energy than other nodes in the round. Thus the location and residual energy of node with respect to optimal number of cluster head are introduced during the generation of cluster head to balance the energy consumption of all nodes in every cluster for prolonging the lifetime of network. Thus, on the design of cost functions, all of these factors should be taken into account and reflected in the expressions.

In our work, the following cost function is employed.

$$C(i) = \frac{d(i)}{E(i)} K_{opt} \tag{5.12}$$

The motivations of the new cost function (5.12) are given in the following:

- $d(i)$ is the distance from node *i* to the BS. This factor checks whether the node to be selected as cluster head belongs to the density popular area as well as the distance from the node to the BS is minimum.
- $E(i)$ is the residual energy accounting for whether the node to be selected as cluster head has maximum residual energy.
- K_{opt} is the optimal number of cluster heads. This factor guarantees the selection of cluster heads of each round is optimal.

- With this new cost function, we claim that cluster head selection process is done in a very energy efficient manner. Considering all three factors, the modified threshold T(n) becomes:

$$T(n) = \begin{cases} \dfrac{p}{1 - p(r \bmod \left(\dfrac{1}{p}\right)} (C(i)), & \text{if } n \in G \\ 0 & \text{, otherwise} \end{cases} \tag{5.13}$$

Where P is the cluster head probability, r is the number of the current round and G is the set of nodes that have not been cluster-heads in the last 1/P rounds. In order to select cluster heads each node n determines a random number between 0 and 1. If the number is less than the threshold T (n), the node becomes a cluster-head for the current round. Using this threshold, each node will get a chance to be cluster head that have not been cluster-heads in the last 1/P rounds. Thus, the new approach selects the optimized node as cluster head node which has minimal cost function in terms of the above mentioned three factors.

5.5 SIMULATION RESULTS:

The performance of the proposed clustering-based protocol is evaluated using MATLAB both for homogeneous and heterogeneous networks. In the network, 100 nodes are randomly deployed in a 100m x 100m region where the BS is located at the center as illustrated in Figure 3.3.

The proposed algorithm is compared with LEACH, DEEC, and SEP in terms of dead and alive nodes per round, energy consumption of the network, and overall throughput. The total number of rounds used in our experiments is 5000.

Network model parameters are summarized in Table 5.3.

Table 5.3. Network model parameters

Parameter name	**Value**
E_0	0.5 J
Packet size	4000 bits
Number of nodes	100
$E_{tx} = E_{rx}$	50 nJ/bit
E_{fs}	10 pJ/bits/m^2
E_{mp}	0.0013 pJ/bits/m^2
E_{DA}	5 nJ
Area of network	100*100

Here all nodes have different amount of initial energies. The initial energies are uniformly distributed on [0.5, 1] resulting the average initial energy of 0.75 J. Several experiments are conducted, the average stability periods are calculated, and the results are shown in Figures 4, 5, 6 and 7.

Figure 5.1shows the number of dead nodes per round indicating stability time of the networks. The death of the first node occurs at the round 1869 in the proposed protocol whereas the death of the first node occurs at rounds 1036, 1382, 1482 in LEACH, DEEC and SEP respectively. The death of the last node occurs at the round 3707 in the proposed protocol whereas the death of the last node occurs at rounds 2626, 2691, 2047 in LEACH, DEEC and SEP respectively. Hence, the proposed protocol has better stability time and network lifetime as compared to the other protocols.

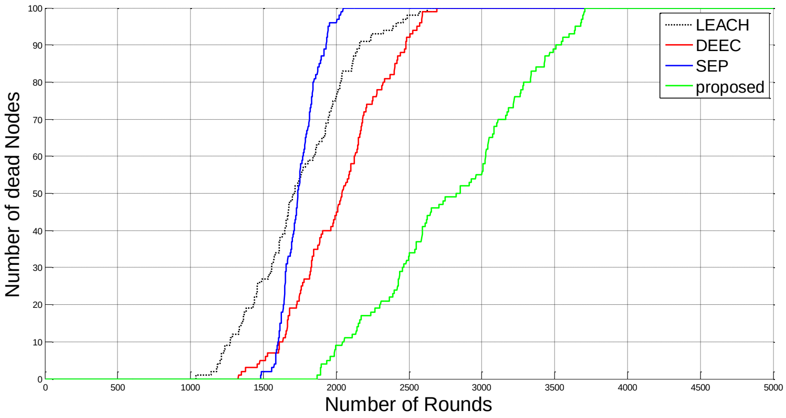


Figure 5.1. Number of dead nodes per round

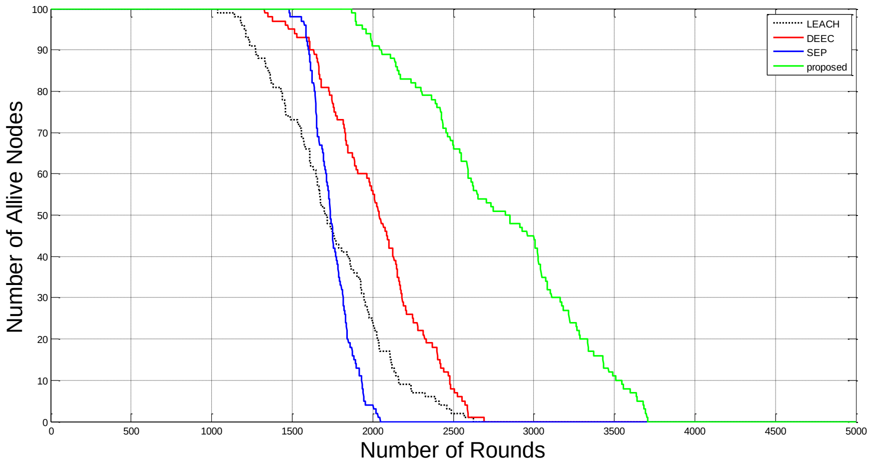


Figure 5.2. Total number of live nodes in each round

The proposed protocol has also better energy comsumption and higher throughput than the other protocols considered which can be seen from the Figure 5.2 and Figure 5.3. Initial energy E_0 of the network is consumed at the round 3600 in the proposed protocol whereas the initial energy E_0 of the network is consumed at rounds 2300, 2350, 2100 in LEACH, DEEC and SEP respectively. Similarly, Figure 5.4shows the superiority of the proposed algorithm in terms of the throughput thanks to the wiser selection of CHs.

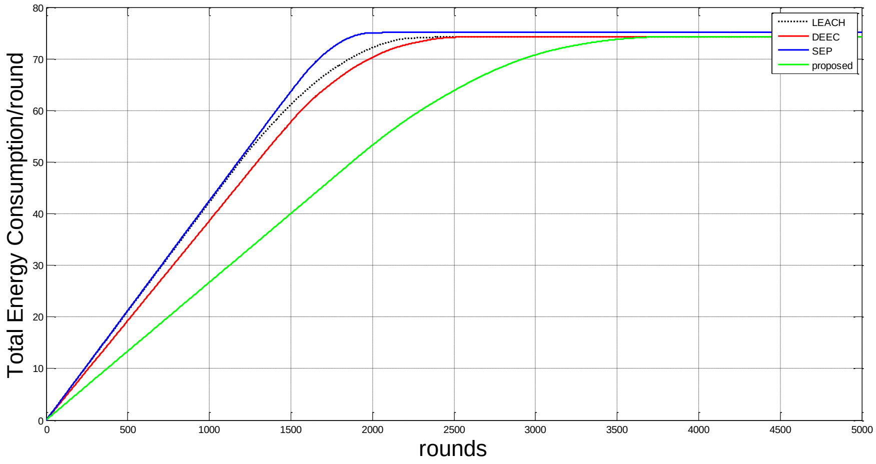


Figure 5.3. Energy consumption

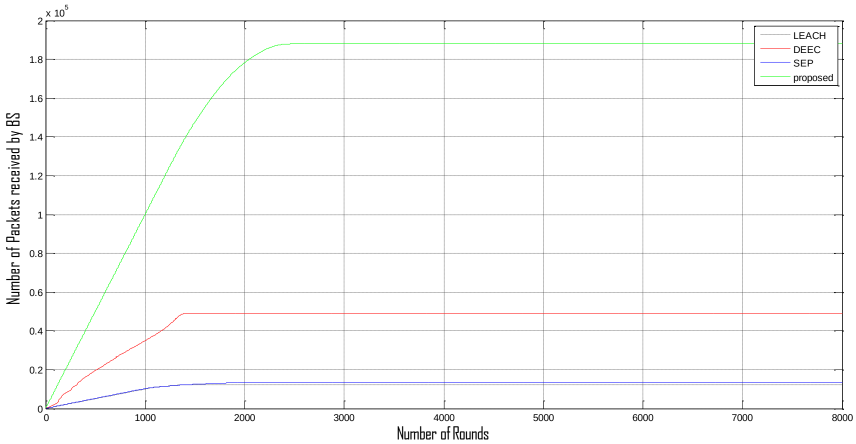


Figure 5.4. Throughput

5.6 Results and Discussion

This chapter presents a new clustering-based protocol for heterogeneous WSNs. Heterogeneity of the network comes from nodes with different energy levels. The lifetime and reliability of the network can be improved by heterogeneity. Further, a single-hop transmission approach is adopted for intra-cluster and inter-cluster communication.

Formation of clusters and selection of cluster heads are very important tasks in clustering-based schemes affecting energy efficiency of the network. CHs require more energy than all other nodes because they perform processing, sensing, communication and aggregation. Hence, they die earlier and if so, the entire network becomes useless. We propose an optimized routing scheme where the main focus is to enhance cluster head selection process. CHs are selected in each cluster on the basis of residual node energy and the distance with respect to the optimal number of cluster heads. From the conducted experiments, it is seen that:

Stability period of the network is enhanced compared to the other well-known clustering-based protocols including LEACH, DEEC and SEP. Superior network lifetime is obtained for different scenarios. Last but not least, the throughput of the proposed protocol is significantly better than the other protocols considered. Thus, the proposed protocol improves energy efficiency of the network and prolongs the network lifetime

6. MULTI-HOP EFFICENT PROTOCOL FOR ZIGBEE, BLUETOOH LOW- ENERGY AND ANT SENSOR NODES

6.1 Motivation

Wireless Sensor Networks (WSNs) have been used for many applications. Typically, a WSN consists of a number of sensing nodes that gather data from the surrounding environment and deliver it to a Base Station (BS). Each sensor node has limited computation capability and limited amount of energy. It is difficult or even improbable to replace a node’s battery, especially in areas that cannot be linked easily. Therefore, reducing network’s energy consumption is one of the basic challenges in developing routing techniques for WSNs. Furthermore, fast energy exhaustions in some nodes might cause network divisions and shorten network lifetime. Hence, balancing energy consumption among the nodes is another problematic cause to be considered. This paper deals with above challenges by considering energy-efficient routing techniques. In WPANs, sensor nodes are operated with limited energy source. It is required to use minimum power for transmitting data from sensor nodes to BS. One of the major disadvantages of WPAN is be difficultly to recharge the batteries. An energy efficient routing protocol is required to overcome this issue of recharging batteries. Many energy efficient routing protocols are proposed in WSN technology [114], [115], [116].

For the majority of the embedded electronics industry, the trend towards extremely low power technology is based on the use of batteries as the prime power source. Extremely low power technology, therefore, is synonymous with battery power and, in today’s applications, this typically translates to single or dual cell supplies comprising of a coin cell battery. The nodes stay usable unless the voltage of batteries go below 2.5, most devices operate with voltages within a range of 2-3 volt.

Many routing protocols can improve the performance of energy efficiency and network lifetime by introducing intelligent clustering methods for considering energy, rang etc. however, most of these energy efficient routing protocols used dynamic cluster heads. The communication range of sensor nodes is based on

IEEE 802.15.4(WPAN) which is one of the transmission standards for WSNs. IEEE 802.15.4 typically extends up to 10 m in all directions [117].

In this section, we present a multi-hop protocol to solve the energy usage for sensor nodes; in this study we don't consider a cluster head, each sensor node contains information about the location of BS, distance between them, distance to the BS node, residual energy. Thus each node can make intelligent decision about the next hop (forwarder) based on the maximum residual energy and minimum distance in the sensor network.

6.2 Network Model

In this section, we use a radio energy dissipation model given in Figure 3.1.

$$E_{Tx}(L,d) = E_{Tx-elec}(L) + E_{Tx-amp}(L,d)$$

$$E_{Tx}(L,d) = E_{Tx-elec} \times L + E_{Tx-amp} \times L \times d^4 \qquad (6.1)$$

$$E_{Rx}(L) = E_{Rx-elec} \times L \qquad (6.2)$$

Where E_{Tx} is the energy consumed in transmission, E_{Rx} is the energy consumed by receiver, $E_{Tx\text{-}elec,}$, $E_{Rx\text{-}elec}$ are the energies required to run the electronic circuit of transmitter and receiver, respectively. The energy parameters given in equations (1and 2) depend on the hardware. We consider that three transceiver technologies are used frequently in WPAN technology. The BLE node CC 2450 chip (Texas Instrument), AP2 transceiver modules (Nordic Semiconductor) were used for ANT, and the other transceiver is ZigBee. The operating frequencies of these transceivers are 2.4 GHz. Some of the characteristics of these RF modules are given in Table 6.1.

The power attenuation is depending on the distance between the transmitter and receiver; the propagation loss can be modeled as inversely proportional to d^2 (free space model for short distances) or to d^4 (multi path model for longer distances). In this study we used the multipath fading model (d^4), since the system will be used indoor causing multipath problem.

From the parameters given in Table 6.1 we can find the radio energy parameters, the transmit energy per bit is given by:

$$E_{Tx-amp} = \frac{P_t}{R_b} \tag{6.3}$$

TABLE 6.I: CHARACTERISTICS OF RF MODULES

Transceiver	ZigBee	BLE	ANT
Rx sensitivity	-102 dB	-87 dB	-85 dB
Tx Power	0 dBm	0 dBm	0 dBm
Frequency	2.4 GHz	2.4 GHz	2.4 GHz
Radio Chip	X BeeS2	CC 2450	AP2
Bit rate	250 kb/s	250 kb/s	250 kb/s
Packet size	100 byte	100 byte	100 byte
Number of nodes	8	8	8
Initial energy of node (E_0)	0.5	0.5	0.5
E_{TX-amp}	4 nJ/bit	4 nJ/bit	4 nJ/bit
ε_{mp}	0.049 pJ/b/m^4	1.57 pJ/b/m^4	2.5 pJ/b/m^4
Propagation model	Two ray ground (multi-path)	Two ray ground (multi-path)	Two ray ground (multi-path)
Node type	Homogenous	Homogenous	Homogenous
power supply	3.3 V	3.3 V	3.3 V

$$\varepsilon_{mp} = \frac{P_r}{R_b\ G_t\ G_r\ h_t^2\ h_r^2} \tag{6.4}$$

where ε_{mp} is the energy require for the amplifier circuit, this parameter will depend on the required receiver sensitivity and the receiver noise figure, as the transmit power needs to be adjusted that the power at the receiver is above a certain threshold, where P_r is the sensitivity of the receiver, G_t is the gain of a transmitting antenna, G_r is the gain of a receiving antenna, λ is the wavelength of the carrier signal, h_t is the height of the transmitted antenna above the ground and h_r is the height of the received antenna above the ground. In simulations following values are given ($G_t = G_r = 1, h_t = h_r = 1.5$ m, $R_b = 250$ Kbps) into equations 3 and 4 given in Table 6.1.

6.3 Proposed Protocol

In this section, we present a new routing protocol for WPANs. The limited number of nodes in WPANs give opportunity to ease the constraints in routing protocols. We improve the network stability period and throughput of the network. Following sections give the details of the system model and proposed protocol. In this scheme, we deploy eight sensor nodes on region under the assumption that there can be at most 8 sensors in a personal area network. All sensor nodes consume equal energy and have similar computation capabilities. BS is placed at the center of the square region. Fig 6.2 shows the placement of eight nodes and BS in square region (50 x 50 m).

Next, we present a selection criterion for a node to become primary node or forwarder. To balance energy consumption among sensor nodes and to reduce energy consumption of the network, our proposed algorithm selects a new forwarder in each round.

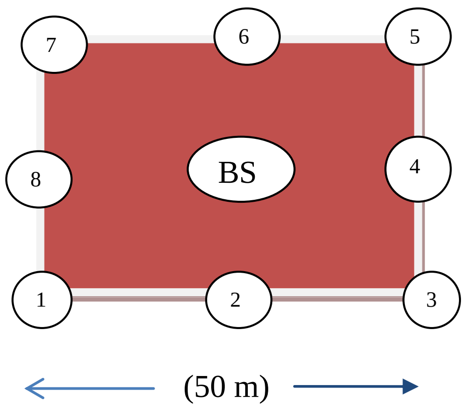


Fig. 6.1: An illustration of the network

BS node knows the ID, distance and residual energy status of the nodes. BS computes a cost function for all. other nodes need to know these costs. On the basis of this cost function, each node decides whether to become a forwarder node or not. For a given node i the cost function is computed as follows:

$$C(i) = \frac{d(i)}{\mathrm{Re}\,(i)} \tag{6.5}$$

where $d(i)$ is the distance between the node i and the BS, $\mathrm{Re}\,(i)$ is the residual energy of node i. A node with minimum cost function is preferred as a forwarder. All neighbor nodes stick together with forwarder node data is aggregated and forwarder to the BS. Forwarder node has maximum residual energy and minimum distance to BS; therefore, it consumes minimum energy to forward data to the BS.

6.4 Path Loss Model

Path loss represents the signal attenuation and is measured in decibels (dB). Signal power is also degraded by Additive White Gaussian Noise (AWGN). Path loss is the difference between the transmitted power and the received power. Path loss usually occurs due to the increasing surface area of propagating wave front. Transmitting antenna radiates power outward and any object between the transmitter and the receiver causes attenuated of the radiated signal. Path loss is related to the distance and frequency and expressed as:

$$PL(f,d) = PL(f) \times PL(d) \tag{6.6}$$

The propagation model including both path loss model and long-normal shadowing are used in our simulations. In this model, the received power at distance*d* ($P_r(d)$) is represented by:

$$[P_r(d) / P_r(d_0)]_{dB} = -10\, n \log_{10}\left(\frac{d}{d_0}\right) + X_{dB} \tag{6.7}$$

Where $P_r(d_0)$ is the received power at a reference distance and it is expressed as:

$$P_r(d_0) = 10 \log_{10} \frac{(4\,\pi \times d \times f)^2}{c} \tag{6.8}$$

where f is the operating frequency, c speed of light, d is the distance between the transmitter and receiver. The value of the reference distance d_0 is 0.1 m, n is the path loss exponent, and X_{dB} is a zero-mean Gaussian random variable representing the shadowing. In our simulations, the path loss exponent is set to 4 and the shadowing deviation is set to 7.4. This corresponds to a harsh environment with many obstacles [118].

6.5 Simulation Results

To evaluate the proposed protocol, we have conducted an extensive set of experiments using MATLAB with three transceiver modules. For the simplicity an ideal MAC layer and error free communication links are assumed. We calculate each nodes energy consumption from data transmission per round. According to the IEEE 802.15.4 standard, the length of data packet is 800 bits and is assumed to be constant before and after data fusion. The simulations are run to compare the average energy dissipation in each round before the first node dies, and to compare the number of communication rounds before a certain percentage of nodes die with different protocols.

Table 6.2 shows the average network uptime of the proposed scheme. The proposed new cost function to select a forwarder node plays an important role to balance the energy consumption among the sensor nodes. New forwarder in each round is selected based on computed cost function. Table II clearly depicts the average number of dead nodes per round indicating the stability time of the networks. The death of the first node occurs at the round 2962 in ZigBee whereas the death of the first node occurs at rounds 94 and 59 in BLE and ANT, respectively. The death of the last node occurs at the round 7676 in ZigBee protocol whereas the death of the last node occurs at rounds 255and 160 in BLE and ANT, respectively. Hence, ZigBee protocol has better stability time and network lifetime as compared to the other protocols.

A. Throughput

The throughput is defined to be the rate of successful packet received at the BS. WPAN has data to send, requires a protocol which has minumum packet drop and maximum successful data received by BS. ZigBee protocol achieves a higher throughput level than BLE and ANT protocols, as shown in Fig. 6.3. The average number packets send in eah round to BS depends on the number of alive nodes. More alive nodes send more packets to BS which increases the throughput of network. The stability period for both ANT and BLE protocols are shorter than the ZigBee protocol implying that packets sent to BS are decreased. On the other hand, ZigBee protocol achieves high throughput due to longer stability period.

TABLE 6.2: The round when first and last node dies

Protocol	ZigBee	BLE	ANT
First dead node (round)	2962	94	59
All dead node (round)	7696	255	160

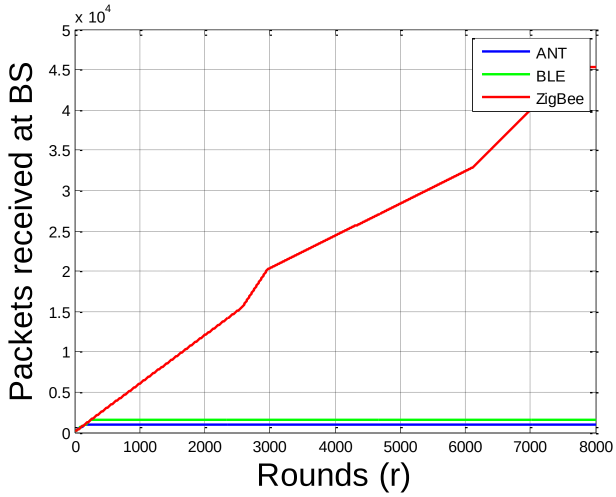


Fig. 6.2: Throughput

B. Residual Energy

The average energy of the network consumed at each round is presented in Fig. 6.4. The proposed scheme uses multi-hop topology, in which farthest node transmits its data to BS through a forwarder node. Forwarder node is selected using a cost function. Selection of the most appropriate forwarder in each round contributes to save energy. To transfer packets to BS, our multi-hop topology use different forwarder node in each round. Simulation results show that ZigBee protocol consumes minimum energy among BLE and ANT protocols. It means, in stability period, more nodes have enough energy and they transmit more data packet to BS.

C. Path Loss

Fig. 6.5 presents the path loss of different sensors. Path loss is afunction of frequency and distance. Path loss shown in Fig 6.5 is a function of distance. It is calculated from its distance to BS with constant frequency 2.4 GHz. We use path loss coefficient 4 and 7.4 for standard deviation.

Path loss for BLE and ANT protocols are almost the same, but the ZigBee protocol has more path loss than the others due to the fact that the nodes in ZigBee need more time to die .

6.6 Results and Discussion

In this chapter, we propose a new algorithm to route data in WPANs. The proposed scheme uses a cost function to select the appropriate route to BS. Cost function is calculated based on the residual energy of nodes and their distance from BS. In this paper we analyzed the lifetime, throughput, energy consumption and the path loss for the ANT, ZigBee, and BLE protocols. We found that ZigBee protocol yield a longest lifetime, throughput and lowest energy consumption, followed by BLE and ANT.

The results of this study should not be generalized to other scenarios. Furthermore, the lifetime, throughput, energy consumption and path loss of theses protocols might changes depending on other factors such as packet size variations, transmitter and receiver distances.

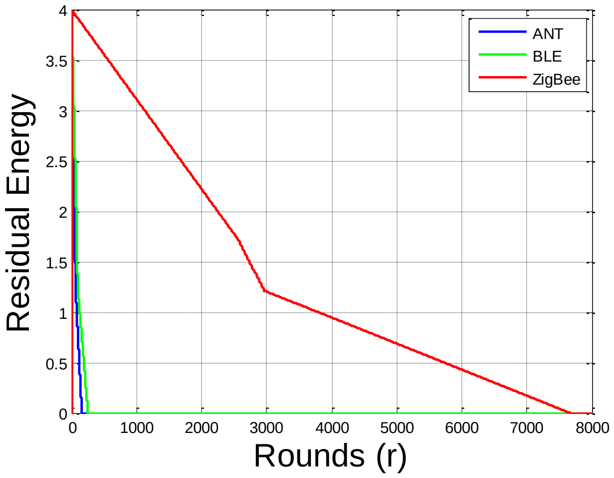


Fig. 6.3: Energy consumption

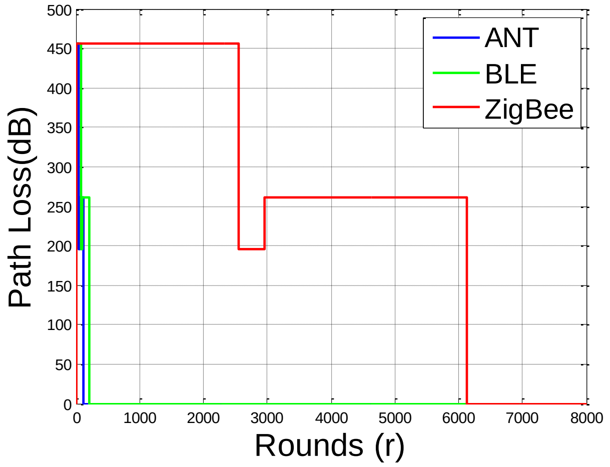


Fig. 6.4: Network Path Loss

7. **CONCLUSIONS AND FUTURE WORK**

In this thesis, we proposed a new clustering protocols for WSNs. Our objectives is prolong the network lifetime of WSNs by reducing and balancing energy consumption during routing process from cluster head selection and optimal number of cluster head point of view. These techniques imply better distribution of cluster heads in the network.

In chapter 3, We proposed a new clustering-based energy-efficient (EE) protocol for single-hop, heterogeneous WSNs. In EE-Heterogeneous LEACH, CHs are selected by using weighted probabilities. These weighted probabilities are evaluated based on the ratio between residual energy and the best channel of each node and average energy of the network. The rotating epoch (time interval) for each node is different according to its initial and residual energy. Nodes with high initial and residual energy will be more likely to become CHs per round per epoch. CHs collect data from member nodes in their respective clusters, aggregate the received data and send it to the BS using single-hop communication.

Simulation results show that the proposed protocol extends network lifetime and improves energy consumption compared to other well known protocols including LEACH, DEEC, and SEP.

In chapter 4, we developed a new distributed clustering protocol for heterogeneous WSNs, namely cooperative protocol, based on decode-and-forward (DF) cooperative communication. In this protocol, both CSI and REI are taken into consideration to select the source and relay nodes in a cooperative mode. Under the constraint of maximum transmission power, the optimal power allocation scheme is formulated to satisfy the average BER requirement. Simulation results show that cooperative protocol can largely improve network lifetime compared with the non-cooperative schemes such as minimum residual energy, random selection. Through simulation results, we can see that with the same average BER constraint the lifetime performance of BPSK is much better QAM and other modulation schemes.

In chapter 5, we improved an optimized routing scheme where the main focus is to enhance cluster head selection process. Due to the fact the factor of number of optimal cluster plays an important role on many network metrics such as energy consumption, CHs are selected in each cluster on the basis of residual node energy and the distance with respect to the optimal number of cluster heads. CH independent of other region. This technique encourages better distribution of CHs in the network. Simulation results show that the throughputs of the proposed protocols are significantly better than the other protocols considered. Thus, we claim that the proposed protocols have improved energy efficiency and effective in prolonging the network lifetime.

In chapter 6, we proposed a mechanism to route data for multi-hop communication in WPANs. The proposed scheme use a cost function to select appropriate route to the BS. Cost function is calculated based on the residual energy of node and its distance from the BS. Nodes with less value of cost function are selected as forwarder node, other nodes send their node to the forwarder node. Our simulation results shows that proposed routing scheme enhance the network stability time and packet delivered to the BS.

The protocols discussed in this thesis have individual advantages and disadvantages. Based on the topology, the protocol and routing strategies can be applied. The factors affecting cluster formation and communication were presented in this thesis for single-hop communication, we want extend our works for multi-hop communication for future research. Moreover, the process of data aggregation and fusion among clusters is also an interesting problem to explore. For realization of sensor networks, it is needed to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, topology change, environment, and power consumption. Since these constraints are stringent and specific for sensor networks, new wireless networking techniques are required to be explored further. Through the performance of the protocols discussed in this thesis promising in terms of energy consumption, further research would be needed to address issues related to quality of serves posed by video and imaging sensors and real-time applications.

References

[1] Vinery Kumar, Sanjeev Jain and Sudarshan Tiwari, "Energy Efficient Clustering Algorithm in Wireless Sensor Networks A survey ", IJCSI International Journal of Computer Science Issues, Vol.8, Issue 5, No 2, September 2011.

[2] M. Weiser, "The computer for the twenty-first century," Scientific American, 265(3), 1991, pp.94-104.

[3] D. Estrin, R. Govindan, J. Heidemann and S. Kumar, "Next century challenges: scalable coordination in sensor networks," Proc. IEEE/ACM MobiCom Conference, 1999, pp.263–270.

[4] D. Estrin, L. Girod, G. Pottie and M. Srivastava, "Instrumenting the world withwireless sensor networks," Proc. International Conference on Acoustics, Speech, and Signal Processing, 2001, pp.2033–2036.

[5] J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler and K. Piste, "System architecture directions for network sensors," Proc. International Conference on Architectural Support for Programming Languages and Operating Systems, 2000.

[6] G. J. Pottie and W. J. Kaiser, "Wireless Sensor Networks," Communications of the ACM, vol. 43, May 2000, pp.51–58.

[7] H. Qi, S. Iyengar, K. Chakrabarty, "Distributed Sensor Networks- a review of recent research," Journal of the Franklin Institute, vol. 338, 2001, pp.655–668.

[8] L. Schwiebert, S.D.S. Gupta and J. Weinmann, "Research challenges in wireless Networks of biomedical sensors," Proc. IEEE/ACM MobiCom, 2001,pp.151–165.

[9] S. Tilak, N. B. Abu-Ghazaleh and W. B. Heinzelman, "A taxonomy of wireless micro-Sensor network models," ACM Mobile Computing and Communications Review, 6(2), 2002.

[10] Chee-Yee Chong and Kumar, S.P. "Sensor Networks: Evolution, opportunities,and challenges," in the Proceedings of IEEE, August 2003.

[11] A. Arora, et al. "A line in the sand: a wireless Sensor Network for target detection, classification, and tracking," Computer Networks, 46(5):605-634, 2004.

[12] J. Deng, Y. S. Han, W. B. Heinzelman, and P. K. Varshney, "Scheduling Sleeping Nodes in High Density Cluster based Sensor Networks," ACM/Kluwer Mobile Networks and Applications (MONET) Special Issue on Energy Constraints and Lifetime Performance in Wireless Sensor Networks, 2005.

[13] Yun Wang, Demin Wang, Weihuang Fu, and Dharma P. Agrawal, "Hops based Sleep Scheduling Algorithm for Enhancing Lifetime of Wireless Sensor Networks," Proc. of IEEE International Conference on Mobile Ad hoc and Sensor Systems (MASS), Canada, 2006, pp.709-714.

[14] Xiaoling Wu, Jinsung Cho, Brian J. d'Auriol, and Sung young Lee, "Sleep Nodes Scheduling in Cluster-based Heterogeneous Sensor Networks Using AHP," Proc. of the International Conference on Embedded Software and System, May 2007.

[15] M. Dong, K.Yung, and W. Kaiser, "Low Power Signal Processing Architectures for Network Microsensors," in the Proceedings of International Symposium on Low Power Electronics and Design, August 1997, pp.173-177.

[16] K. Akkaya, M. Younis, "A Survey on Routing Protocols for Wireless Sensor Networks," Elsevier Ad Hoc Network Journal, vol 3, 2005, pp.325-349.

[17] Al-Karaki, J. N. and A. E. Kamal, "Routing Techniques in Wireless Sensor Networks: A Survey," IEEE Wireless Communications, 11(6), Dec., 2004.

[18] W. Ye, J. Heidemann, and D. Estrin, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks," in the Proceedings of the 21st International Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM), New York, 2002.

[19] J. Razavilar, F. Rashid-Farrokhi and K. Liu, "Software Radio Architecture with Smart Antennas: A Tutorial on Algorithms and Complexity," IEEE Journal on Selected Areas in Communications, 17(4):662-676, April 1999.

[20] G. G. Finn, "Routing and addressing problems in large metropolitan-scale Inter networks," USC ISI Report ISI/RR-87-180, 1987.

[21] M. Dong, K.Yung, and W. Kaiser, "Low Power Signal Processing Architectures for Network Microsensors," in the Proceedings of International Symposium on Low Power Electronics and Design, August 1997, pp.173-177.

[22] D. Hall, “Mathematical Techniques in Multi sensor Data Fusion,” Artech House, Boston, MA, 1992.

[23] L. Klein, “Sensor and Data Fusion Concepts and Applications,” SPIE Optical Enginnering Press, WA, 1993.

[24] S. Lindsey, C. S. Raghavendra and K. Sivalingam, “Data Gathering in Sensor Networks using the Energy*Delay Metric,” in the Proceedings of the IPDPS Workshop on Issues in Wireless Networks and Mobile Computing, San Francisco, CA, April 2001.

[25] Yan Yu, Ramesh Govindan and Deborah Estrin, “Geographical and Energy Aware Routing: a recursive data dissemination protocol for wireless sensor networks,” UCLA Computer Science Department Technical Report UCLA/CSD-TR-01-0023, May 2001.

[26] Wensheng Zhang; Guohong Cao; La Porta, T, “Data dissemination with ring based index for wireless sensor networks,” in the Proceedings of the 11th IEEE International Conference on Network Protocols, Nov. 2003.

[27] K. Kalpakis, K. Dasgupta and P. Namjoshi, “Maximum lifetime data gathering and aggregation in wireless sensor networks,” in the Proceedings of IEEE International Conference on Networking (NETWORKS '02), Atlanta, GA, August 2002.

[28] K. Dasgupta et al., “An efficient clustering-based heuristic for data gathering and aggregation in sensor networks,” in the Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC’03), New Orleans, Louisiana, March 2003.

[29] Jamal N. Al-Karaki, A.E. Kamal, “On the Correlated Data Gathering Problem in Wireless Sensor Networks,” in the Proceedings of the 9th IEEE Symposium On Computers and Communications, Alexandria, Egypt, July 2004.

[30] A. Perrig, R. Szewzyk, J.D. Tygar, V. Wen, and D. E. Culler, “SPINS: security protocols for sensor networks,” Wireless Networks, Vol (8), 2000, pp.521-534.

[31] Karlof, C. and Wagner, D., “Secure Routing in Wireless Sensor Networks: Attacks and Countermeasures,” in the Proceeding of the first IEEE International Workshop on Sensor Network Protocols and Applications (SPNA), AK, USA, May 2003, pp.113-127.

[32] Lee, S.B; Choi, Y.H, “A secure alternate path routing in sensor networks,” Computer Communication, 30(1):153-165, 2006.

[33] W. B. Heinzelman, A. P. Chandrakasan and H. Balakrishanan, “An application-specific protocol architecture of wireless microsensor networks,” IEEE Transaction on Wireless Communications, pp. 660-670, October 2002.

[34] M.S. Ali, T. Dey and R. Biswas " ALEACH: Advanced LEACH Routing Protocol for Wireless Microsensor Networks", 5th International Conference on Electrical and Computer Engineering Conference on Electrical and Computer Engineering ICECE 2008, pp.909-914.

[35] Xin, G., Yang, W.H., Gang, D.D.:"EEHCA: an energy-efficient clustering algorithm for wireless sensor network”, Inf.Technol. 2008, pp.245-252.

[36] G. Yi, S. Guiling, L. Weixiang and P. Yong "Recluster-LEACH: A recluster control algorithm based on density for wireless sensor network " 2nd International Conference on Power Electronics and Intelligent Transportation System vol.3, pp.198-202, 2009.

[37] W. B. Heinzelman. "Application-Specific Protocol Architectures for Wireless Networks” PhD thesis, Massachusetts Institute of Technology, June 2000.

[38] A. Depedri, A. Zanella and R. Verdone," An Energy Efficient Protocol for Wireless Sensor Networks" In Proc. AINS, 2003, pp.1-6.

[39] X. Fan and Y. Song, " Improvement on leach protocol of wireless sensor network, " In Proceeding of the International Conference on Sensor Technologies and Applications, 2007, pp.260-264.

[40] L. Han " LEACH-HIR: An energy efficient routing algorithm for Heterogeneous WSN "IEEE International Conference on Intelligent Computing and Intelligent Systems (ICIS), 2010, vol.2, pp.507-511.

[41] Yao-Win Hong, Wan-Jen Huang, Fu-Hsuan Chiu and C. Jay Kuo. Cooperative Communications in Resource-Constrained Wireless Networks. IEEE Signal Processing. May 2007.

[42] Ahmed S. Ibrahim, Ahmed K. Sadek and K. J. Ray Liu. Cooperative Communications with Relay-Selection: When to Cooperative and Whom to Cooperative With? IEEE Transactions on Wireless Communications, Vol. 7, NO.7, July 2008.

[43] Ahmed S. Ibrahim, Ahmed K. Sadek. Relay Selection in Multi-Node Cooperative Communications: When to Cooperate and Whom to Cooperative with.” Proceedings of the IEEE, 2006.

[44] Chiranjib, Parama, and Debina Chakroborty. “Modified Rumor routing algorithm for sensor networks.” IJCSI International Journal of Computer Science Issues, Vol. 7, Issue 4, No 9, July 2010.

[45] Manjeshwar, Arati, and Dharma P. Agrawal. “TEEN: a routing protocol for enhanced efficiency in wireless sensor networks. “1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing. Vol. 22. 2001.

[46] Lindsey, Stephanie, and Cauligi S. Raghavendra. “PEGASIS: Power-efficient gathering in sensor information systems.” Aerospace conference proceeding. IEEE, 2002.

[47] C.P Gupta and Arun Kumar" Optimal Number of Clusters in Wireless Sensor Networks with Mobile Sink ". International Journal of Scientific & Engineering Research, Volume 4, Issue 8, August(2013).

[48] Hongwei, Zhang and Zong " LEACH-G: an Optimal Cluster-head Selection Algorithm based on LEACH ". Journal of Software, Vol, 8, NO, 10, October (2013).

[49] Sharma, Kumar and Tomar " OCEA: An Optimal Cluster Energy Aware Routing Protocol for Wireless Sensor Networks ". Int. J. Emerge. Sci. 3(1), 95-107, March (2013).

[50] Raghuvanshi, Tiwari and Kishor. “Optimal Number of Clusters in Wireless Sensor Networks: An FCM Approach ". IEEE Int. Conf. on Computer & Communication Technology (ICCT 10).

[51] Younis, Ossama, and Sonia Fahmy. "HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks." Mobile Computing, IEEE Transaction on 3.4(2004): 366-379.

[52] X. H. Wu and S. Wang, "Performance Comparison of LEACH and LEACHC Protocols by NS2," Proceedings of 9th International Symposium on Distributed Computing and Application to Business, Engineering and Science, Hong Kong, 10-12 August 2010.

[53] T. Murata and H. Ishibuchi, "Performance Evaluation of Genetic Algorithms for Flow shop Scheduling Problems," proceeding of 1st IEEE Conference Evolutionary Computation, Orlando, 27-29 June 1994.

[54] N. Javid, S. N. Mohammad, K. Latif, U. Qasim and. A. Khan, M. A. Khan, "HEER: Hybrid Energy Efficient Reactive Protocol for Wireless Sensor Network" , 2nd IEEE Saudi International Electronics, Communications and Photonics Conference (SIECPC 13), 2013, Riyadh, Saudi Arabia.

[55] P. Saini and A.K. Sharma, " Energy Efficient Scheme for Clustering Protocol Prolonging the Lifetime of Heterogeneous Wireless Sensor Networks," International Journal of Computer Applications (0975-8887) Vol.6 – No.2, September 2010, pp. 30-36.

[56] H. Kour and A. K. Sharma." Hybrid Energy Distributed Protocol for Heterogeneous Wireless Sensor Network," ," International Journal of Computer Applications (0975-8887) Vol.4 – No.6, July 2010.

[57] Q. Xuegong, M. Fuchang, Ch. Yan, Y. Weizhao," The Protocol of Cluster Multi-Hop Transmission Based on Heterogeneous Wireless Sensor Networks", proceedings of International Conference on Computational Intelligence and Software Engineering, CiSE 2009. pp. 1-4, IEEE.

[58] Younis, O., & Fahmy, S. (2004). HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks. IEEE Transactions on Mobile Computing, 3 (4), 366-379.

[59] Wang, W, Wang, B., Liu, Z, Guo, L., & Xiong, W. (2011). A cluster-based and tree-based power efficient data collection and aggregation protocol for wireless sensor networks. Information Technology Journal, 10, 557-564.

[60] Yi, S. Heo, J., Cho, Y., & Hong, J. (2007). PEACH: Power-efficient and adaptive clustering hierarchy protocol for wireless sensor networks. Computer communications, 30 (14-15), 2842-2852.

[61] Soro, S, & Heinzelman, W. Prolonging the lifetime of wireless sensor networks via unequal clustering. In Parallel and Distributed Processing Symposium, 2005.Proceedings.19th IEEE International. IEEE press.

[62] Wu, X., Chen, G., & Das, S. (2006). On the energy hole problem of non-uniform node distribution in wireless sensor networks. IEEE International Conference on Mobile Ad hoc and Sensor Systems (MASS), 2006 (pp. 180-187). IEEE press.

[63] Wu, M. Y., Li, C., Chen, G, & Jie. (2005). an energy efficient clustering scheme in wireless sensor networks. In Proceedings of the IEEE International Performance Computing and Communications Conference (pp. 535-540). IEEE Press.

[64] Mhatre, V., & Rosenberg, C. (2004). Homogeneous vs heterogeneous clustered sensor networks: a comparative study. IEEE International Conference on Communications, 2004. 6, pp. 3646-651. IEEE press.

[65] Rodoplu, V., Ming, T.H.: Minimum energy mobile wireless networks. IEEE Journal of Selected Areas in Communications 17(8), 1333–1344 (1999).

[66] Li, L. Halpern, and J.Y.: Minimum energy mobile wireless networks revisited. In: The Proceedings of IEEE International Conference on Communications (ICC 2001), Helsinki, Finland (June 2001).

[67] X. N. Fan and Y. L. Song, “Improvement on LEACH Pro- tool of Wireless Sensor Networks,” Proceedings of 2007 International Conference on Sensor Technologies and Applications, Valencia, 2007, pp. 260-264.

[68] B. Aoun and R. Boutaba, “Clustering in WSN with Latency and Energy Consumption Constraints,” Journal of Network and Systems Management, Vol. 14, No. 3, 2006, pp. 415-439.

[69] G. Chen, C. F. Li, M. Ye and J. Wu, “An Unequal Cluster- Based Routing Strategy in Wireless Sensor Networks,” Chinese Journal of Computers, Vol. 30, No. 1, 2007, pp. 27-36.

[70] Duarte-Melo Enrique J, Mingyan Liu.“Analysis of Energy Consumption and Lifetime of Heterogeneous Wireless Sensor Networks“, Proc of IEEE Globecom, Taipei, Taiwan, pp. 21-25, 2002.

[71] Zhang Rui-Hua, Jia Zhi-Ping, Yuan Dong-Feng.“Lifetime analysis in heterogeneous wireless sensor networks” Jilin Daxue Xuebao, vol. 38, no.5, pp. 1136-1140, 2008.

[72] Smaragdakis G, Matta I, Bestavros A. “SEP: A stable election protocol for clustered heterogeneous wireless sensor networks”, Proc of the Int Workshop on SANPA 2004. pp. 251-261, 2004.

[73] Qing, Li; Zhu, Qingxin; etc. “Design of a distributed energy-efficient

clustering algorithm for heterogeneous wireless sensor networks", Computer Communications, August, vol. 29, no.12, pp.2230-2237, 2006.

[74] Li Xiaoya, Huang Daoping, Yang Jian. "Energy efficient routing protocol based residual energy and energy consumption rate for heterogeneous wireless sensor networks", Proceedings of the 26th Chinese Control Conference, Zhangjiajie, China, pp. 587-590, 2007.

[75] A. Manjeshwar and D.P. Agrawal, "TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks", Proc. of 1st Intl. Workshop on Parallel and Distributed Computing, Apr. 2001.

[76] B. Manzoor, N. Javaid, O. Rehman, M. Akbar, Q. Nadeem, A. Iqbal, M. Ishfaq, "Q-LEACH: A New Routing Protocol for WSNs", International Workshop on Body Area Sensor Networks (BASNet-2013) in conjunction with 4th International Conference on Ambient Systems, Networks and Technologies (ANT 2013), 2013, Halifax, Nova Scotia, Canada, Procedia Computer Science, Volume 19, 2013, Pages 926-931, ISSN 1877-0509.

[77] Aslam. M, Javaid. N, Rahim. A, Nazir. U, Bibi. A, Khan. Z. A, "Survey of Extended LEACH-Based Clustering Routing Protocols for Wireless Sensor Networks", 5th International Symposium on Advances of High Performance Computing and Networking (AHPCN-2012)in conjunction with 14th IEEE International Conference on High Performance Computing and Communications (HPCC-2012), 25-27 June, Liverpool, UK, 2012.

[78] Fareed, M.S.; Javaid, N.; Ahmed, S.; Rehman, S.; Qasim, U.; Khan, Z.A., "Analyzing Energy-Efficiency and Route-Selection of Multi-level Hierarchal Routing Protocols in WSNs", Broadband, Wireless Computing, Communication and Applications (BWCCA), 2012 Seventh International Conference on , vol., no., pp.626,631, 12-14 Nov. 2012. doi: 10.1109/BWCCA.2012.109.

[79] Aasia Kashaf, Nadeem Javaid, Zahoor Ali Khan and Imran Ali Khan, "TSEP: Threshold-sensitive Stable Election Protocol for WSNs", 10th IEEE International Conference on Frontiers of Information Technology (FIT' 12), 2012, Pakistan.

[80] Khan. A. A, Javaid. N, Qasim. U, Lu. Z, Khan. Z. A, "HSEP: Heterogeneity-aware Hierarchical Stable Election Protocol for WSNs", 3rd International Workshop on Advances in Sensor Technologies, Systems and Applications

(ASTSA-2012) in conjunction with 7th IEEE International Conference on Broadband and wireless Computing, Communication and Applications (BWCCA 2012), Victoria, Canada, 2012.

[81] T. N. Qureshi, N. Javaid, A. H. Khan, A. Iqbal, E. Akhtar and M. Ishfaq, "BEENISH: Balanced Energy Efficient Network Integrated Super Heterogeneous Protocol for Wireless Sensor Networks", The 4th International Conference on Ambient Systems, Networks and Technologies (ANT 2013), 2013, Halifax, Nova Scotia, Canada, Procedia Computer Science, Volume 19, 2013, Pages 920-925.

[82] Bhaskar Krishnamachari, Networking Wireless Sensors (University of Southern California: Cam-bridge University Press, 2005).

[83] Mustafa I. Abd-El-Barr, Mohamed A. Youssef and Maryam M. Al- Otaibi, Wireless Sensor Networks - Part I: Topology and Design Issues, 18th IEEE Annual Canadian Conference on Electrical and Computer Engineering CCECE 2005.

[84] www.ece.osu.edu/~ ekici/ res_wmsn.html.

[85] J. Burrell, T. Brooke, and R. Beckwith, "Vineyard computing: sensor Networksin agricultural production," IEEE Pervasive Computing, 3(1):38-45, Jan-Mar,2004.

[86] K. Chintalapudi, T. Fu, J. Paek, N. Kothari, S. Rangwala, J. Caffrey, R. Govindan, E. Johnson, and S. Masri, "Monitoring civil structures with a wireless sensor network," IEEE Internet Computing, 10(2):26-34, 2006.

[87] J. Hill and D. Culler, "Mica: a wireless platform for deeply embedded Networks," IEEE Micro, 22(6):12-24, Nov. 2002.

[88] A. Mainwaring et al. "Wireless Sensor Networks for Habitat Monitoring," in the Proc. of ACM International Workshop on Wireless Sensor Networks and Applications, Sept. 2002.

[89] Crossbow Technology Inc. http://www.xbow.com.

[90] G. J. Pottie and W. J. Kaiser, "Embedding the internet: wireless integrated Network sensors," Communications of the ACM, 43(5):51–58, May 2000.

[91] Tinyos, University of California at Berkeley, http://www.tinyos.net.

[92] D. Goense, J. Thelen, and K. Langendoen, "Wireless Sensor Networks for Precise Phytophthora decision support," in the 5th European Conference on Precision Agriculture (5ECPA), Sweden, June 2005.

[93] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks," ACM Wireless Networks, Vol. 8, No. 5, 2002.

[94] Y. Xu, J.Heidemann and D. Estrin, "Adaptive energy-conserving routing for multihop ad hoc networks," Research report, USC/Information Sciences Institute, 2000.

[95] Y. Xu, J. Heidemannn, and D. Estrin, "Geography-informed energy conservation for ad hoc routing," Proc. of the Seventh Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom 2001), Rome, Italy, July 2001.

[96] Josh Broch, David B. Johnson, and David A. Maltz, "The Dynamic Source Routing (DSR) Protocol for Mobile Ad Hoc Networks," Internet-Draft, draftietf-manet-dsr-00.txt, March 1998.

[97] Charles Perkins, "Ad Hoc On Demand Distance Vector (AODV) routing,"Internet-Draft, draft-ietf-manet-aodv-00.txt, Nov. 1997.

[98] C. E. Perkins and P. Bhagvat, "Highly Dynamic Destination Sequenced Distance Vector Routing (DSDV) for Mobile Ad hoc Networks," Computer Communications, Oct. 1994.

[99] J. Broch, D. Maltz, D. Johnson, Y. Hu, and J. Jetcheva, "A Performance Comparison of Multi-hop Wireless Ad hoc network routing protocols," Proc. of the 4th ACM International Conference on Mobile Computing and Networking (Mobilecom'98), Oct. 1998.

[100] A. Woo and D. Culler, "A Transmission Control Scheme for Media Access in Sensor Networks," in the Proceedings of the 7th Annual ACM/IEEE International Conference on Mobile Computing and Networking (Mobicom'01), Rome, Italy, July 2001.

[101] T. Dam and K. Langendoen, "An adaptive energy-efficient MAC protocol for Wireless sensor networks," in the first ACM Conf. on Embedded Networked Sensor Systems (SenSys 2003), USA, Nov. 2003.

[102] Prabhat Kumar and M.P.Singh, "A New Clustering Protocol Based on Energy Band for Wireless Sensor Network ", International Journal of Information Technology and Knowledge Management, Volume 3, January –June 2010, ISSN: 0973-4414.

[103] Donghoon Lee, Kaliappan, V.K; Duckwon Chung ; Dugki Min," An

energy efficient dynamic routing scheme for clustered sensor network using a ubiquitous robot Research " , Innovation and Vision for the Future. IEEE International Conference, 2008, page(s): 198-203.

[104] Y.C.Chang and Z.S.Lin and J.L.Chen, Cluster based self-organization management protocols for wireless sensor networks In Proceeding of the IEEE transaction on consumer electronics (February 2006), Vol.52, pp.75-80.

[105] V.Mhatre and C.Rosenberg, "Homogenous vs. heterogeneous clustered sensor networks: A comparative study," in Preceding's of 2004 IEEE, International Conference on Communications (ICC 2004), June 2004.

[106] Panghal Amanjeet, Mittal Nitin, Singh D.P.&Chauhan R.S. (2010) Improved Leach communication protocol for WSN, National Conference on Computational Instrumentation CSIO Chandigarh, INDIA, 177-181.

[107] S. Selvakennedy and S. Sinnappan, "An energy-efficient clustering algorithm for multihop data gathering in wireless sensor networks," Journal of Computers, pp. 1, April 2006.

[108] Depedri, A., anella, A., & Verdone, R. (2003). An energy efficient protocol for wireless sensor networks. Proceeding of the AINS 2003. Menlo Park.

[109] Lee, S. Yoo, J., & Chung, T. (2004). Distance-based energy efficient clustering for wireless sensor networks.29th Annual IEEE International Conference on Local Computer Networks, 2004. , (pp. 567-568).

[110] T. Himsoon, W. P. Siriwongpairat, Z. Han and K. J. R. Liu, "Lifetime maximization via cooperative nodes and relay deployment in wireless networks, " IEEE J. Select. Areas Communication . , vol. 25,pp. 306-317, Feb. 2007.

[111] W. Su, A. K. Sadek, and K. J. R. Liu, "SER performance analysis and optimum power allocation for decode-and-forward cooperation protocol in wireless networks," in Proc. IEEE WCN'05, vol. 2, pp. 984-989, Mar. 2005.

[112] A. K. Sadek, W. Su, and K.J.R. Liu, "Cooperative Communication Protocol In Wireless Networks: Performance Analysis and Optimum Power Allocation", Wireless pers Commun (2008) 44:181-217.

[113] Kumar, D., Aseri, T.C., Patel, R.B.: " EEHC: energy efficient heterogeneous clustered scheme for wireless sensor networks", Elsevier Computes. Communication . , 2009, 32,(4),pp.662-667.

[114] N. Javaid, U. Qasim, Z. A. Khan, M. A. Khan, K. Latif and A. Javaid, "On

EnergyEfficiencyandDelayMinimization in ReactiveProtocols in Wireless Multi-hop Network", 2nd IEEE Saudi International Electronics, Communications andPhotonics Conference (SIECPC 13), 2013, Riyadh, SaudiArabia.

[115] B. Manzoor, N. Javaid, O. Rehman, M. Akbar, Q. Nadeem, A. Iqbal, M. Ishfaq, "Q-LEACH: A New Routing Protocol forWSNs", International Workshop on Body Area Sensor Networks (BASNet-2013) in conjunctionwith 4th International Conference on AmbientSystems, Networks and Technologies (ANT 2013), 2013, Halifax, Nova Scotia, Canada, ProcediaComputerScience, Volume 19, 2013, Pages 926-931, ISSN: 1877-0509.

[116] N. Javaid, R. D. Khan, M. Ilahi, L. Ali, Z. A. Khan, U. Qasim, "Wireless Proactive Routing ProtocolsunderMobilityandScalabilityConstraints", J. Basic. Appl. Sci. Res., 3(1)1187-12001, 2013.

[117] Gutierrz, J.A, Naeve, M, Callaway, E ." A developingStandardforLow-Power Low-Cost Wireless PersonalArea Networks " IEEE Network 2001, 15, 12-19.

[118] RwanIbrahim, Quang-Dung Hoand Tho.Le-Ngoc." An Energy-Efficient and Load Cluster-Based Routing Algorithm for CSMA-Based Wireless Sensor Networks." Wireless Sensor Networks, IEEE 2013.

Curriculum Vitae

RAED SAEED DARAGHMA

Department of Electrical and Electronics Engineering
Doctorate Thesis

Education

B.Sc. 2000 An-Najah University, Nablus, Palestine
Electrical Engineering Sciences, Department of Engineering

M.Sc. 2010 Jordan University of Science and Technology
Irbid, Jordan

Personal Information

Place and Year of Birth: Palestine-Tobas, 23.03.1977

Foreign Language: English