

Study of Clustering Algorithms for Brain Computer Interface using Wireless Sensor Networks

Abhishek Das

(110CS0066)

Amritanshu Mishra

(110CS0585)



**Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Orissa, India**

Study of
Clustering Algorithms for Brain Computer
Interface using Wireless Sensor Networks

*Thesis submitted in partial fulfilment
of the requirements for the degree of*

Bachelor of Technology

in

Computer Science and Engineering

by

Abhishek Das

(Roll: 110CS0066)

&

Amritanshu Mishra

(Roll: 110CS0585)

under the guidance of

Prof. Suchismita Chinara

NIT Rourkela



Department of Computer Science and Engineering

National Institute of Technology Rourkela

Rourkela-769 008, Orissa, India

May 2014



Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Orissa, India.

May 3, 2013

Certificate

This is to certify that the work in the thesis entitled ***Study of Clustering Algorithms for Brain Computer Interface using Wireless Sensor Networks*** by Abhishek Das & Amritanshu Mishra is a record of an original research work carried out under my supervision and guidance in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Computer Science and Engineering. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

Dr. Suchismita Chinara
Assistant Professor
CSE department of NIT Rourkela

Acknowledgment

We would like to express our earnest gratitude to our project guide, Prof. Suchismita Chinara, for believing in our ability to work on the challenging domain of BCI and WSN. Her profound insights have enriched our research work. The flexibility of work she has offered us has deeply encouraged us producing the research.

We are highly indebted to Prof.S.K.Rath, Head-CSE Department, for his continuous encouragement and support, as he has always been eager to help. We are also thankful to Prof. A.K.Turuk, Prof. S. K. Jena, Prof. B. Majhi and all the faculty members and staffs of the department for their support.

We are thankful to all our friends. Our sincere thanks to everyone who has provided us with inspirational words, a welcome ear, new ideas, constructive criticism, and their invaluable time, we are truly indebted.

We must acknowledge the academic resources that we have acquired from NIT Rourkela. We would like to thank the administrative and technical staff members of the department who have been kind enough to advise and help in their respective roles.

Last, but not the least, we would like to dedicate this project to our families, for their love, patience, and understanding.

Abhishek Das
Amritanshu Mishra

Authors Declaration

I hereby declare that all the work contained in this report is my own work unless otherwise acknowledged. Also, all of my work has not been previously submitted for any academic degree. All sources of quoted information have been acknowledged by means of appropriate references.

Abhishek Das

Amritanshu Mishra

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Abstract

BCIs are often directed at expanding, assisting or restoring human sensory-motor or cognitive functions by offering a direct communication route between the human brain and any external devices. In Invasive BCI the sensors are implanted inside the brain on the surface of cerebrum. So far invasive BCI using wireless sensors has not been achieved. Most research to date regarding invasive BCI using wireless sensors has revolved around communications along the surface of the body by the use of traditional electromagnetic (EM) radio-frequency carrier waves. The major impediment that we face today in order to enable this dream of networked-implantable-devices is caused by the physical nature of propagation in humans. Our body is composed primarily of water, which is a medium through which Radio frequency EM waves do not easily propagate. Therefore, in this article we take a distinctive perspective and inspect the possibility of using ultrasonic waves to wirelessly interconnect sensors in the brain. We propose a new energy model required for ultrasonic propagation. Since the sensors need to be implanted inside the brain, therefore to avoid frequent implants we design a new clustering algorithm which overcomes the drawbacks of existing LEACH algorithm and uses lesser energy, hence enhancing the lifetime of sensors.

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List of Abbreviations

Eamp	Energy in Amplification
Eelec	Energy by Electric Circuitry
BS	Base Station
BCI	Brain Computer Interface
CDMA	Code Division Multiple Access
CH	Cluster Head
EDA	Energy for Diffusion or Aggregation
LEACH	Low-Energy Adaptive Clustering Hierarchy
TDMA	Time Division Multiple Access
WSN	Wireless Sensor Network

Chapter 1

Introduction

1.1 Brain Computer Interface

Brain computer Interface or BCI or Brain Machine Interface or sometimes called a direct neural interface is a type of direct communication pathway from the brain to an external device. BCI's are often focussed at assisting, augmenting or restoring human cognitive or sensory-motor functions. Development and research in BCI's focuses chiefly on neuroprosthetics functions that are aimed at repairing damaged sight, hearing and movement.

BCI Principle: BCI works on the following principles (highlighted in Figure 1.1)

- a) The primary motor area delivers movement instructions to the muscles via the spinal cord in healthy individuals
- b) But in paralyzed persons the above pathway is interrupted.
- c) A Computer based decoder translates this action into instructions for muscle movement and control.

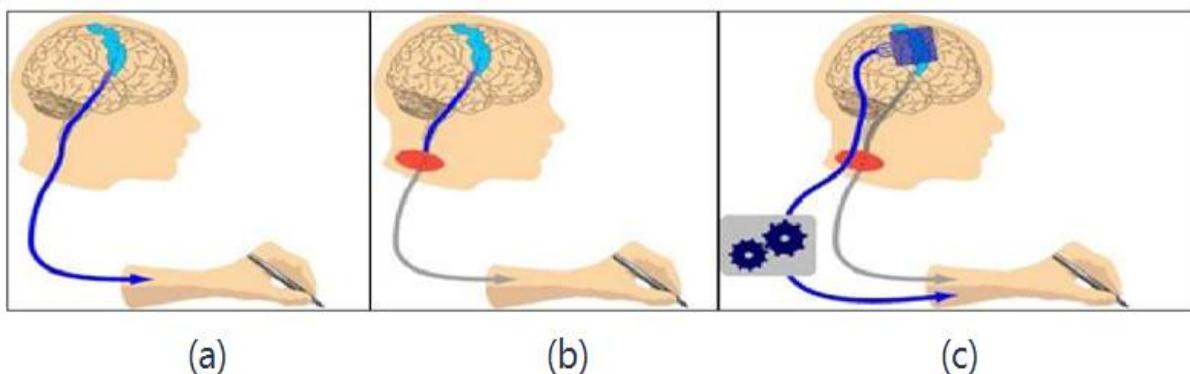


Figure 1.1: Principle of BCI

Types of BCI systems:

- Non-Invasive BCI – A structure with attached wires is worn outside the brain as a cap.
- Partially Invasive BCI – sensors are implanted underneath the skull but reside outside the brain. Sensors are not placed on the grey matter.
- Invasive BCI – sensors are directly implanted on the grey matter during neurosurgery.

Figure 1.2 shows the types of BCI systems and how the signals are transmitted in a BCI system.

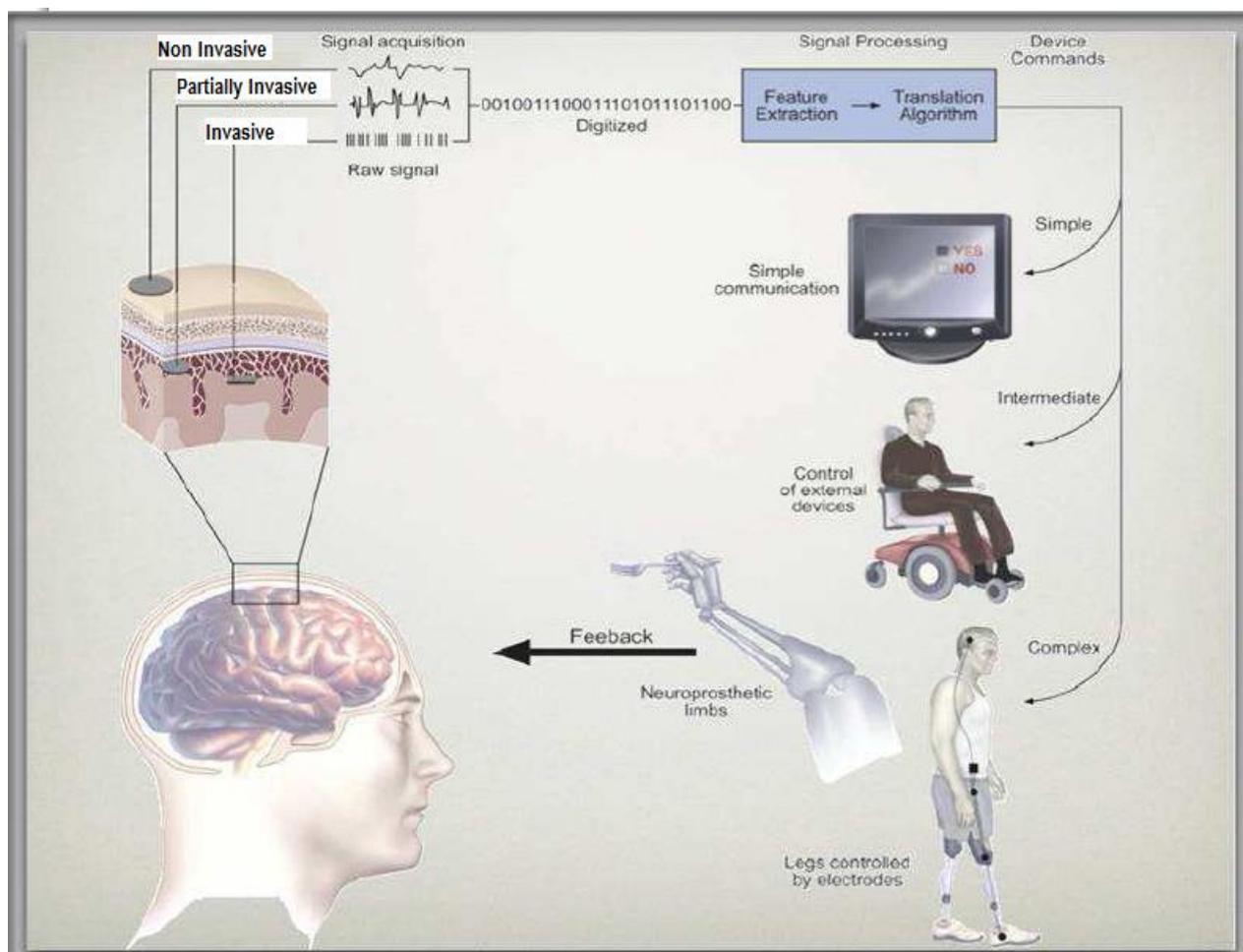


Figure 1.2: BCI System

1.2 Wireless Sensor Network

Wireless sensor networks consist of spatially scattered autonomous sensors those help in jointly monitoring the ecological or physical conditions like sound, temperature, vibration, motion, pressure or contaminants. The WSN is built of a varying number of nodes which may range from a limited to some hundreds or thousands, wherein each node is connected to one or more sensors. Figure 1.3 depicts the structure of WSN.

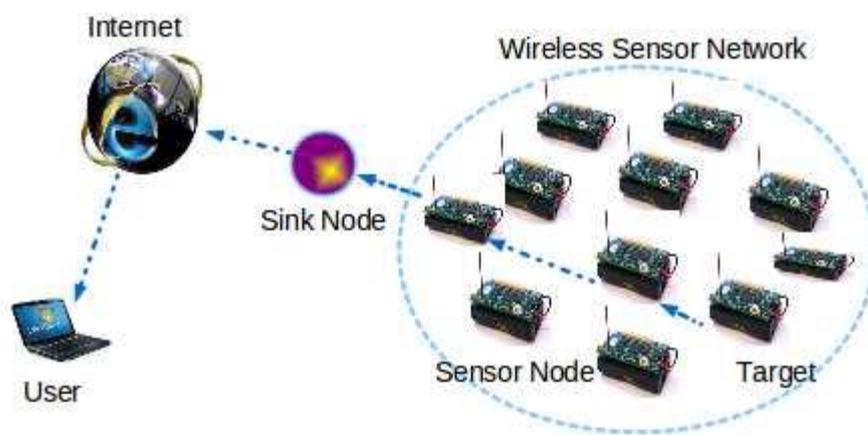


Figure 1.3: Wireless Sensor Network

The main characteristics of WSNs include,

- Ease of use
- Ability to survive even if certain nodes fail.
- Failure in Communication
- Scalability to large-scale disposition
- Constraints in power consumption for nodes that use batteries or Energy harvesting
- Their ability to cooperate with harsh environmental conditions, etc.

1.3 Routing in WSN

The aim of WSN's is to monitor a particular environment. The primary aim of a sensor node is collecting data from certain domains, processing them and forwarding it to the BS, where the application is located. However, by guaranteeing a direct communication pathway between the sink and sensors may drain the nodes' power very quickly, because of higher energy requirement in transferring messages. Therefore, it is sometimes required that the nodes are collaborated to ensure communication of remote nodes with sink. In this way, data are propagated through intermediary nodes by establishing a pathway to the sink. Routing protocols for WSN are responsible for the discovery and maintenance of routes in the network [1].

According to the involvement pattern of sensors, routing protocols in WSN can be categorized as the following three types.

Direct Communication:

In the case of direct communication, every sensor node is capable of transmitting information directly to the Base Station (BS). Applying this routing technique in very large networks may drain the energy of the sensors very rapidly. Scalability of such a system is very small. Example: SPIN.

Flat:

In this type of protocols, if a node desires to send data, first it searches for a route to the BS and then it transmits the information. In this way, nodes around the BS may exhaust their energy extremely rapidly. Scalability in this case is moderate. An example is Rumor routing.

Clustering:

In the clustering routing protocols, the total area is partitioned into numerous clusters where each cluster has a cluster head (CH) which communicates directly with the sink. The nodes in a cluster transmit their information to the corresponding CHs. TEEN is an example of Clustering.

1.4 Key Issues in the Design of Routing Protocols for WSN

There are some issues in the designing of routing protocols for WSNs due to various constraints in the network. WSNs suffer from the drawbacks of several network resources such as bandwidth, energy, storage and computation power. The challenges in the design of sensor networks include the following key aspects [2]:

Limitations in energy capacity:

Because sensors run on batteries which have a certain limit to their capacity, energy is a major impediment for network designers in hostile situations. In a battlefield, for example, it is almost impossible to get access to the sensors and to recharge their batteries. Also, when a sensor's energy exceeds a certain threshold, it becomes faulty and may not function properly, which can have a huge influence on the performance of the network. Hence, the routing protocols that are designed for WSN's should be extremely energy efficient so as to prolong the lifetime of the sensors in turn extending the lifetime of the network while making sure that we get a decent overall performance.

Locations of sensors:

Another major challenge that is faced during the designing of routing protocols is in managing the positions of the sensor nodes. Most protocols make an assumption that sensors are either attached with Global Positioning System transmitters/receivers or they use certain kind of localization techniques in order to learn about their positions.

Limitation in hardware resources:

The processing and storage capacities of sensors are also limited as the energy capacity. Thus, they can only carry out restricted computational functionality. These constraints give rise to several challenges in the designing of network protocols for WSN, which must not only consider the energy efficiency of sensors, but also the storage capacities and the processing powers.

Massive and random node deployment:

Deployment of sensor nodes in WSNs is function dependent and affects the routing protocol's performance. Sensors may be scattered haphazardly in a specified area or they may be dropped massively over a hostile/remote location in most of the applications. When the resultant node-distribution is un-uniform, optimal clustering helps in connectivity and in enabling network operation to be energy efficient.

Network characteristics and dynamic environment:

Sensor networks generally operate in unreliable and dynamic environments. The network topology which is described by sensor nodes and the communication links between them, changes regularly because of sensor deletion, addition, damages, energy depletion or node failures. Furthermore, the sensors are linked by wireless media, which are noisy, susceptible to errors and vary with time. Thus, routing protocols should consider network topology dynamics in order to sustain particular application necessities in terms of connectivity and coverage.

Data Aggregation:

Sensors may generate a lot of unnecessary information. So, alike packets from several sensors can be combined to reduce amount of transmissions. Data aggregation techniques are being used for achieving energy efficiency and to optimize data/message transfer in the routing protocols.

Diverse application requirements:

WSNs have a variety of applications each having different requirements. There is no network protocol which can meet all the necessities of every application. Hence, routing protocols should ensure delivery of data and its accuracy to provide the BS with the expected knowledge about the environmental and physical condition on time.

Scalability:

Routing protocols must be made such that they are capable of scaling with the size of the network. Sensor nodes need not have the same capabilities in terms of processing, communication and energy. So, interaction pathways between sensor

nodes might not be symmetric. This should be taken care of in the design of routing protocols.

1.5 Clustering in WSN

The major benefit of WSN is their ability to position themselves in an adhoc manner [3], as organizing these nodes into groups pre-deployment is not feasible. For this reason, a lot of research has been conducted on the ways to create these organizational clusters or structures [4]. A clustering scheme divides the sensor nodes in a WSN into several virtual groups, according to a certain set of rules. In a cluster structure, sensors may be assigned a different function or status, such as cluster member or cluster head [5].

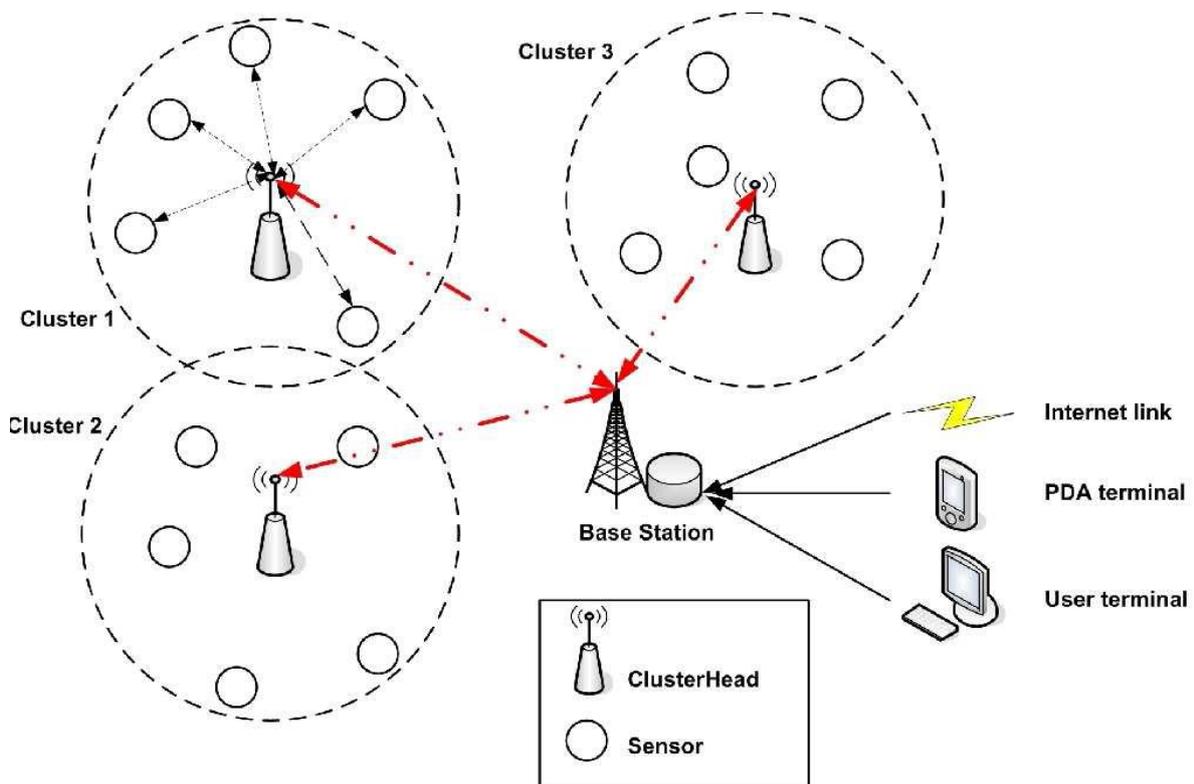


Figure 1.4: Clusters in WSN

We can see in the Figure 1.4, the architecture of a generic WSN, and inspect how clustering is an integral part of its organizational structure [4].

Sensor Nodes: Sensors are the building blocks of a WSN. They can play various roles in a WSN, such as data storage, data processing, routing and simple sensing.

Clusters: The structural unit of WSNs are called clusters. WSN's dense nature requires them to be split into clusters in order to simplify tasks such as routing.

Cluster heads: Cluster head may be called as the organizational chief of a cluster. It organizes the activities in a cluster. The activities include data-aggregation, diffusion, organizing the communication agenda of the cluster, etc.

Base Station: Often located far away from the network. It provides the communication pathway between the end-user and the WSN.

End User: Data that is obtained from sensor networks may be utilized for various purposes. A particular application can use the network data over the internet, using a PDA, or a personal computer. In queried sensor networks, queries are generated by the end user.

1.6 Clustering Algorithms

Several algorithms have been put forward for routing in WSN. Clustering algorithms have gained popularity in this field. Clustering algorithms may be classified as:

- Distributed algorithm,
- Centralized algorithm &
- Hybrid algorithm

In distributed clustering techniques, any sensor node can select itself as a CH or join an already established cluster on its own, independent of other nodes. Distributed clustering techniques are further divided into 4 categories basing on the criteria for cluster formation and the parameters used for the election of Cluster Heads as neighbourhood information or identity based, iterative and probabilistic. In centralized methods, the BS requires global information of the sensor network in order to control the network. CHs are elected by the base station. Hybrid schemes are comprised of distributed and centralized approaches. In a hybrid environment, distributed schemes are used for coordination between CHs, and centralized approaches are followed for CHs in order to build individual clusters.

In design of routing protocols for WSN, clustering algorithms have following advantages:

- Clustering minimizes the quantity of nodes which take part in remote transmission.
- Clustering algorithms are scalable for large number of nodes.
- They reduce communication overhead.
- Energy is utilized properly by the use of clustering algorithms.

Chapter 2

Literature Review

2.1 Clustering

Grouping sensor nodes into clusters is a widely adopted research area which is done to achieve scalability and more often than not obtain high energy efficiency and thus enhance the network lifetime in large-scale Wireless Sensor Network environments.

The corresponding hierarchical routing and data gathering protocols imply cluster-based organization of the sensor nodes in order that data fusion and aggregation are possible thus leading to a lot of energy being saved. Each cluster has a cluster head (CH) which is the leader of the cluster and usually performs special functions like fusion and data aggregation. Every cluster also contains several sensor nodes as members.

Cluster formation leads to a two-level hierarchy where the CH nodes form the higher level of the hierarchy and the members form the lower level. The sensors regularly transmit their data to their respective CH nodes. CH nodes aggregate the data (which ensures that the total number of transferred packets is reduced) and transmit this aggregated data to the base station. The CH's exhaust more energy because of the large amount of data transmission to longer distances. The solution is to periodically re-elect new CHs in each cluster so as to balance the energy consumption among all the sensor nodes in the network.

The BS is the data processing point for the data received which are received from the sensor nodes. BS is generally located far from the sensor nodes in the network.

The advantages of Clustering are:

- to transmit the aggregated data to the sink node (BS)
- it reduces the number of nodes that take part in transmission
- Energy consumption is reduced
- It is scalable for a large number of nodes

- It helps in reducing the communication overhead for single-hop as well as multi-hop networks

2.2 LEACH

Low-Energy Adaptive Clustering Hierarchy also known as LEACH is one of the initial clustering routing protocols that have been proven to be better when compared to other clustering algorithms. It is a distributed clustering algorithm, first proposed in 2000 by W. R. Heinzelman et al. [6].

The authors have suggested a hierarchical adaptive approach in which CHs are selected with a random probability independent of others to organize the nodes into clusters.

The main objectives of LEACH, was to find a way to low consumption of energy in the cluster and to improve the life time of WSN.

LEACH adopts a hierarchical and adaptive methodology to divide the sensor network into sets of clusters which are administered by selected CHs. The CH perform multiple tasks like collection of data from cluster members at regular interval of time, removal of redundancy among correlated values by aggregating data, transmitting aggregated data directly to the base station through a single hop method, creation and advertisement of a TDMA schedule. In the schedule created by the CH, every node of the cluster is allocated a time slot which the non-CH nodes use to transmit data and information. The CHs broadcast the schedule to their corresponding cluster members. For reducing the likelihood of collisions among sensor nodes, a Code Division Multiple Access (CDMA) based method is used by LEACH for communication. Figure 2.1 depicts the network model used by LEACH.

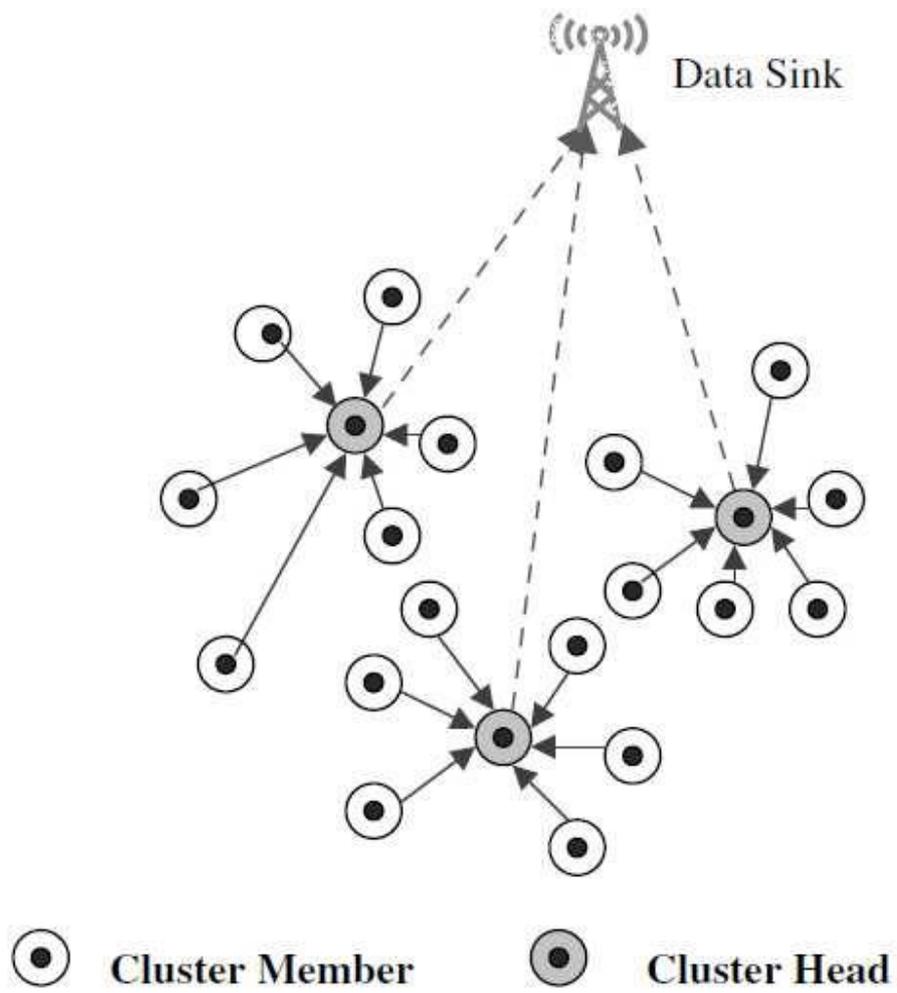


Figure 2.1: A model of leach

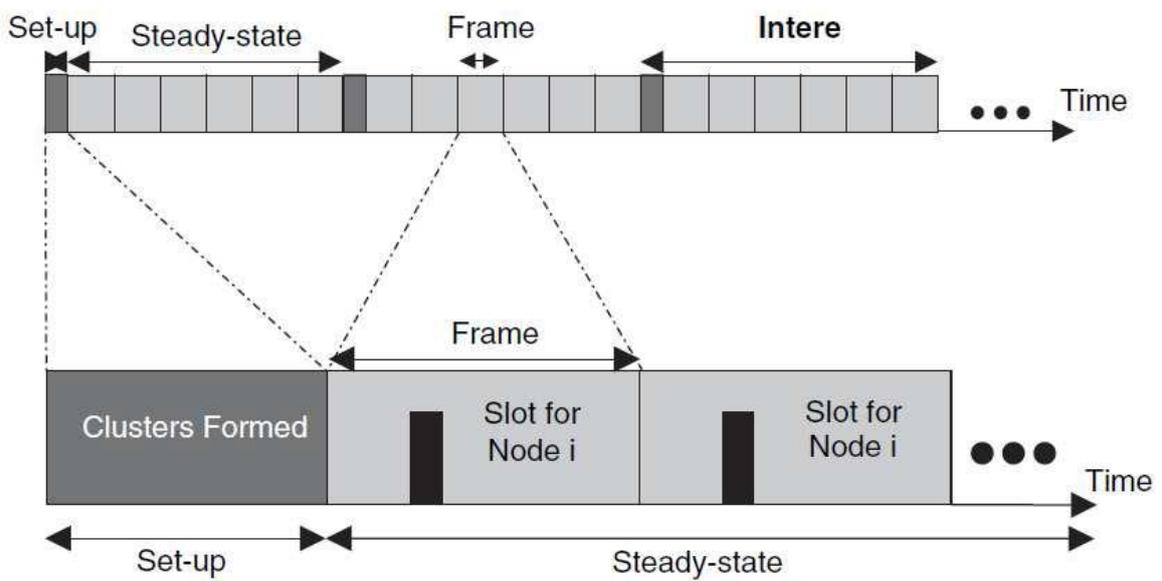


Figure 2.2: Phases of leach

2.2.1 Operations of LEACH

The execution of LEACH consists of many rounds where each round comprises of two phases. The phases of LEACH are shown in Fig 2.2.

Phase 1 also called the setup phase, contains three steps,

- CH advertisement,
- Cluster set-up and
- Transmission schedule creation.

Phase 2 also known as the steady-state phase, consists of,

- Data transmission to cluster heads,
- Signal processing (data aggregation/fusion) and
- Delivering data to the Base Station.

To minimize the overhead of the protocol, it is assumed that the time duration of the setup phase shorter than the time duration of the steady-state phase.

The very first step of the setup phase is cluster head selection. With the aim to distribute energy consumption uniformly across the network nodes, the task of cluster head rotates among the sensor nodes. LEACH uses a probabilistic approach for a node to determine if it is going to be a CH. A random number x (ranging between 0 and 1) is generated, and compared with the CH selection threshold $T(n)$ to decide if a node is a CH for that particular round.[7]

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

Where,

- P represents the desired percentage of CHs,
- r represents current round
- G represents the set of nodes which were not selected as cluster heads in former $1/P$ rounds.

If the value x generated by the node is lesser than $T(n)$, then that node is a CH. The CH selection threshold i.e. $T(n)$ is aimed to guarantee with high probability that a

predetermined division of nodes, P , should be selected as CHs at each round. It also ensures that the nodes, which have been cluster heads in the last $1/P$ rounds, are not elected in the current round as CHs. After the completion of the procedure of CH selection, every node which is a CH broadcasts its ID to the rest of the network in order to advertise its task as CH. Upon receiving the advertised signals the remaining nodes select a cluster to join, on the basis of the strength of the received signal (or Euclidian distance). Then the nodes inform their corresponding CHs of their wish to join as a member of the cluster. Once the cluster is formed, each CH creates and allocates a TDMA schedule that specifies the time slots of each member of the cluster for transmitting data or information. CHs likewise select CDMA code so as to reduce inter-cluster interference, which is then distributed to all members of its cluster [10].

After the end of the setup phase, the steady state phase begins. In this phase, nodes gather the required data and use their assigned slots to transmit it to the CH. Data collection is performed in a periodic manner. When, the CH nodes receive the whole data; it aggregates them before sending to the base station. The network moves back into the setup phase after completing one round. The round time is predetermined.

2.2.2 Advantages and Drawbacks of LEACH

Some advantages of LEACH protocol include:

- It integrates data-fusion into routing protocol.
- It is 4-8 times effective over direct communication in prolonging the network lifetime.

The major drawbacks of LEACH protocol are:

- Desired number of clusters is not obtained.
- Number of sensors in each cluster is not uniform.
- Randomized rotation of cluster heads.

2.3 ULTRASONIC SENSORS

The research done so far concentrates on communications along the surface of the body among devices connected through conventional electromagnetic (RF) carrier waves; nevertheless the basic challenge of enabling networked intra-body miniaturized sensors and actuators that communicate through body tissues is largely not addressed.

The basic hurdle to enable this idea of networked implantable devices is due to the physical nature of propagation in the human body. The human body is made up of 65 per cent of water, a medium through which RF waves, even at relatively low frequencies, do not easily propagate. Therefore we look for other alternatives for the transmission of signals in BCI or Body Area Network. We suggest the use of ultrasonic communications (UC) for BCI.

The advantages of using ultrasonic communications (UC) as compared to RF communications (RFC) can be summarized as follows:[8]

- Propagation: Ultrasonic waves are subject to much lower absorption as compared to electromagnetic signals, the primary reason being the significant water content in human tissues. Attenuation values ranging from 20dB at 100MHz to 60dB at 1GHz have been reported for distances less than 10 cm, which make RF based communication inside the human body very difficult.
- Health Concerns: Scientists have used ultrasounds successfully for diagnostic and therapeutic purposes inside the human body with no known damaging repercussions. The medical community is still unable to decide on the risks caused that are caused by exposure of human tissues to RF radiations. The medical experience of the past several years has demonstrated that ultrasounds are fundamentally *safe*, as long as acoustic power dissipation in tissue is less than 50 J/cm²
- Interference Management: The radio spectrum is crowded. Therefore, malicious interference or environmental interference may potentially RF devices if planted intra-body.

Chapter 3

Proposed Work

We propose an algorithm which overcomes certain disadvantages of LEACH and develop an energy model which can be used for ultrasonic sensors.[11]

3.1 Proposed Algorithm

Basic Features of Proposed Algorithm

- Every node has a distinct ID.
- The positions of all sensor nodes are fixed and known
- All the sensor nodes can carry out data fusion
- Sending node is capable of adjusting the transmit power depending on the distance to transmit so as to save energy
- Base station has infinite energy.
- Sensors are in the communication range of the base station.

Virtual Cluster Formation

- Every node sends its energy and location to BS.
- BS divides the network into k number of optimal clusters.

Cluster Formation

- BS forms the distance matrix and residual energy matrix and broadcasts it to each node.
- The node with the most energy from each partition is selected as the cluster heads. (If there are more than 1 nodes' with equal energy, smallest ID is CH).
- The sink node broadcasts the ID of CH's to all nodes.
- All nodes affiliate themselves to the closest CH using the distance matrix.

Re-Clustering

- When the energy of a cluster head becomes less than the threshold percentage (of its initial energy), then the cluster heads are chosen again.
- When the cluster heads are changed, the BS updates the energy matrix based on the amount of data received from each cluster head.

Termination

- When energy of most of the sensors goes below a particular threshold value, the sensors need to be replaced.

3.2 Modelling the Energy for Ultrasonic Communication

- If the initial pressure is P_0 and the pressure at a distance d is given by $P(d)$, then we know,

$$P(d) = P_0 e^{-\alpha d}$$

where,

$$\alpha = a f^b \quad (\text{Attenuation coefficient})$$

Here, f : carrier frequency

a, b : attenuation parameters characterizing the tissue

Tissue	a	a	b
Blood	0.095–0.13 @ 5 MHz	0.014–0.018	1.19–1.23
Heart	0.23 @ 1 MHz	0.23	1
Kidney	0.23 @ 2 MHz	0.115	1
Liver	0.17–0.57 @ 5MHz	0.041–0.07	0.9–1.3

Table 1. *Parameters characterizing body tissues.*

Figure 3.1: Table showing different attenuation parameters [9]

- Power Consumption in a transducer : $P_c = C_0 f[10]$

where,

C_0 : Capacitance of the piezoelectric element

f : charge discharge frequency of capacitor

- Hence we can derive,

$$P_c = \epsilon_{aa} \left(1/d\right)^{1/b}$$

where,

$$\epsilon_{aa} = \left(\left(\frac{-1}{a} \right) \ln \left(\frac{P(d)}{P_0} \right) \right)^{1/b}$$

- Energy utilized by the Cluster Heads:

$$E_{CH} = lC_0\epsilon_{aa} \left(1/d_1\right)^{1/b} \left(\frac{N}{k} - 1\right) + lEDA\frac{N}{k} + lC_0\epsilon_{aa} \left(1/d_2\right)^{1/b}$$

- Energy utilized by Non-Cluster Heads:

$$E_{non-CH} = lC_0\epsilon_{aa} \left(1/d_1\right)^{1/b}$$

Here,

d_1 : Avg. distance between CH and nodes

d_2 : Avg. distance between CH and Base station

Chapter 4

Implementation

4.1 ns2 (network simulator)

The implementation of the clustering algorithms including the proposed S-clus algorithm is done using ns2.

4.1.1 What is ns2?

Ns2 is simply an event-driven simulation tool that has proved useful in studying the dynamic nature of communication networks. NS2 can be used to perform simulations of wired and wireless network protocols and functions. In general, NS2 provides its users with a method of specifying such network protocols and for simulating their corresponding behaviours.

4.1.2 What is the core of ns2

- Discrete-event driven network simulation and Object Oriented
- NS-2 is an extended Tcl (OTcl) interpreter
- NS-2 is written in OTcl and C++
 - OTCl = Tcl + OO
 - C++ implements the code that executes frequently
 - Otcl configures the system

4.1.3 Components of NS-2 Package

NS2 consists of the following major packages:

- Tcl/TK: ns-2 is an extended Tcl interpreter
- TclCL comprises of Tcl with classes library
- OTcl or Object Tcl
- NS-2
- xgraph which is used for Plotting and Graphing
- nam-1 which is a Network Animator

4.1.4 NS-2 Architecture

Figure 4.1 shows the architecture of Network Simulator 2.

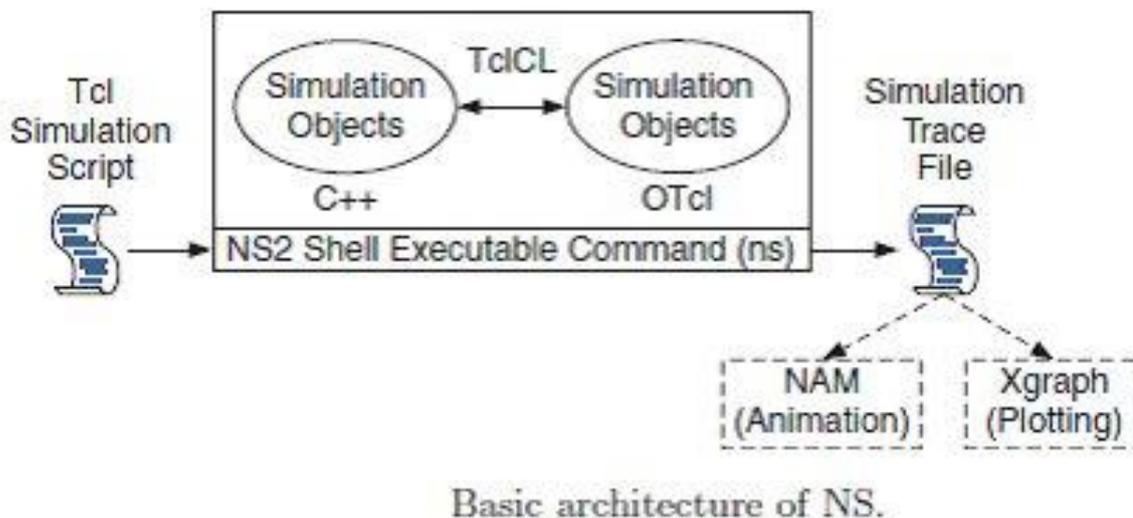


Figure 4.1: Architecture of NS-2

4.1.5 Advantages of Using NS-2

- It is free
- Majority of network components are implemented
- Researchers make active contributions.
- Modifying and/or adding new functions are easy.

4.2 Assumptions

We took the following assumptions while implementing the clustering algorithms for WSN's.

- Network is homogenous i.e. initial energy of all nodes are the same
- Homogenous distribution of nodes
- Nodes have adequate transmission range to reach other nodes.
- Nodes are static
- BS is positioned at a central position in relation to the distribution of nodes.

4.3 Parameters

The parameters and their values taken for simulation of each algorithm is shown in the following table 4.1

Sl. No.	Parameters	Values	LEACH	S-Clus
1.	Environment Size	100*100	Yes	Yes
2.	Number of nodes	100	Yes	Yes
3.	Position of base station	[50.50]	Yes	Yes
4.	Election probability value of CHs(P)	0.15	Yes	No
5.	Time period of each round	20s	Yes	Yes
6.	Maximum Amount of Time	3000s	Yes	Yes
7.	Initial energy per node (E_0)	2J	Yes	Yes
8.	EDA	5nJ/bit	Yes	Yes
9.	E_{elec}	50nJ/bit	Yes	Yes
10.	E_{amp}	10pJ/bit/m ²	Yes	Yes

Table 4.1: Parameters Used in Simulation of Leach and S-clus **

** E_{elec} denotes the total energy that is consumed per bit of message in the transmitter / receiver circuitry. E_{amp} is the amount of energy consumed per bit per metre square by the transmit amplifier.

Chapter 5

Results and Analysis

This segment shows the simulation results and analysis of LEACH and the proposed S-Clus in ns2. The parameters taken into consideration for evaluating both the algorithms are as follows:

- Number of Cluster-Heads vs Time
- Number of Nodes Alive vs Time
- Number of Data Items Received by BS vs Time
- Data Items received by BS per given amount of Energy
- Number of nodes alive vs Number of data items received by BS

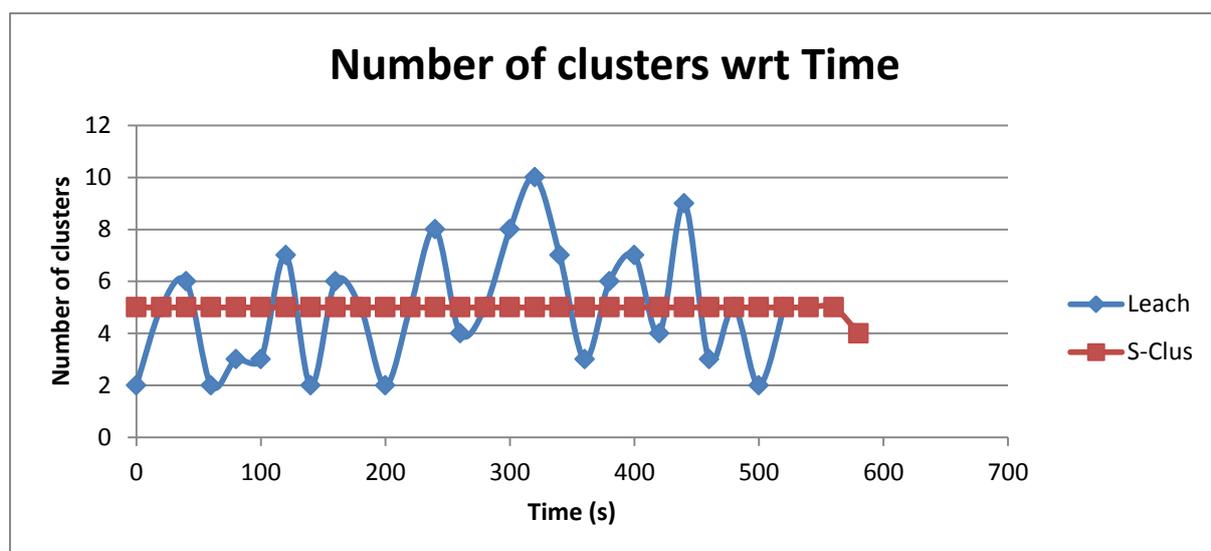


Figure 5.1 Number of Cluster Heads vs Time

It is perceived from the graph shown in Fig 5.1 that the primary CHs formed in S-Clus are uniform in each round, unlike LEACH where the cluster heads vary. This is because of the centralised scheme used for cluster formation that selects CHs based upon position and average energy of nodes instead of the probabilistic approach followed in LEACH.

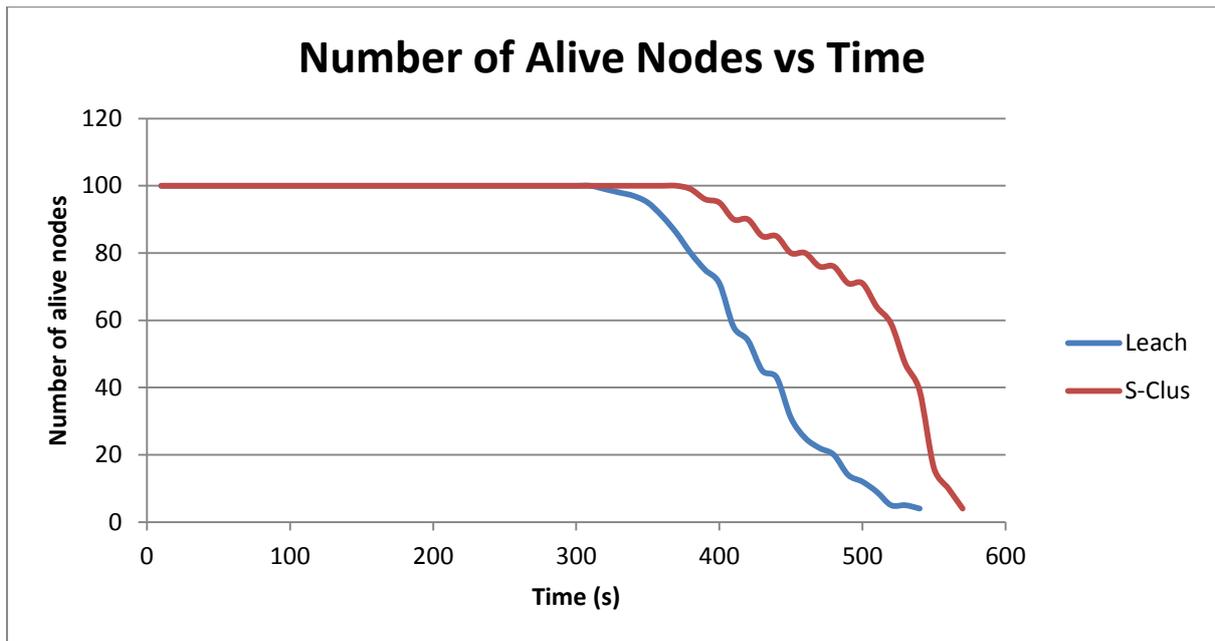


Figure 5.2: Number of Alive Nodes vs Time

Graph in Fig 5.2 shows that the proposed scheme, S-Clus outperforms LEACH in terms of network life time and number of nodes alive, which decreases less with time as compared to others. This is because of the uneven distribution and undesired number of primary CHs formed in LEACH. On the other hand, in S-Clus, primary CHs are evenly distributed and as it is centralised, BS forms an appropriate number of clusters.

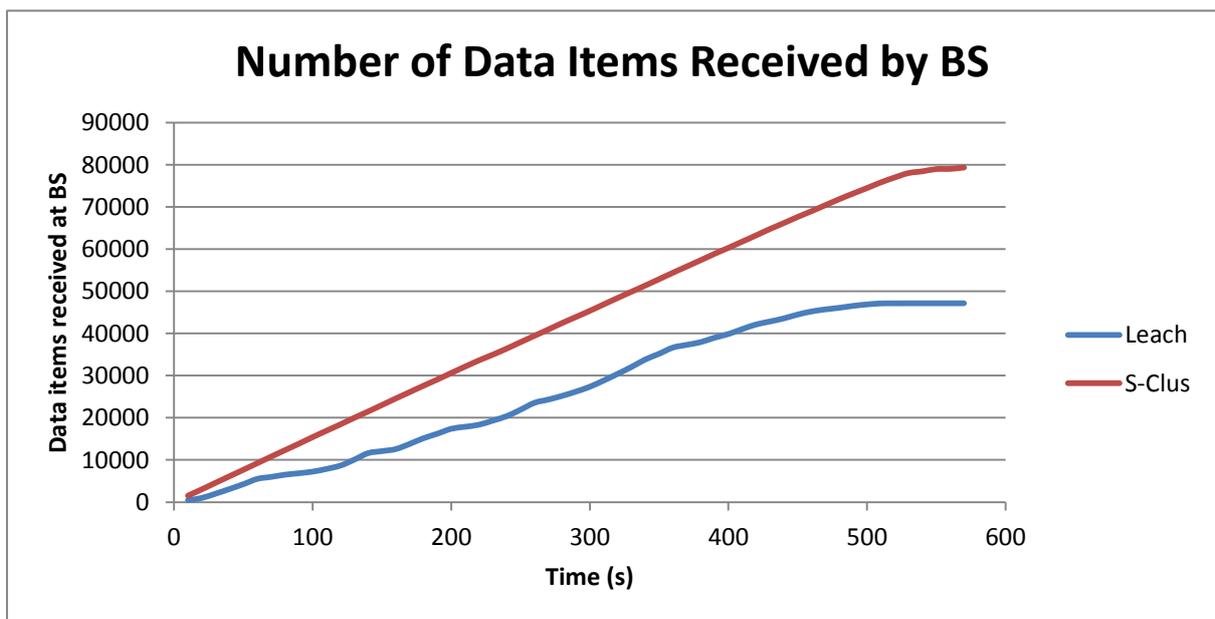


Figure 5.3: Number of Data Items Received by BS vs Time

Graph in Fig 5.3 conveys that as the time progresses, number of data signals obtained by BS using S-Clus increase linearly compared to that of LEACH. S-Clus is able to send more number of data signals when analysed with that of LEACH because in S-Clus, each node decides for itself which is the best cluster for it to choose using the distance matrix.

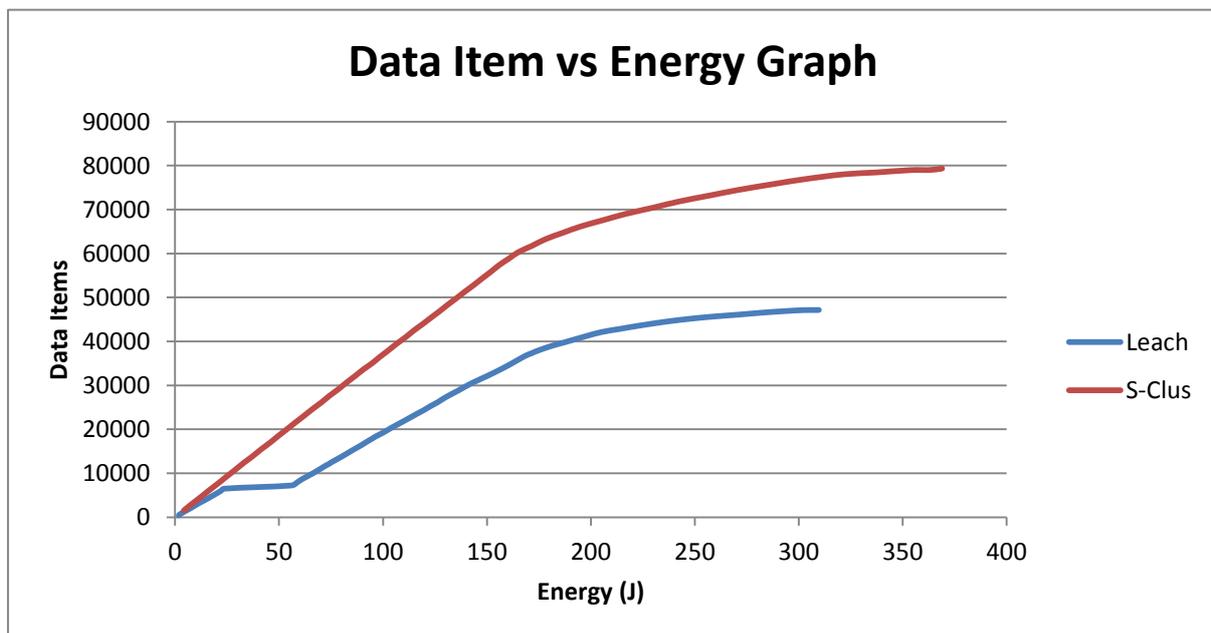


Figure 5.4: Number of Data Items Received by BS vs Energy

Fig 5.4 depicts the total data obtained at the BS for a given amount of energy. From this graph we can conclude that S-Clus delivers most data per unit energy as compared to LEACH attaining both energy efficiency as well as latency. Hence we can say that for S-Clus the data per energy transfer ratio is higher as compared to that of a simple LEACH algorithm.

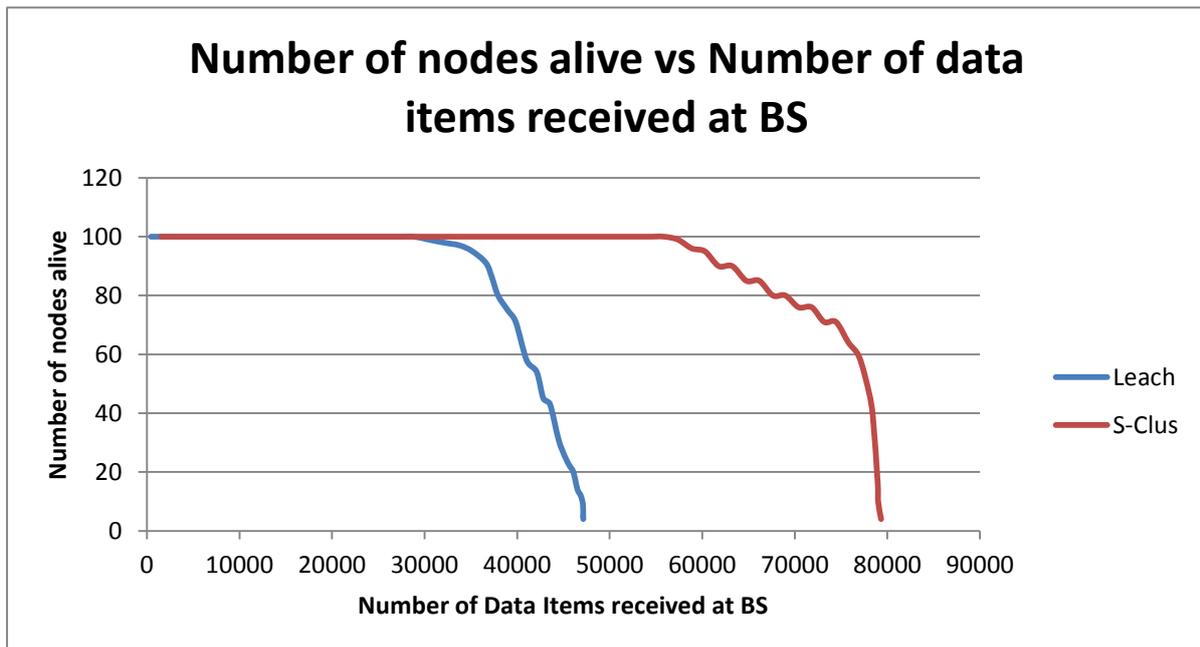


Figure 5.5: Number of nodes alive vs Number of data items received by BS

In Fig 5.5, we can observe that nodes in S-Clus can deliver as much as twice the data than LEACH for the same number of node deaths. There are two reasons that LEACH consumes more energy to transmit data to the BS: Probabilistic cluster head selection and difference in number of CH's.

Chapter 6

Conclusions

We discussed fundamental aspects of ultrasonic propagation in human tissues, and explored system trade-offs, including the selection of a transmission power, transmission frequency, and transducer size. We also discussed limitations of Radio Frequency electromagnetic communications in tissues, thus motivating the choice of ultrasonic waves. We proposed a new energy model required for ultrasonic propagation. Then we analysed one of the standard clustering algorithm LEACH and discussed its drawbacks and proposed a new algorithm for clustering S-Clus which uses distance and energy matrix to decide the cluster heads and divide clusters in a network. The simulation results in ns2 (shown in Chapter 4) demonstrated that the proposed algorithm S-Clus outperforms the existing protocol LEACH, in energy consumption and network lifetime. We obtained that our protocol is able to deliver more data signals to the BS than in normal clustering algorithms. Thus the proposed algorithm aims on enhancing the lifetime of sensors which are implanted in brain and hence avoids frequent implantation of sensors into the brain. The approach discussed in this work may thus pave the way for a new communication paradigm for Brain Computer Interface and has the potential to enable new applications for medical implants of sensors into the brain for physically impaired people.

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