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This is to certify that the thesis entitled **“Spatial Correlation Models Analysis for Wireless Sensor Network”** done by **ANIL KUMAR** (Roll Number: **2K12/SWT/04**) for the partial fulfillment of the requirements for the award of degree of **Master of Technology** in **Software Technology** in the **Department of Computer Science & Engineering**, Delhi Technological University, New Delhi is an authentic work carried out by him under my guidance.

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ABSTRACT

Wireless sensor networks (WSN) are deployed very densely so that accurate monitoring can be achieved in many applications. For example, the deployment density can be as high as 20 nodes/m3[1]. As sensor nodes are deployed with high density, the information observed and transmitted by sensor nodes in an area at the time an event is occurred is spatially correlated. It means there is spatial correlation in the sensors observations. The spatial correlation along with collaborative nature of the Wireless sensor networks (WSN) has potential advantages in designing energy-efficient models of Communication protocols.

There exists a spatial correlation function[7], which describes correlation characteristics of information sensed by sensor nodes, which is related to location and coverage model of sensor nodes.

This paper presents a study of various cluster head selection algorithms and proposes an energy efficient model for wireless sensor network by exploiting spatial correlation among various sensor nodes of the network. Firstly, study the behavior of wireless sensor network without spatial correlation. Secondly, we divide entire wireless sensor network into clusters assuming spatial correlation among the observations within the nodes of a cluster. One of the nodes of the cluster is considered as Cluster Head (CH) on random selection and sends the observation to Base Station (BS). In last part of analysis we make one of the Cluster Head (CH) as super Node (SN) that aggregates observations from all Cluster Head (CHs) and sends information to Base Station (BS). Finally, based on the above analysis and their results we propose an energy efficient model for wireless sensor network.

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LIST OF ABREVIATIONS

ACW : Adaptive Contention Window

BS : Base Station

CH : Cluster Head

CIPRA : Clustering and In Network Processing Routing Algorithm

EECHSSDA : Efficient CH Selection Scheme for Data Aggregation

ERA : Energy Residue Aware

HEED : Hybrid Energy-Efficient Distributed

HEF : High Energy First

LELACH : Low Energy Adaptive Clustering Hierarchy

SN : Super Node

TDMD : Time Division Multiple Access

WSN : Wireless Sensor Network

Chapter 1

Introduction

1.1 General Concepts

1.1.1 Wireless Sensor Network

A wireless sensor network (WSN) consists of spatially distributed sensor nodes [1], [2], [3] which monitors physical or environmental conditions, for example temperature, pressure or sound etc. These autonomous sensor nodes cooperate with each other and jointly pass their observations to main location through the network. A wireless sensor network may also be bi-directional which enables control of sensor nodes. The military applications have played significant role in evolvement of wireless sensor networks e.g. battlefield surveillance. The wireless sensor network is in use in many consumer and industrial applications, for example industrial process or machine monitoring and control [4] etc.

As mentioned above a wireless sensor network consists of "sensor nodes". On the basis of the type of application the wireless network is used, the total number of nodes in a sensor network may vary from a very [8] few e.g. 3 to several hundred/thousands. In WSN each node is communicating to one or many other sensors nodes. A wireless sensor node is consists of following parts:

- A radio transceiver
- A microcontroller, which is an electronic circuit, which interfaces with the sensors
- A source of source, a battery

Depending on the type of application a sensor node is used, complexity, its size and cost may vary from very tiny to lager and few to hundreds of dollars. These two constraints on sensor nodes i.e. Size and cost correspond to other constraints on resources e.g. computational speed, memory, energy and communications bandwidth. The various sensor nodes when connected to form a WSN, the topology may vary from star network to multi-hop.

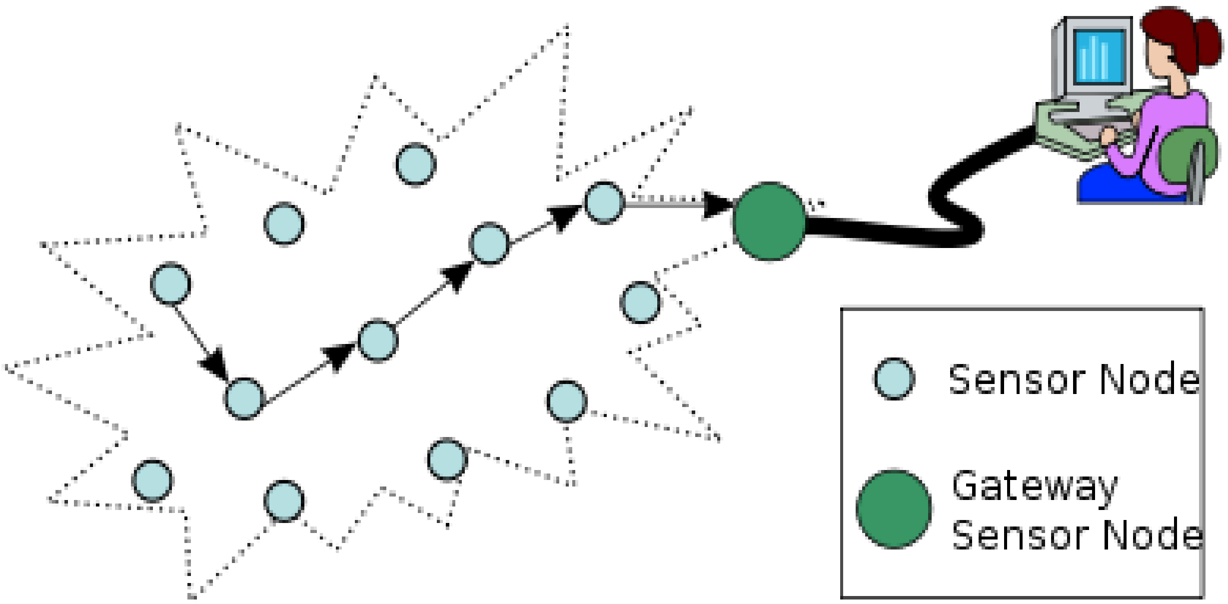

Figure 1: Wireless Sensor Network

1.1.2 Sink Node

A Wireless Sensor Network (WSN) generally has a sink node, which is also known as Base Station (BS) and a number of other sensor nodes, which are also called as regular nodes. The sink node is generally secure and has unlimited energy whereas the sensor nodes are generally unsecured and has limited energy. Each of the sensor nodes in wireless sensor network monitors surrounding geographical area and collect sensory observations. The collected Sensory information is sent to the BS through Wireless hop-by-hop transmissions. The collected sensory information is aggregated at an intermediate sensor node by using a suitable aggregation function. By aggregation the amount of network traffic is reduced which helps in saving energy of sensor nodes. The sink node is the entity which provides data access to end user.

1.1.3 Clustering And Cluster Head

In wireless sensor network (WSN) the entire network should be able to operate without any human intervention as human access to sensor nodes and their close monitoring is not easy. In most of the WSN applications the sensor nodes are randomly deployed in the area of interest. Since the area of interest is generally large and considering limited battery life of sensors nodes generally large nos. of sensor nodes are deployed which may vary from hundreds to even thousands. The sensor nodes having limited battery power are placed in such an area where recharging or replacing the sensor nodes battery is not easy.

To increase efficiency and network lifetime the sensor nodes in network are grouped together to form a ‘Cluster’ [5]. Once a cluster of sensor nodes is formed various routing and data aggregation algorithms are applied which results in large amount of overall energy saving of sensor nodes. In every cluster we have one node, which act as a leader; this node is known as ‘Cluster Head’ (CH). This cluster head node collects data from other nodes of cluster, aggregates and sends data to sink node.

Generally a WSN with clusters has two level of hierarchy, at higher level we have CHs and at lover level we have other sensor nodes of a cluster. The sensor nodes from lover level and transmit the sensory information they have to corresponding CH nodes. The CH nodes perform aggregation function and transmit the data to sink node. As CH nodes send aggregated data to sink node, which is located at a relatively far distance they spent more energy than other sensor nodes of network and may die sooner. Thus to balance the energy level of all sensor nodes of the network we need to re-elect the CH node in all the clusters periodically.

1.1.4 Super Node

In our model we consider a super node, which receives data from all CHs nodes, aggregates the data and sends to the sink node. The other way Super Node acts as BS for CHs.

1.1.5 Spatial Correlation

A wireless sensor network (WSN) consists of no. of sensor nodes which report the sensory observations to the sink node (BS). These nodes are deployed densely as they have limited battery energy. It has been observed that neighboring sensor nodes typically make similar kind of observations means they end up in reporting redundant information. This redundancy in data is because of spatial correlation among the sensor nodes [7].

1.2 Motivation

In wireless sensor network, the sensor nodes with limited capabilities are deployed randomly in the area of interest. One of the major goals while designing a wireless sensor network is to reduce energy dissipation and increase the lifetime of the network. Clustering is one of the approaches, which help in achieving this goal. There exists spatial correlation among the deployed sensor nodes of the network [7]. In this project we exploit spatial correlation model and with the help of experiments propose a wireless sensor model, which maximize the overall lifetime of the network.

1.3 Scope of work

This paper presents a study of various cluster head selection algorithms and proposes an energy efficient model for wireless sensor network by exploiting spatial correlation among various sensor nodes of the network. Firstly, study the behavior of wireless sensor network without spatial correlation. Secondly, we divide entire wireless sensor network into clusters assuming spatial correlation among the observations within the nodes of a cluster. One of the nodes of the cluster is considered as Cluster Head (CH) on random selection and sends the observation to Base Station (BS) on behalf of other sensor nodes of the cluster. In last part of analysis we make one of the Cluster Head (CH) as super Node (SN) that aggregates observations from all Cluster Heads (CHs) and sends information to Base Station (BS). Finally, based on the above analysis and their results we propose an energy efficient model for wireless sensor network.

1.4 Thesis organization

Chapter 1 begins with General concepts of wireless sensor network. It also addresses the topics like Motivation, Scope of work, and thesis organization.

Chapter 2 provides details about the background and related work. It talks about existing spatial correlation model.

Chapter 3 mentions the problem description.

Chapter 4 mentions about various cluster head selection methods.

Chapter 5 presents the proposed research methodology.

Chapter 6 shows simulation and results of proposed methodology.

Chapter 7 concludes the thesis.

Chapter 2

Background and Related work

2.1 Introduction

The wireless sensor network consists of low cost and power sensor nodes. The sensor nodes collect information from sensing environment such as surveillance fields, process the information and transmit it to sink nodes[7]. These sensor nodes cooperatively monitor physical environmental conditions (for examples temperature, sound, pressure etc.) accurately in space and time to detect the events of interest. Since sensor nodes have limited battery power, which gets depleted easily, the sensor nodes will die out in the network. The failure of nodes should not affect the overall performance of the network. However, it could be impossible to replace/change the battery, because sensor nodes may be deployed in remote locations and thus replacing the batteries could be costly or time-consuming. A significant amount of energy is consumed in transmission and reception and idle mode, while very low energy loss in sleep mode. Therefore, forcing the nodes into sleep mode whenever possible will be optimal solution to increase lifetime of the network.

The primary function of a sensor network is to sample sensory information from its vicinity such as temperature, light etc., and send this information to the base station node. The base station node mostly forwards all the data wire-line or an independent wireless network to control center. The sensor nodes in such network operate as a collective structure, which makes this network different than traditional ad-hoc networks.

As sensor nodes are deployed densely, spatially correlated information is collected and transmitted by neighboring sensor nodes once an interest of event appeared in sensor field. Thus it may not be necessary that every sensor nodes should report its sensed data to the sink due to redundancy in data. For example, in Fig. 2(a), four black nodes denote active nodes inside event area, and big circle denotes the correlation region, in which sensor nodes have similar readings. We can see that these four sensor nodes are selected according to correlation region to cover whole event area. Hence observed information from these selected sensor nodes are sufficient to detect/estimate the event source at the sink.

In addition, it is also noted here that redundant reports are minimized according to correlation characteristics among sensor nodes. For example, in Fig. 2(b) the six black nodes are insufficient to cover the entire event area and redundant information is also observed from these nodes at sink.

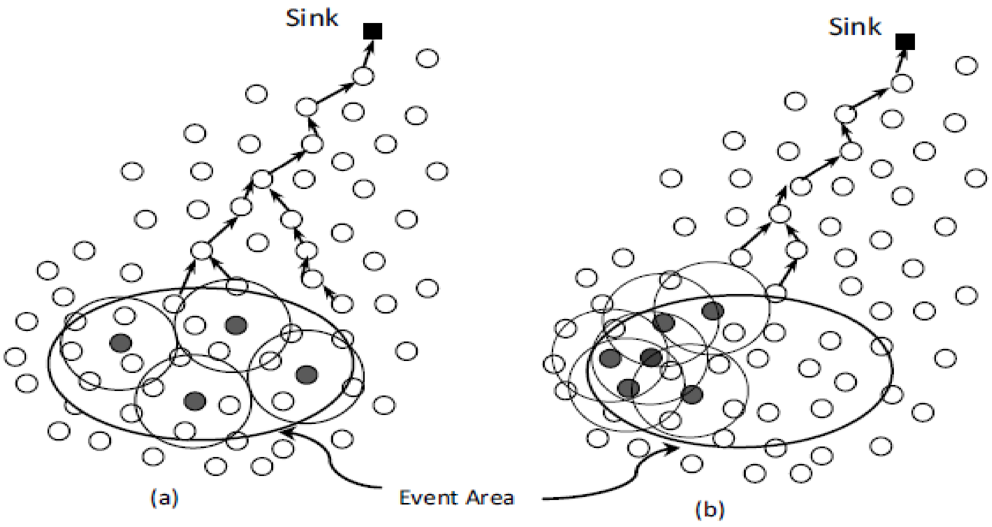

Figure 2: Examples of reporting of event information in an event area

The correlation characteristics among sensor nodes for various applications use in wireless sensor networks have been studied by Vuran et al. [9], Scaglione and Servetto [10], Yoon and Shahabi [11],Guoqiang et al. [12] etc. Based on sensor coverage model and location of nodes, a mathematical framework to drive correlation function for sensor network applications has been proposed. More specifically, given a certain area of interest, suppose there are N sensor nodes that can sense it. Correlation coefficients to describe the degree of correlation between N sensor nodes have been derived. After getting the spatial correlation coefficient (i.e. correlation function), the relationship between positions of nodes and correlation function has been studied. Intuitively, the spatial correlation between sensor nodes is directly related to the correlation characteristics of event information observed by these sensor nodes. If the sensor nodes are less correlated, they will provide more reliable information to the sink.

In densely deployed WSN, many sensor nodes in an event area observe the event information and send this information to the sink. Due to physical properties related to sensed event, this information is highly correlated based on correlation degree between sensor nodes, which is related to placement or location of sensor nodes. Fig. 2 gives the examples of such behavior. For a certain area of interest, suppose there are N sensor nodes that can sense it, we denote them N = {n1, n2, n3, ...} with spatial coordinates, {s1, s2, s3...}. There exists correlation among these nodes based on location, which is exploited to increase the overall network performance.

2.2 The Correlation Model

The correlation model helps in determining the mutually correlated nodes based on spatial location in randomly deployed sensor networks.

2.2.1 Sensor Deploying Model

Considering a sensor network application where large numbers of sensor nodes are deployed randomly over the surveillance region. An example of nodes deployment for WSN is shown in Fig. 3. The circle area indicates the event area; the dashed circle represents valid sensing area of the sensors; black node represents sink node; white nodes represent sensor nodes; and a random event is represented by star. Recall that wireless sensor networks are characterized by their coverage range (i.e., sensing range for detecting the events) and transmitting range (for communicating with sensor nodes).

The followings are the assumptions:

- All the sensor nodes are assumed to follow the Boolean disk coverage Model, which means that sensor nodes have fixed sensing radius and sensing area is represented by a disk centered at the sensor node’s spatial position. All the events within such a disk are sensed by the sensor node while no event outside the disk is sensed. This sensing model is traditionally known as omni directional sensing model [13].

- Apart from sensing range, each sensor node has a communication range, which is much larger than sensing range.
- The sink node is only interested in collective reports from all nodes of a detected event.
- There is no movement among sensor nodes after deployment, so the location information of each node is known and distance between its neighbors can also be acquired.

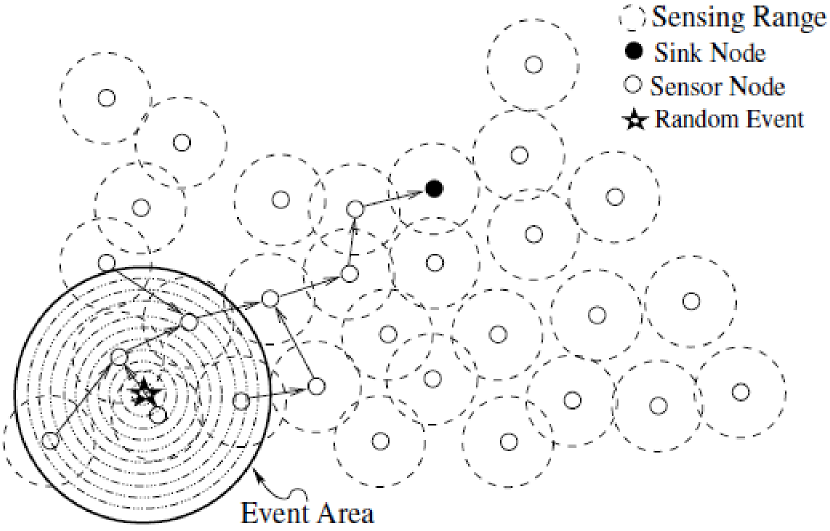

Figure 3: The Model Architecture

2.2.2 The Model

A correlation function to describe the degree of correlation among sensor nodes in the event area has been derived. Since a Boolean disk coverage model is considered with sensing range r at location si, sj , the fraction of common sensing area covered by two circular disks represents the correlation coefficient, denoted by Kθ{||si − sj ||} which is function of distance (i.e., ||si − sj ||) between sensor node ni and nj as shown in Fig. 4. Here θ will be a control parameter discussed later.

It is noted that intuitively, the spatial correlation between sensor nodes is directly related to the correlation characteristics of event information observed by these sensor nodes in spatial domain [10].

To find the correlation coefficient among N nodes in event area, assuming that N nodes observe the event source S in the event area. A mathematical model to compute the correlation with respect to event source S is constructed. The correlation between different sensor nodes can be described by their readings, which will be represented as a covariance function in set Z.

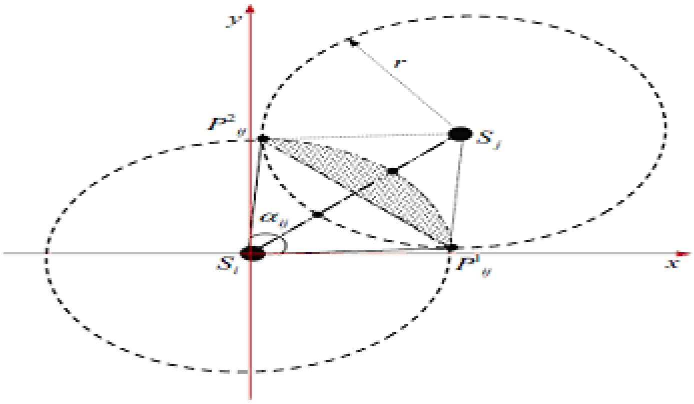

Figure 4: The spatial circular correlation model

From statistical properties, here Z is assumed to be a random matrix associated with measured readings of sensor nodes (i.e. correlation coefficients). Consider event area S is random field, total sensor nodes, N = {n1, n2, n3, ...} are within event area with spatial coordinates, {s1, s2, s3...}. The data set Z = {z(n1), z(n2), z(n3), ...} contains the measured information from all the sensor nodes. The sink node will be responsible for collecting these readings to compute the correlation characteristics between sensor nodes. Note that since event area is random variable, so Z is also assumed to be random variable. We use the notations zi,zj instead of z(ni), z(ni) for simplicity. The data set Z is associated with covariance function Kθ(.), which is function of correlation coefficients between the sensor nodes. Now, we found from statistical properties:

corr{zi, zj} = cov{zi, zj} / var{zi}.var{zj} = Kθ{||si − sj ||} (1)

where Kθ{||si − sj ||} denotes the correlation coefficient of sensor node ni and nj . The Kθ{||si − sj ||} decreases monotonically with distance d (i.e. ||si −sj ||) between sensor node ni and nj , located at si and sj respectively.

The correlation model derived can be represented in general form as following.

$$\begin{aligned} K_\theta(d) &= \frac{\cos^{-1}\left(\frac{d}{\theta}\right)}{\pi} - \frac{d}{\pi\theta^2}\cdot\sqrt{(\theta^2 - d^2)} && \text{For } 0 \le d \le \theta; \\ &= 0 && \text{For } d > \theta. \end{aligned}$$

θ = 2r, and d = ||si − sj ||. (2)

It is clearly seen from Eq. (2) that when covariance function Kθ (d) is 0, it means that there is no correlation between sensor node ni and nj, located at distance d to each other. If it is equal to 1, then sensor nodes are highly correlated.

The correlation model can do the best by partitioning the entire event area into correlated disjoint and equal-sized hexagons with radius Rcorr. A clustering mechanism is used for exploiting the spatial correlation in event area so that redundant transmissions from correlated neighbors can be suppressed more effectively. Exploiting the spatial correlation can be done into two phases using proposed correlation model, as following. In first phase, each cluster-head run the procedure of Algorithm 1 before execution of its dynamic clustering procedure. Hence cluster-head divides its clustered region into highly correlated regions according to application requirements in term of required reliability/distortion. Then in next phase, cluster-head will select only one member node in each correlation region to remain active during current round. After correlation-based selection, clustering protocol can execute its dynamic procedure on currently selected active member nodes. For example, best clustering protocol, LEACH [14] can perform the above operation before executing its dynamic clustering on selected active sensor nodes. Therefore, entire sensor field is represented by a subset of active sensor nodes, which perform its task well. In each round, clustering protocol can repeat the above procedure dynamically, further by exploiting the spatial correlation according to immediate application requirements in term of reliability/distortion. More specifically, the cluster head can run above procedure whenever there is need to change on the closeness among sensor nodes (by tuning θ), required reliability/distortion (by tuning ξ), and active member nodes due to depletion of energy of active member node. Therefore network-lifetime can be improved dynamically using correlation model.

Chapter 3

Problem Definition

As seen above in WSN to optimize the overall energy of sensor nodes and to increase the overall lifetime of network we group sensor nodes into clusters. Generally, the nodes of a cluster perform similar type of tasks [7]. Once a cluster of sensor nodes is formed various routing and data aggregation algorithms are applied which results in large amount of overall energy saving of sensor nodes [5]. In every cluster we have one node, which act as a leader, this node is known as ‘Cluster Head’ (CH). This cluster head node collects data from other nodes of cluster, performs fusion and aggregation and sends data to sink node.

This paper presents a study of various cluster head selection algorithms and proposes an energy efficient model for wireless sensor network by exploiting spatial correlation among various sensor nodes of the network. Firstly, study the behavior of wireless sensor network without spatial correlation. Secondly, we divide entire wireless sensor network into clusters assuming spatial correlation among the observations within the nodes of a cluster. One of the nodes of the cluster is considered as Cluster Head (CH) on random selection and sends the observation to Base Station (BS) on behalf of other sensor nodes of the cluster. In last part of analysis we make one of the Cluster Head (CH) as super Node (SN) that aggregates observations from all Cluster Heads (CHs) and sends information to Base Station (BS). Finally, based on the above analysis and their results we propose an energy efficient model for wireless sensor network.

Clustering is efficient scheme for data aggregation in the wireless sensor network [5]. In clustering each regular sensor node sends its sensory information data to the cluster head (CH) node. The cluster head aggregate the data received from all sensor nodes and then send the final aggregated data to the sink node. This data aggregation at cluster head also results in additional energy dissipation due to which cluster node dies sooner than other regular nodes which again results in need of re-clustering and cluster head selection. In this paper we study the behavior of the wireless sensor network with and without clustering and spatial correlation. In this propose method we will focus on avoiding re-clustering, reduce the overhead of clustering process, reduce the load over cluster head, and reduce the energy consumption within cluster in large-scale and dense sensor networks with the help of cluster head selection and cluster formation. To achieve these objectives we would like to present an algorithm in which CHs are selected from same cluster in each round and data are sent to sink node by CH to prolong increase the lifetime of network.

Chapter 4

Cluster Head Selection Methods

A wireless sensor network (WSN) [1], [2], [3] consists of spatially distributed sensor nodes, which monitors physical or environmental conditions, for example temperature, pressure or sound etc. These autonomous sensor nodes cooperate with each other and jointly pass their observations to main location through the network.

To increase efficiency and network lifetime the sensor nodes in the network are grouped together to form a 'Cluster'.

4.1 Clustering In WSN

As seen above in WSN to optimize the overall energy of sensor nodes and to increase the overall lifetime of network we need to group sensor nodes into clusters [5]. Generally, the nodes of a cluster perform similar type of tasks. Once a cluster of sensor nodes is formed various routing and data aggregation algorithms are applied which results in large amount of overall energy saving of sensor nodes. In every cluster we have one node, which acts as a leader, this node is known as 'Cluster Head' (CH). This cluster head node collects sensory information from other nodes of cluster, performs fusion and aggregation and sends the combined information to sink node (BS). Following parameters [6] we need to consider at the time of clustering of wireless sensor network:

4.1.1 Clustering Parameters

- Number of Clusters
- Intra-cluster Communication
- Node Type and Roles
- Cluster Head Selection
- Multiple Levels

4.1.2 Issues to be considered in Clustering

The way clusters are formed in WSN plays an important role as it directly influences the overall performance of the network in terms of energy dissipation and overall lifetime of the network. Following are some of the key limitations, which must be considered while forming the clusters:

- **Limited Energy:** The cluster nodes have limited energy, which needs to be considered while forming the clusters to optimize overall energy dissipation in the network.
- **Network Lifetime:** Since the cluster nodes have limited energy, the overall goal of clustering mechanism should be to save the energy, so that network lifetime can be enhanced.
- **Application Dependency:** A good clustering mechanism should be adapted for various kinds of applications.
- **Limited Abilities:** Since small sensor nodes of a cluster has small size and limited energy so clustering mechanism should use the shared resources in distributed structure while taking into consideration the limitation on individual sensor node abilities.

4.2 CLUSTERING ALGORITHMS BASED ON WITHOUT ENERGY CONSIDERATION

4.2.1 LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH)

In WSN nodes can be divided into following 2 types:

- Regular nodes
- Cluster Head nodes

Regular Nodes: These nodes send their sensory information to cluster heads

Cluster Head nodes: These nodes receive data from regular nodes, aggregate it and send to sink node. One-way cluster head nodes serve as sink node for regular nodes.

In this algorithm [14], sensor nodes are organized by LEACH protocol itself. The cluster Head(CH) selection is based on following:

- The desired % of CH nodes in the network and
- No.of times the node has been selected CH so far

This approach makes use of a random number for cluster head selection. A random number (between 0 and 1) is generated by each node of the network. A node becomes CH the random number generated by it is lesser than the set threshold value. The threshold value is calculated using following formula:

$T(n) = \{ Pd/1-Pd*(r \bmod 1/Pd)$, if $n \varepsilon G$ where

P*d* - > the desired percentage of clusters

r - > current round

G - > group of those which have not been considered as CH in last 1/P*d* rounds

Round: A time instant at which cluster formation, CH selection and data transmission take place. There are following two phases in each round:

- Set-up Phase
- Steady State Phase

Set-up Phase: Here CH announces its election by transmitting an advertisement signal to all other sensor nodes to construct a cluster.

Steady State Phase: I this phase each of the cluster head of network generates a time schedule for other nodes of the cluster based on TDMA. This time schedule tells the regular nodes when they should transmit their information to the CH node. All regular nodes of network send their sensory information to their respective cluster head nodes at the allocate time slot in schedule. The regular nodes switch ON their radio only at the allocated time period and for rest of the time their radio is kept switched OFF.

This results in lowering the energy dissipation of the regular nodes and thus saving the energy of all regular nodes and which results in achieving high network lifetime. At the end CH will aggregate the sensory information received from all the nodes and sends it to the sink node(BS).

Limitations: Following are some of the limitations of LEACH:

- As cluster head selection is random and there is no consideration about energy dissipation of nodes, there may be a case that CH may die sooner than regular nodes. If it happens, the whole cluster will become useless.
- This approach is not good to cover large area
- In this approach Cluster heads are not placed uniformly
- This approach does not address the schedulability and predictability

4.2.2 ADAPTIVE CONTENTION WINDOW BASED (ACW)

In this algorithm [15] back off value is used in cluster head selection. While transmission when nodes detect an idle channel, they send a frame, which is known back off. The node with minimum value is selected as CH. At the time of collision the node wait for a random time period and then start the transmission again. In this approach cluster heads are uniformly distributed and the probability of CH selection is more than that of LEACH algorithm. The nodes choose back off value from the contention window. But as in LEACH, this algorithm also does not consider the energy dissipation of nodes. The initial length of the contention window needs to be set properly otherwise it may lead to low probability of successful cluster head selection. As mentioned above in this algorithm cluster head selection is better than that of LEACH but this algorithm also does not consider predictability.

4.2.3 CLUSTERING AND IN NETWORK PROCESSING ROUTING ALGORITHM (CIPRA)

In this algorithm clustering and construction of routing tree are performed at the same time to reduce their energy, which is required to form a routing tree of sensed data (the routing is multi-hop routing tree in case. In this approach, data aggregation is done by all nodes to reduce the amount of data transmission. CH selection is based on the total nos. of sensor nodes and their unique ID. Formula i mod N for every round is used to obtain the CH. CH selection is rerun if nodes do not obtain the elected message. The routing tree is constructed after selection of CH and after this data is transmitted [16]. Each node while receiving message from parent nodes consumes an amount of energy. In this sensor nodes are dynamically able to adjust radio transmission energy to adapt the changes in network topology.

4.3 CLUSTERING ALGOS BASED ON ENERYGY CONSIDERATION

4.3.1 ENERGY RESIDUE AWARE (ERA)

In ERA, method of electing Cluster Head is similar to LEACH. However formation of cluster (i.e. how CH associates with other nodes) is different. Once CH selection is one, CH estimates it's RE [17] and broadcasts it's RE value in a message to all other nodes. CH calculates its RE as following:

RE*ch* = energy dissipation required for transmitting data to sink node - remaining energy of CH in current round

All other regular nodes of network also calculate their RE as following:

RE*rn* = energy dissipation required for transmitting data to every CH - remaining energy of node in current round

After this the regular nodes selects their CH as per the sum of maximum energy residue path. In this way ERA maximizes overall network lifetime by balancing the energy dissipation of the network. As compared to LEACH, ERA maximize overall network lifetime by balancing the energy dissipation of nodes.

4.3.2 LEACH CERTRALIZED (LEACH - C)

In LEACH-C algorithm CH selection is based on current location of node and RE [18]. In the beginning current location of node and its RE level is transmitted to sink node. Based on energy level information received from each node, the sink node calculates the average energy level. The nodes whose energy level is more than the calculated average energy level will be elected as CHs. Once sink node selected the CHs, it broadcasts the CH's Id information message to all the nodes whose energy level was considered while calculating the average energy level. Once the nodes receive this message the node whose Id is mentioned in the message becomes CH. Since LEACH-C is based on current location and RE, Cluster Heads are located throughout the network. As average energy level calculated at sink node is based on RE level received from each node, if any of the node fails to report its energy level to sink node then CH selection will not be appropriate.

4.3.3 EFFICIENT CH SELECTION SCHEME FOR DATA AGGREGATION (EECHSSDA)

EECHSSDA [19] is advanced version of LEACH-C to overcome its problem. CH selection algorithm of EECHSSDA is same as of LEACH-C. Once energy level is decreased at CH, it selects Associate CH (A_{CH}). When CHs energy decreased and it’s going to die, A_{CH} becomes CH. The node, which has more energy level when the energy level of CH is lesser than average energy becomes A_{CH}. As we have A_{CH}, there is no need to select the CH again and again. This algorithm reduces load overhead, energy dissipation and thereby no need to select CH again and again. EECHSSDA ensures to select best cluster head, energy efficiency, but it does not address any schedulability bounds of network; hence it is not focused on predictability.

4.3.4 HYBRID ENERGY-EFFICIENT DISTRIBUTED CLUSTERING (HEED)

This algorithm [20] is generally used in hierarchical, distribute network. In this approach there is single hop communication between cluster nodes whereas between CHs and sink node multi-hop communication is used. There are two parameters to decide on CH selection:

- Residual energy of sensor nodes of cluster (RE)
- The communication cost within the cluster (CC)

RE is used to select initial set of CHs whereas decision to join a cluster or not is based on CC. The CC is based on node‘s proximity to its neighbor.

The probability (P_{ch}) of becoming a CH is calculated as follows by each sensor node as follow:

$$P_{ch} = P_{ch} * RE/E_{max}$$

This Pch value should not exceed the threshold value P_{min}. The threshold value P_{min} is inversely proportional to E_{max}.

The number of iterations is constant in this algorithm. The nodes keep on going through this iteration until they locate a cluster head with minimum CC.

P*ch* value for every node is doubled at the end of iteration. Iteration keeps on going till P*ch* value becomes 1. Based on Pch value two types of status are share with neighboring nodes:

i) Node becomes a tentative CH with P*ch* value < 1

ii) Node becomes permanently a CH if its P*ch* ~ 1

At the end final CHs are known to be CHs, and tentative CH are called as regular sensor nodes.

4.3.5 PROBALILISTIC CLUSTERING ALGORITHM

Probabilistic Clustering algorithm is advance and enhanced version of HEED [21]. This algorithm is mainly used in sparse networks where it generates small no. of cluster head in just lesser no. of rounds. This is achieved in following three steps:

i) Firstly select a Core Head

ii) Then select Cluster Head

iii) Then Finalize the CH

While selecting Core Head each node with least cost elect itself as Core Head, if a node does not find its cost as least cost then it will elect its neighbor, which has least cost as Core Head.

While selecting Cluster Head all other nodes than which are elected as Core Heads are considered. Selection of Cluster Head is same as HEED. While finalizing the CH, final CHs are known to be CHs, and tentative CHs are called as regular sensor nodes.

4.3.6 HIGH ENERGY FIRST ALGORITHM (HEF)

HEF algorithm is used to select best CH and to maximize the lifetime of network [22]. This algorithm works on the concept of maximum residual energy. We calculate energy dissipation of CH and other sensor nodes of network after each round. After calculation of energy dissipation the cluster node with maximum energy will be elected as CH. Here formation of cluster is similar to LEACH. As this is based on residual energy, the node with high residual energy is selected as CH at each round. In this way energy dissipation rate of all sensor nodes of network is linear which results in high packet delivery rate.

Chapter 5

Proposed Methodology

In our analysis we are considering a network of 100 nodes, which are deployed randomly. The sink node with unlimited is located at 110 * 110 position. The sensor nodes have limited lifetime and sense information from surrounding environment and send to sink node. The battery of sensor nodes is not chargeable. Therefore there is a need to design energy efficient wireless sensor network to achieve maximum lifetime of overall network. The sensor nodes are considered equal in terms of capabilities and given equal importance. The all sensor nodes provide similar kind of information from their surrounding area.

As mentioned in Chapter 2, ‘Related Work’ the nodes, which are spatially co-related, observe similar kind of information so the entire sensing area can be divided to form clusters [7]. We divide the entire sensing area and sensor nodes based on their location into 10 clusters and select one node from each cluster as cluster head on random basis. This cluster head sends the information to sink node, which other nodes remain in sleep mode.

In last part we propose that one super node will be selected among the 10 cluster head nodes. Each cluster head will send its information to the super node which will aggregate all information received from all 10 cluster head nodes apply compression and sends the final information to the sink node.

In our analysis, we assume that a sensor node will consume 50nJ/bit energy (E) for sending and receiving the data. The energy dissipated by a sensor node n in sending an N-bit data packet will be,

$E_D = E.\ N\ .D$ *where* (1)

E_D *-> Energy dissipated by sensor node in each round*

E -> Energy dissipated by sensor node for sending or receiving per bit

N -> Data packet size

D -> Distance of node from sink node which is calculated as following:

$$D = \text{sqrt}\left((\text{node}\ [n].\ x - 110)*(\text{node}\ [n].\ x - 110) + (\text{node}\ [n].\ y - 110)*(\text{node}\ [n].\ y - 110)\right) \qquad (2)$$

Where x and y are position coordinate of node n.

Chapter 6

Simulation and Results

In this chapter we simulate the proposed methodology using C.

6.1 Wireless Sensor Network Configuration

In the simulation, we have taken a wireless sensor network which 100 sensor nodes and one sink node. The sensor nodes are deployed randomly and distributed in a 100×100 square meter area. The position of sink node is considered as 110*110. The sink node has no energy limitation whereas other sensor nodes which are also called as common nodes have limited energy. We assume that all sensor nodes position is fixed and they have no mobility. For the simulation we set the energy dissipated (E) per bit by a sensor node to be 50 nJ. Assuming all sensor nodes have initial energy as 100 Joule. Also we consider that packet size of sensory data sent by a sensor node to be 200 Kbytes, which includes a header of 4 Bytes.

Sr. No.	Parameter	Value
1	Initial Node Power	100 Joule
2	Total No. of Nodes	100
3	Nodes Distribution	Random
4	N/W Area	100 * 100 Sq Meter
5	Nodes Mobility	No
6	Information Packet Size	200 KBytes
7	Packet Header Size	4 Bytes
8	E(Energy Required in Transmission)	50 nJ/Bit
9	Sink Node Position	110 * 110

Table 1: Wireless Sensor Network Configuration Parameters

6.2 Direct Transmission (without Spatial Correlation)

In Direct Transmission we consider that each node of sensor network i.e. all regular nodes sense the information from the surrounding environment and send that information to the sink node directly. Here no consideration is given to spatial correlation and clustering is one among the nodes. We have taken 100 nodes, which are deployed randomly. As mentioned above the energy dissipation in sending a data packet of sensory information to sink node is dependant on distance of sensor node from sink node. This is the reason the nodes, which are near to the sink node, can live longer whereas the nodes which are far from the sink die sooner. In this approach we see that average lifetime of overall network is 1,673 rounds whereas some of the nodes die sooner than the average lifetime, on the other hand the nodes which are near to the sink last for around 3, 000 rounds.

Table 2 shows the simulation for 11 nodes i.e. Node 1, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100. It mentions total rounds of data transmission each node is able to perform before it dies. Among the 11 nodes node 7, which located at farthest distance (x 29: y: 25) from the sink node dies sooner than other 10 nodes. Whereas the node 1, which is locate at nearest distance (x 80: y: 83) last for longer and dies after all other 1 nodes.

The simulation results are also shown in graphical form in figure 5. In figure 5, in the graph on Y-axis we have plotted the energy level of nodes and on X-axis we have considered total nos. of rounds.

Direct Transmission (Energy Dissipation Vs Total Rounds)											
Node	**1** **X: 41** **Y: 85**	**10** **X: 80** **Y: 83**	**20** **X: 67** **Y: 97**	**30** **X: 57** **Y: 71**	**40** **X: 52** **Y: 13**	**50** **X: 02** **Y: 78**	**60** **X: 47** **Y: 59**	**70** **X: 29** **Y: 25**	**80** **X: 77** **Y: 39**	**90** **X: 74** **Y: 42**	**100** **X: 88** **Y: 20**
Total Rounds	**1,704**	**3,098**	**2,783**	**1,900**	**1,107**	**1,110**	**1,426**	**1,065**	**1,597**	**1,625**	**1,350**
100	94.13	96.77	96.41	94.74	90.96	90.99	92.98	90.61	93.74	93.84	92.59
200	88.26	93.54	92.81	89.47	81.92	81.98	85.97	81.21	87.47	87.69	85.18
400	76.52	87.08	85.62	78.94	63.83	63.95	71.94	62.43	74.95	75.38	70.35
800	53.03	74.17	71.25	57.89	27.67	27.91	43.88	24.86	49.89	50.76	40.70
1,065	37.47	65.61	61.73	43.94	3.71	4.03	25.29	-0.04	33.29	34.45	21.06
1,107	35.01	64.26	60.22	41.73	-0.09	0.25	22.34		30.66	31.86	17.95
1,110	34.83	64.16	60.11	41.57		-0.03	22.13		30.47	31.68	17.73
1,350	20.74	56.41	51.48	28.93			5.29		15.44	16.90	-0.06
1,426	16.28	53.96	48.75	24.93			-0.04		10.68	12.23	
1,597	6.24	48.43	42.61	15.93					-0.03	1.70	
1,625	4.59	47.53	41.60	14.46						-0.02	
1,704	-0.04	44.98	38.76	10.30							
1,900		38.65	31.72	-0.02							
2,783		10.14	-0.01								
3,098		-0.03									

Table 2: Direct Transmission (Energy Dissipation Vs Total Rounds)

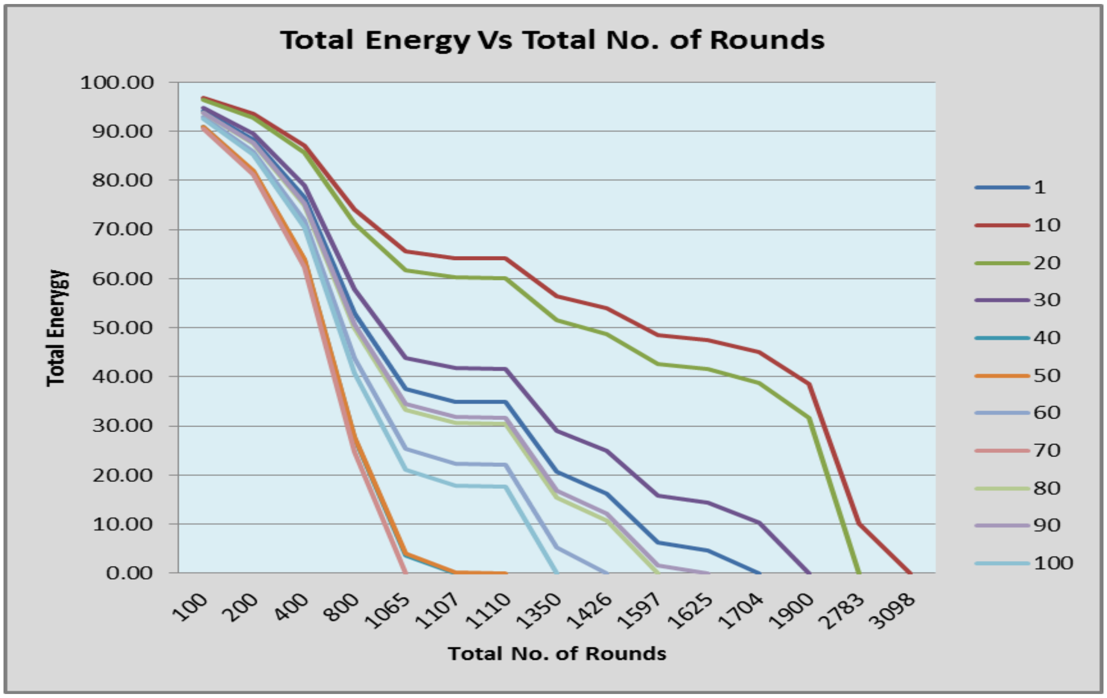

Figure 5: Direct Transmission (Energy Dissipation Vs Total Rounds)

6.3 Cluster Head Transmission (without Spatial Correlation)

In cluster head transmission first we divide entire wireless sensor network of 100 regular sensor nodes (which are deployed randomly) into 10 clusters. Each cluster consists of 10 sensor nodes. Assuming no spatial correlation among the observations within the nodes of a cluster we make all nodes of the cluster to send the observed sensory information to sink node (BS). However, sending all nodes directly to sink node (BS), one node (cluster head) will collect the information and send the information to sink node (BS). The CH node will collect information from nodes of cluster and send the combined information to sink node (BS). The selection of cluster head is done randomly. This node, which sends information to sink node, is selected randomly. We called this node as cluster head. The CH node will remove the redundant information such as common header information, aggregate the information and apply the compression on the aggregate information and send the final data to the sink node (BS).Once cluster head dies we select another cluster head among the remaining 9 nodes of the cluster and this process continues till all nodes of the cluster die. This way we are able to save energy of the sensor nodes and increase the total lifetime of the network (1,976 rounds) which is approximately 300 rounds more than that of direct transmission (1,673 rounds).

Table 3 shows total nos. of rounds after every 10 nodes of the network die i.e. after total nos. of live nodes 100, 90, 80, 70, 60, 50, 40, 30, 20, 10 and 1. From the simulation results we found that first node of the network dies after20 rounds whereas the last node of the network dies after 1,976 rounds.

No. of Live Nodes	Rounds
100	20
90	250
80	429
70	604
60	789
50	950
40	1,150
30	1,365
20	1,592
10	1,808
1	1,976

Table 3: CH Transmission – without Spatial Correlation

The simulation results are also shown in graphical form in figure 6. In figure 6, in the graph on Y-axis we have plotted the total nos. of rounds and on X-axis we have considered total nos. of live nodes of the network.

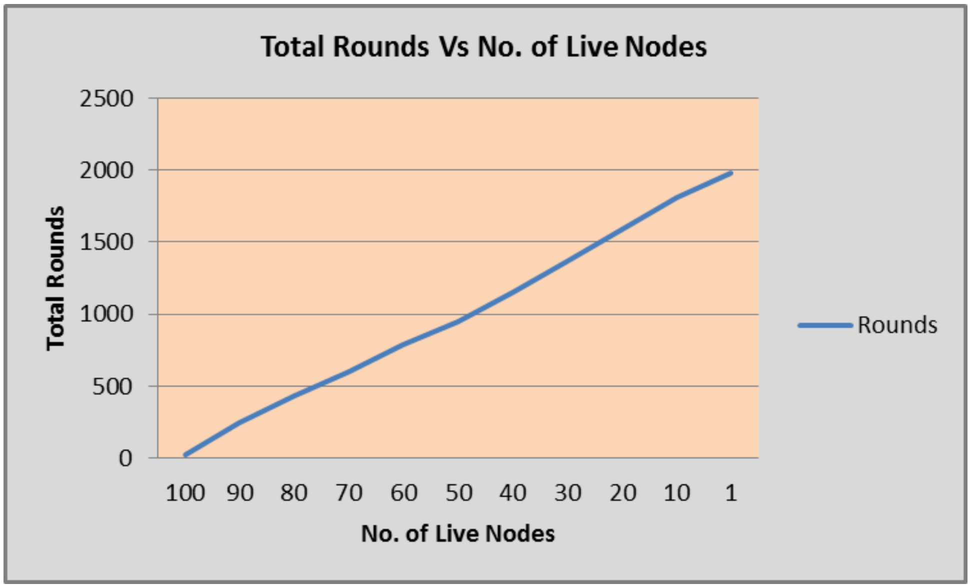

Figure 6: CH Transmission – without Spatial Correlation

6.4 Cluster Head Transmission (with Spatial Correlation)

In cluster head transmission first we divide entire wireless sensor network of 100 regular sensor nodes (which are deployed randomly) into 10 clusters. Each cluster consists of 10 sensor nodes. Assuming spatial correlation among the observations within the nodes of a cluster we make only one node of the cluster to send the observed sensory information to sink node. This node, which sends information to sink node, is selected randomly. We called this node as cluster head. While cluster head sends the information to sink node all other nodes of the cluster remain in sleep mode i.e. energy dissipation is caused only for cluster head node and not for other regular nodes of the cluster. Once cluster head dies we select another cluster head among the remaining 9 nodes of the cluster and this process continues till all nodes of the cluster die. This way we are able to save energy of the sensor nodes and increase the total lifetime of the network (16,737 rounds) which is approximately 8 times more than that of CH transmission(without Spatial Correlation) (1,976 rounds).

Table 4 shows total nos. of rounds after every 10 nodes of the network die i.e. after total nos. of live nodes 100, 90, 80, 70, 60, 50, 40, 30, 20, 10 and 1. From the simulation results we found that first node of the network dies after 170 rounds whereas the last node of the network dies after 16,737 rounds.

No. of Live Nodes	Rounds
100	170
90	2,119
80	3,639
70	5,117
60	6,689
50	8,052
40	9740
30	11,562
20	13,485
10	15,317
1	16,737

Table 4: CH Transmission – with Spatial Correlation

The simulation results are also shown in graphical form in figure 7. In figure 7, in the graph on Y-axis we have plotted the total nos. of rounds and on X-axis we have considered total nos. of live nodes of the network.

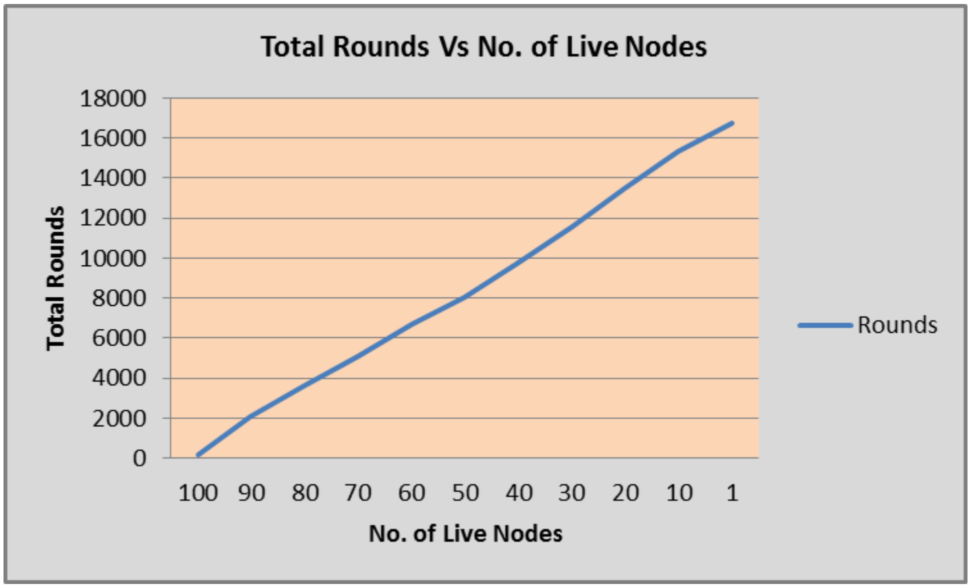

Figure 7: CH Transmission – with Spatial Correlation

6.5 Super Node Transmission (without Spatial Correlation)

In super node transmission first we follow the same steps as in ‘cluster head transmission (without spatial correlation)’ to divide entire wireless sensor network of 100 regular sensor nodes (which are deployed randomly) into 10 clusters. Each cluster consists of 10 sensor nodes. Assuming no spatial correlation among the observations within the nodes of the cluster the information sensed by all nodes from the cluster will be sent to sink node (BS). However, sending all nodes directly to sink node (BS), one node (cluster head) will collect the information and send the information to super node. The super node will collect information from all cluster heads and send the combined information to sink node (BS). The selection of cluster head and super node is done randomly. As mentioned we have 10 clusters and 10 cluster heads. We make one cluster head as super node among the 10 cluster heads. All cluster heads will send their information to super node, the super will remove the redundant information such as common header information, aggregate the information and apply the compression on the aggregate information and send the final data to the sink node (BS). When super node dies we select another cluster head and super node based on above methodology and this process continues till all nodes of the network die. This way the energy of sensor nodes is saved to enhance the total lifetime of the network (2,286 rounds), which is approximately 310 rounds more than that of cluster head transmission (without spatial correlation) (1,976 rounds).

Table 5 shows total nos. of rounds after every 10 nodes of the network die i.e. after total nos. of live nodes 100, 90, 80, 70, 60, 50, 40, 30, 20, 10 and 1. From the simulation results we found that first node of the network dies after 23 rounds whereas the last node of the network dies after 2,286 rounds.

No. of Live Nodes	Rounds
100	23
90	288
80	496
70	698
60	912
50	1,099
40	1,329
30	1,578
20	1,841
10	2,091
1	2,286

Table 5: SN Transmission – without Spatial Correlation

The simulation results are also shown in graphical form in figure 8. In figure 8, in the graph on Y-axis we have plotted the total nos. of rounds and on X-axis we have considered total nos. of live nodes of the network.

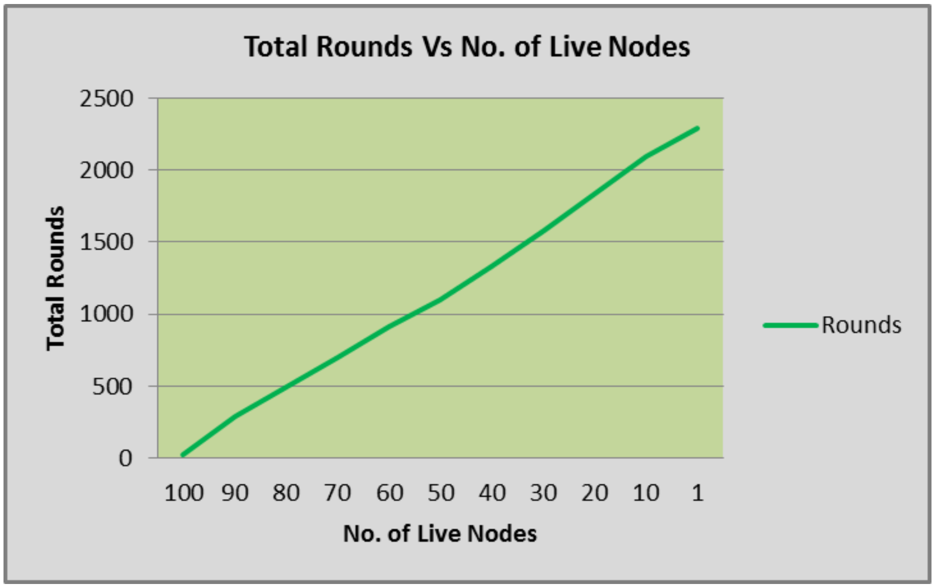

Figure 8: SN Transmission – without Spatial Correlation

6.6 Super Node Transmission (with Spatial Correlation)

In super node transmission first we follow the same steps as in 'cluster head transmission' to divide entire wireless sensor network of 100 regular sensor nodes (which are deployed randomly) into 10 clusters. Each cluster consists of 10 sensor nodes. Assuming spatial correlation among the observations within the nodes of a cluster the information sensed by only one node from the cluster will be sent to sink node (BS). The selection of this node, whose information will be sent, is done randomly. We called this node as cluster head. In this case the cluster head will not be sending information to sink node directly. As mentioned we have 10 clusters and 10 cluster heads. We make one cluster head as super node among the 10 cluster heads. All cluster heads will send their information to super node, the super will remove the redundant information such as common header information, aggregate the information and apply the compression on the aggregate information and send the final data to the sink node (BS). When super node dies we select another cluster head and super node based on above methodology and this process continues till all nodes of the network die. This way the energy of sensor nodes is saved to enhance the total lifetime of the network (22,401 rounds), which is approximately 33% more than that of cluster head transmission (16,737 rounds).

Table 6 shows total nos. of rounds after every 10 nodes of the network die i.e. after total nos. of live nodes 100, 90, 80, 70, 60, 50, 40, 30, 20, 10 and 1. From the simulation results we found that first node of the network dies after 228 rounds whereas the last node of the network dies after 22,401 rounds.

No. of Live Nodes	Rounds
100	228
90	2,836
80	4,871
70	6,850
60	8,955
50	10,779
40	13,037
30	15,475
20	18,049
10	20,500
1	22,401

Table 6: SN Transmission – with Spatial Correlation

The simulation results are also shown in graphical form in figure 9. In figure 9, in the graph on Y-axis we have plotted the total nos. of rounds and on X-axis we have considered total nos. of live nodes of the network.

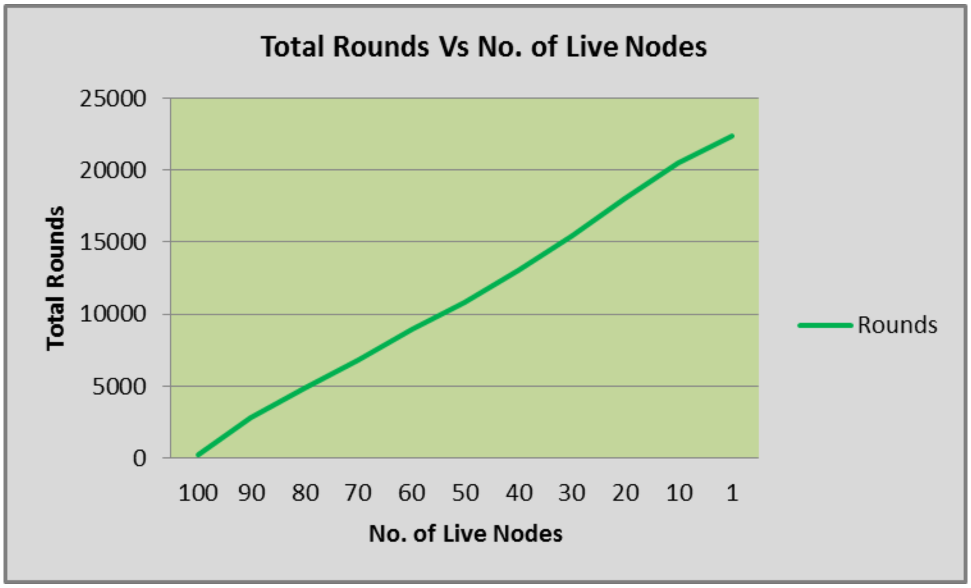

Figure 9: SN Transmission – with Spatial Correlation

6.7 Discussion

As seen above in our simulation results in section 6.2, 6.3, 6.4, 6.5 and 6.6 by exploiting spatial correlation between the sensor nodes we are able to increase the total lifetime of the network. Table 7 shows total nos. of rounds after every 10 nodes of the network die i.e. after total nos. of live nodes 100, 90, 80, 70, 60, 50, 40, 30, 20, 10 and 1 for CH and SN transmission with and without considering spatial correlation between the sensor nodes of the network and same is represented in graphical form in figure 8.

No. of Live Nodes	No. of Rounds			
	No Spatial Correlation		With Spatial Correlation	
	CH1	SN1	CH2	SN2
100	20	23	170	228
90	250	288	2,119	2,836
80	429	496	3,639	4,871
70	604	698	5,117	6,850
60	789	912	6,689	8,955
50	950	1,099	8,052	10,779
40	1,150	1,329	9,740	13,037
30	1,365	1,578	11,562	15,475
20	1,592	1,841	13,485	18,049
10	1,808	2,091	15,317	20,500
1	1,976	2,286	16,737	22,401

Table 7: CH and SN Transmission Comparison with and without Spatial Correlation

In figure 10, in the graph on Y-axis we have plotted the total nos. of rounds and on X-axis we have considered total nos. of live nodes of the network.

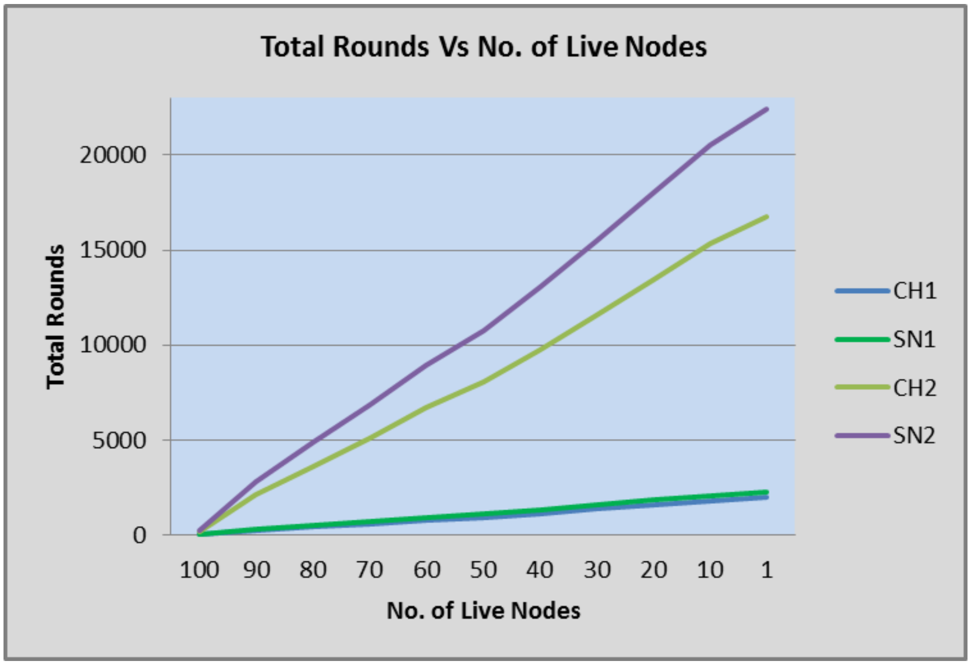

Figure 10: CH and SN Transmission Comparison with and without Spatial Correlation

Chapter 7

Conclusion & Future Work

Based on our simulation results in last chapter we conclude that total lifetime of the wireless sensor network increases when we perform clustering among the sensor nodes based on Spatial Correlation and make the transmission through cluster head and super node. In our simulation we have selected the cluster head node and super node randomly and we have proven that considering spatial correlation among the sensor nodes, clustering and transmission through cluster head node and super node increases total lifetime of network around 10 times and 13 times than that of direct transmission. In future we will apply various combinations of cluster head selection approaches as mentioned in Chapter 4 to elect the cluster head node and super node and propose a comparative study to decide on most efficient wireless sensor network configuration.

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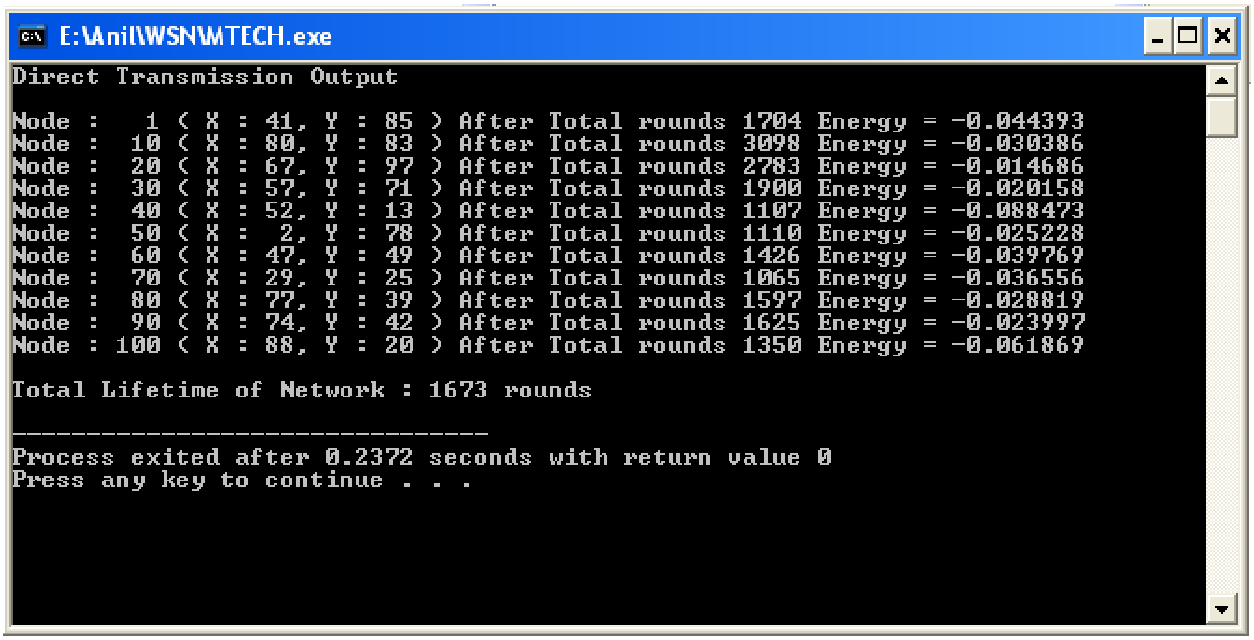
Appendix

- **A1 : Direct Transmission (without Spatial Correlation)**



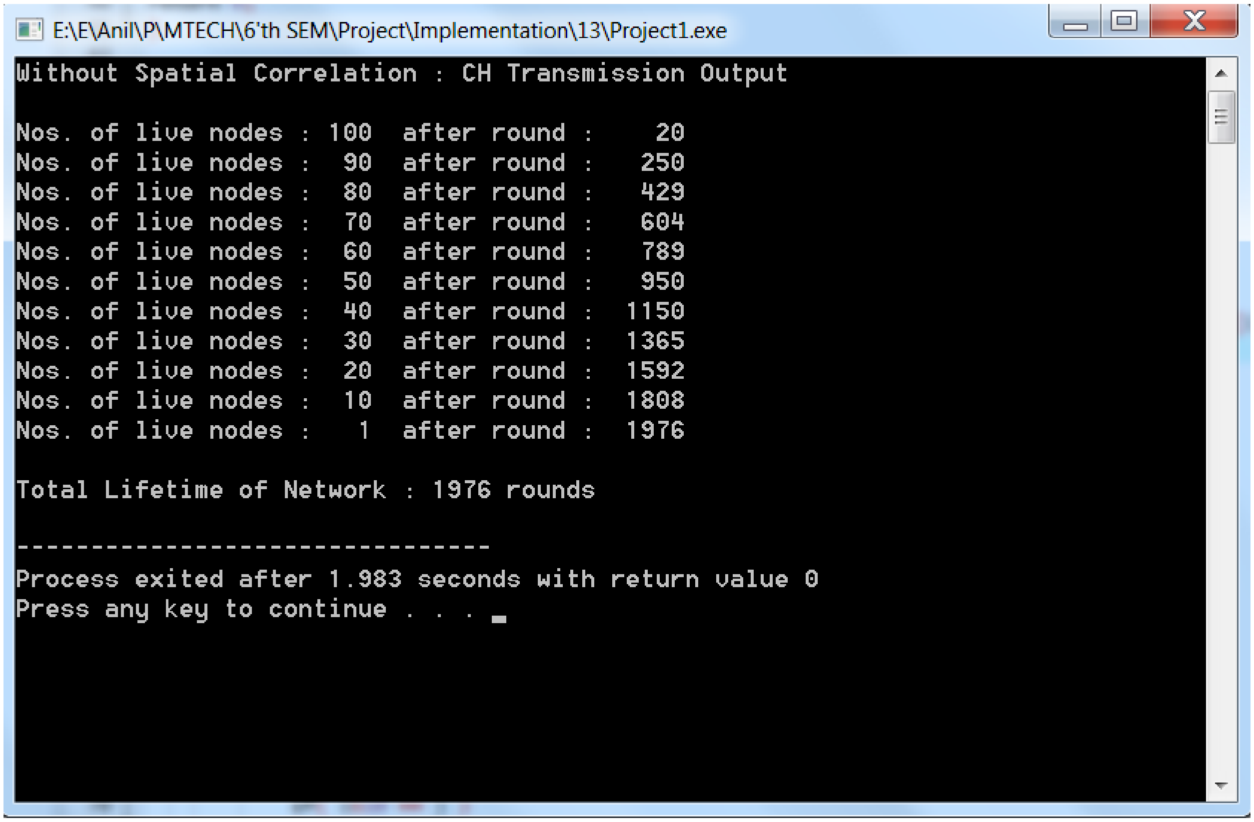
```
Direct Transmission Output

Node :   1 ( X : 41, Y : 85 ) After Total rounds 1704 Energy = -0.044393
Node :  10 ( X : 80, Y : 83 ) After Total rounds 3098 Energy = -0.030386
Node :  20 ( X : 67, Y : 97 ) After Total rounds 2783 Energy = -0.014686
Node :  30 ( X : 57, Y : 71 ) After Total rounds 1900 Energy = -0.020158
Node :  40 ( X : 52, Y : 13 ) After Total rounds 1107 Energy = -0.088473
Node :  50 ( X :  2, Y : 78 ) After Total rounds 1110 Energy = -0.025228
Node :  60 ( X : 47, Y : 49 ) After Total rounds 1426 Energy = -0.039769
Node :  70 ( X : 29, Y : 25 ) After Total rounds 1065 Energy = -0.036556
Node :  80 ( X : 77, Y : 39 ) After Total rounds 1597 Energy = -0.028819
Node :  90 ( X : 74, Y : 42 ) After Total rounds 1625 Energy = -0.023997
Node : 100 ( X : 88, Y : 20 ) After Total rounds 1350 Energy = -0.061869

Total Lifetime of Network : 1673 rounds

--------------------------------
Process exited after 0.2372 seconds with return value 0
Press any key to continue . . .
```

- **A2 : CH Transmission (without Spatial Correlation)**



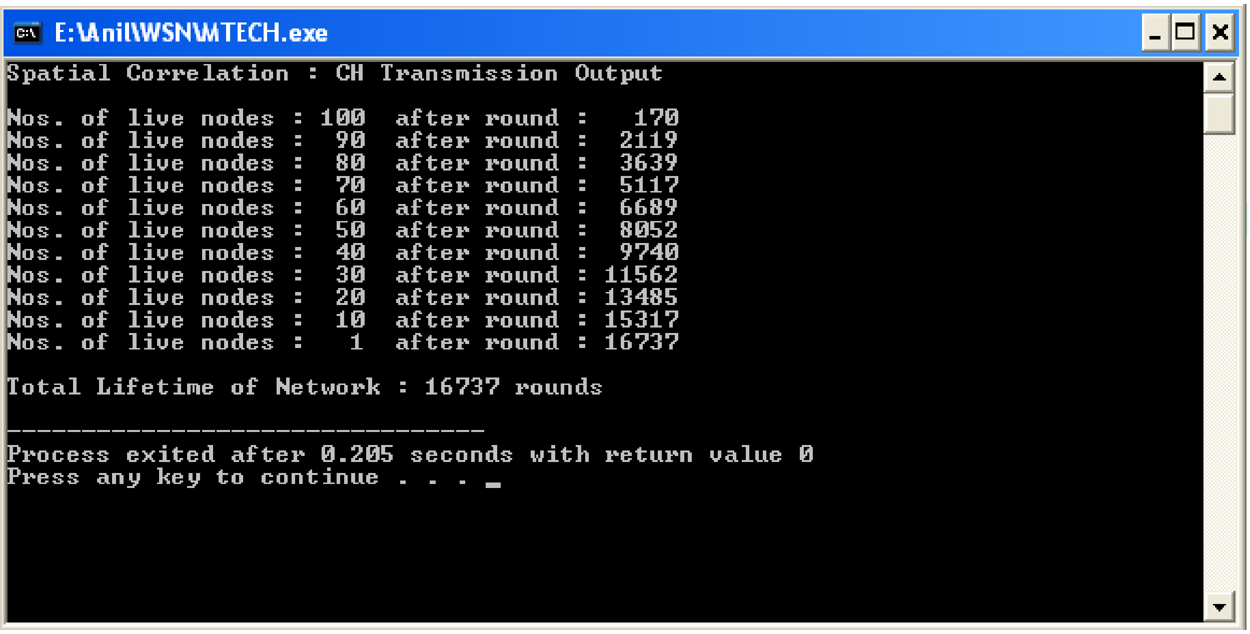
```
Without Spatial Correlation : CH Transmission Output

Nos. of live nodes : 100  after round :    20
Nos. of live nodes :  90  after round :   250
Nos. of live nodes :  80  after round :   429
Nos. of live nodes :  70  after round :   604
Nos. of live nodes :  60  after round :   789
Nos. of live nodes :  50  after round :   950
Nos. of live nodes :  40  after round :  1150
Nos. of live nodes :  30  after round :  1365
Nos. of live nodes :  20  after round :  1592
Nos. of live nodes :  10  after round :  1808
Nos. of live nodes :   1  after round :  1976

Total Lifetime of Network : 1976 rounds

--------------------------------
Process exited after 1.983 seconds with return value 0
Press any key to continue . . .
```

A3: CH Transmission (with Spatial Correlation)



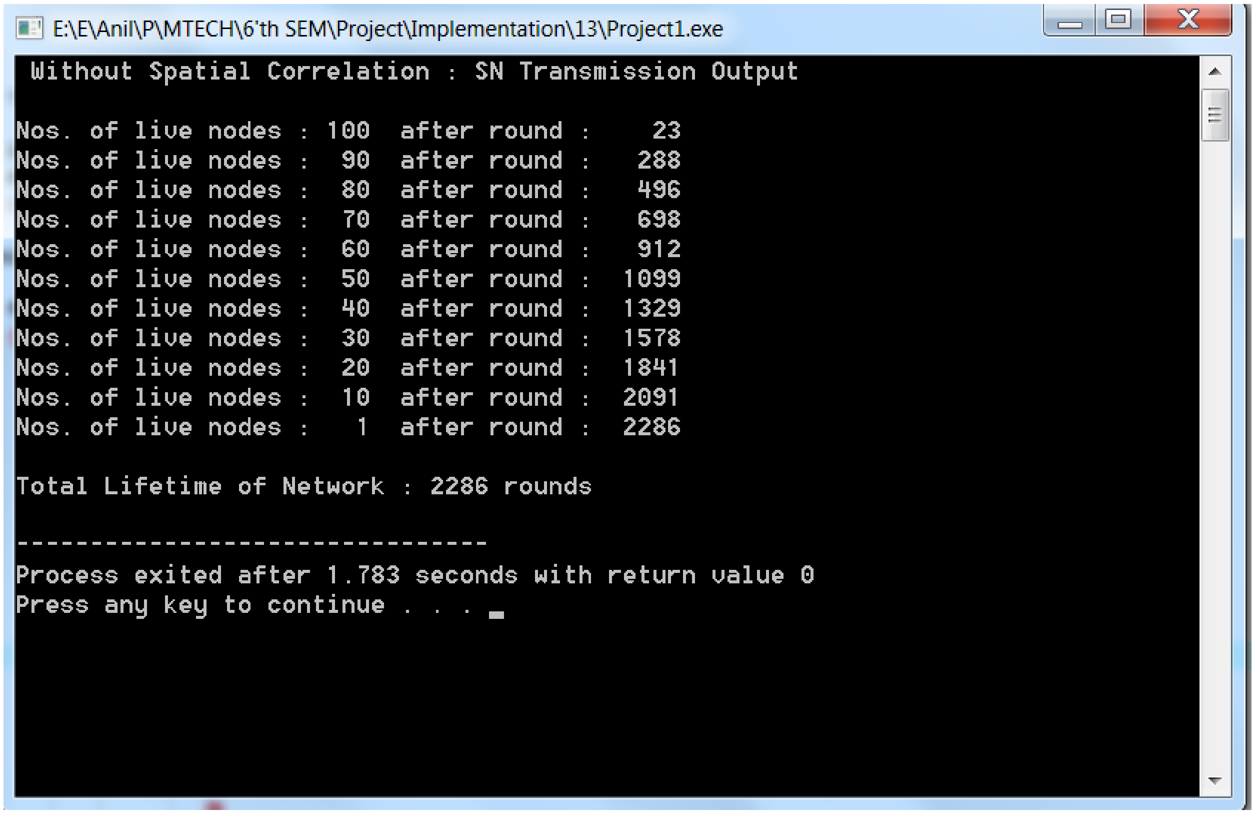
```
Spatial Correlation : CH Transmission Output

Nos. of live nodes : 100  after round :   170
Nos. of live nodes :  90  after round :  2119
Nos. of live nodes :  80  after round :  3639
Nos. of live nodes :  70  after round :  5117
Nos. of live nodes :  60  after round :  6689
Nos. of live nodes :  50  after round :  8052
Nos. of live nodes :  40  after round :  9740
Nos. of live nodes :  30  after round : 11562
Nos. of live nodes :  20  after round : 13485
Nos. of live nodes :  10  after round : 15317
Nos. of live nodes :   1  after round : 16737

Total Lifetime of Network : 16737 rounds

--------------------------------
Process exited after 0.205 seconds with return value 0
Press any key to continue . . . _
```

- **A4 : SN Transmission (without Spatial Correlation)**



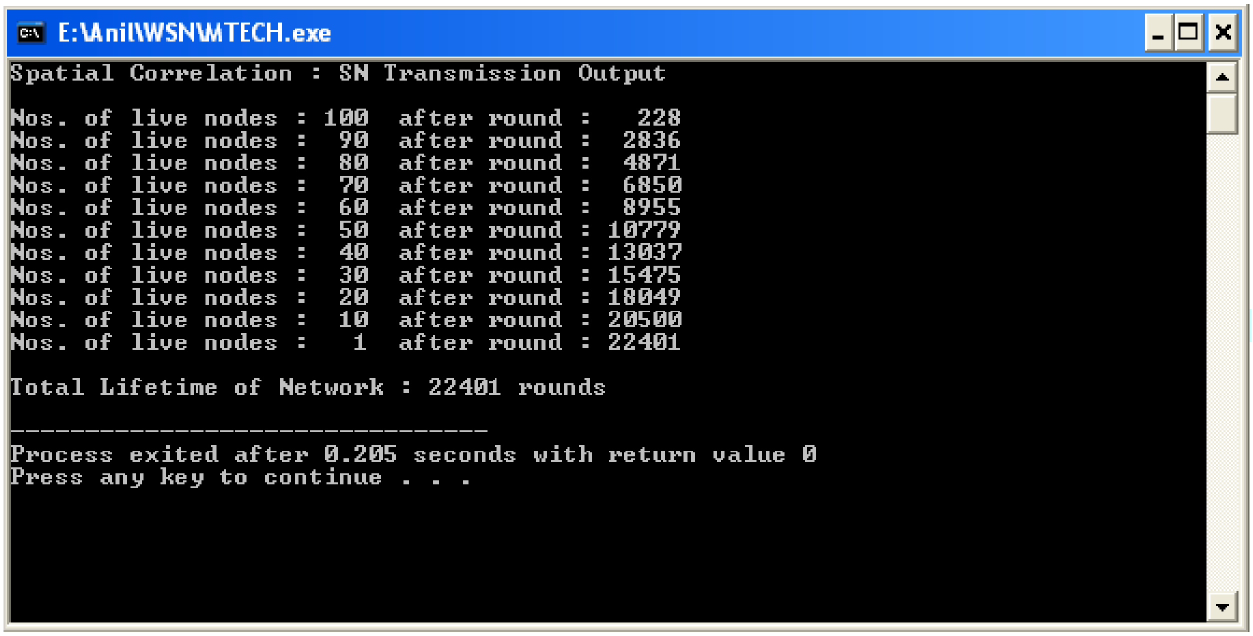
```
 Without Spatial Correlation : SN Transmission Output

Nos. of live nodes : 100  after round :    23
Nos. of live nodes :  90  after round :   288
Nos. of live nodes :  80  after round :   496
Nos. of live nodes :  70  after round :   698
Nos. of live nodes :  60  after round :   912
Nos. of live nodes :  50  after round :  1099
Nos. of live nodes :  40  after round :  1329
Nos. of live nodes :  30  after round :  1578
Nos. of live nodes :  20  after round :  1841
Nos. of live nodes :  10  after round :  2091
Nos. of live nodes :   1  after round :  2286

Total Lifetime of Network : 2286 rounds

--------------------------------
Process exited after 1.783 seconds with return value 0
Press any key to continue . . .
```

A5: SN Transmission (with Spatial Correlation)



```
Spatial Correlation : SN Transmission Output

Nos. of live nodes : 100  after round :   228
Nos. of live nodes :  90  after round :  2836
Nos. of live nodes :  80  after round :  4871
Nos. of live nodes :  70  after round :  6850
Nos. of live nodes :  60  after round :  8955
Nos. of live nodes :  50  after round : 10779
Nos. of live nodes :  40  after round : 13037
Nos. of live nodes :  30  after round : 15475
Nos. of live nodes :  20  after round : 18049
Nos. of live nodes :  10  after round : 20500
Nos. of live nodes :   1  after round : 22401

Total Lifetime of Network : 22401 rounds

--------------------------------
Process exited after 0.205 seconds with return value 0
Press any key to continue . . .
```