ENERGY EFFICENCY IN LINEAR WIRELESS SENSOR NETWORK FOR AUTONOMOUS MONITORING AND MAINTENANCE OF LIFELINE INFRASTRUCTURES

By

MADIHA NOREEN

Supervised By

Dr. FAZLI SUBHAN

Co-Supervisor

Dr. MOEENUDDIN TARIQ

Submitted for partial fulfillment of the requirements of the degree of MSCS to the Faculty of Engineering and Computer Science

NATIONAL UNIVERSITY OF MODERN LANGUAGES,

ISLAMABAD

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THESIS AND DEFENSE APPROVAL FORM

The undersigned certify that they have read the following thesis, examined the defense, are satisfied with overall exam performance, and recommend the thesis to the Faculty of Engineering and Computer Sciences.

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Submitted By: Madiha Noreen

Registration #: MSCS-AS16-ID-017

Master of computer Science
Degree Name in Full

Computer Science
Name of Discipline

Dr. Fazli Subhan
Name of Research Supervisor

Signature: ____________________________

Dr. Moeenuddin Tariq
Name of Co-Supervisor

Signature: ____________________________

Dr. Muhammad Akbar
Name of Dean (FE&CS)

Signature: ____________________________

Brigadier Muhammad Ibrahim
Name of Director General (NUML)

Signature: ____________________________

23, January 2019

CANDIDATE DECLARATION

I declare that this thesis entitled “*Energy Efficiency in linear wireless sensor network for autonomous monitoring and maintenance of lifeline infrastructure* “is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	______________________
Name	:	Madiha Noreen
Date	:	January 23, 2019

ABSTRACT

Recently, linear wireless sensor networks (LWSNs) have been eliciting increasing attention because of their suitability for applications such as protection of critical infrastructures. Most of these applications require LWSN to remain operational for a longer period. However, the non-replenishable limited battery power of sensor nodes does not allow them to meet these expectations. Therefore, a shorter network lifetime is one of the most prominent barriers in large-scale deployment of LWSN. Unlike most existing studies, in this study, we analyze the impact of node placement and clustering on LWSN network lifetime. This research work has implemented and analyzed conventional clustering protocols such as Distributed Energy-efficient Clustering (DEEC), Developed Distributed Energy-Efficient Clustering (DDEEC), and Energy Efficient Scheme for Clustering Protocol Prolonging the Lifetime of Heterogeneous Wireless Sensor Networks (TDEEC) in context LWSN.

First, existing node placement and clustering schemes have been categorized and classified for LWSN and various node placement schemes have been introduced for disparate applications. Then, we highlight the peculiarities of LWSN applications and discuss their unique characteristics. The research work has implemented and analyzed different node placement schemes for linear wireless sensor network. Simulation results use MATLAB clearly indicates that, Grid-Triangular node placement scheme, enhances network lifetime as compared linear sequential and linear parallel node placement scheme. The performance metric used in all node placement schemes is similar to DEEC, DDEEC and TDEEC based conventional clustering schemes. Grid Triangular node placement scheme improves 51 % network lifetime compared to linear sequential and linear parallel node placement schemes. Other than this, it has also been observed that, node placement and clustering schemes significantly affect LWSN lifetime.

Keywords Linear wireless sensor networks, node placement, clustering, network lifetime, energy efficiency, performance analysis.

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter presents a brief overview of Linear Wireless Sensor Networks (LWSN), its applications with reference to energy efficiency through efficient node placement schemes for linear wireless sensor networks. Moreover existing node placement schemes are analyzed in order to improve network lifetime in case the network is deployed to monitor lifetime infrastructure in linear configuration.

1.2 Wireless sensor network

The arrival of computer technologies and fast communication is the result of many innovations like low cost, easy deployment, less power consumption, more reliable and self-organized wireless sensors. Wireless sensor networks consist of a large of sensor nodes, which can sense various information of surrounding environment, such as temperature, pressure, humidity, speed, and so on. In wireless sensor network each sensor senses and transmits data to base station (BS). The sensors collect data from the cells and send it to the base station or gateway. Deployment of sensor network is revolutionary, as it is useful in military, disaster management, space exploration, tracking, border monitoring, bridge monitoring, pipeline (gas, water and oil) monitoring, street light monitoring environmental and traffic based monitoring [1]. Figure 1.1 shows the architecture of WSN.

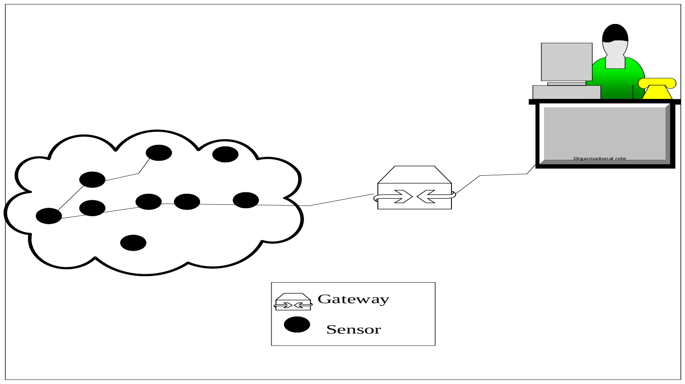


Figure. 1.1 Architecture of WSN.

1.2.1 Linear Wireless Sensor Network

Monitoring and protection of critical infrastructures [2] has become a vital issue in recent years. Thus, researchers have identified and distinguished a subclass of Wireless Sensor Networks (WSNs) applications based on the geometry of the deployment region. Such applications include real-time monitoring of pipelines [3] (e.g., oil, gas, water and sewerage), international borders, railway tracks, tunnels, bridges, and high power transmission and distribution cables [4]. In the mentioned applications, a common characteristic is their linear topology. Thus, a subclass of wireless sensor network in which sensor are placed in linear shape is known as linear wireless sensor network (LWSN). Unlike traditional WSNs, real-time monitoring in these applications necessitate linear placement of sensor nodes to determine and report an event of interest to the base station (BS). Typical applications which have linear form of infrastructure include monitoring of (water, oil and gas) pipelines, international borders, railroads and street lights etc.

In this thesis, we analyzed the impact of node placement, clustering and routing on the performance of LWSN. First, we described various characteristics of some prominent applications of LWSN for critical infrastructure monitoring and highlighted their peculiarities. Then, we categorized and classified various node placement strategies that are suitable for various applications of LWSN. A brief working description of some recent prominent WSN clustering protocols is also presented in context of LWSN. Finally, we analyzed the performance of various LWSN node placement techniques and comparative analysis of clustering protocols. After extensive analysis of node placement schemes embedded in conventional clustering schemes such as DEEC, DDEEC and TDEEC we have concluded that, TDEEC performs better in Grid-Triangular based node placement scheme.

1.3 Motivation

Energy consumption and network lifetime highly depend on node placement, clustering and routing. Using WSN for monitoring lifeline infrastructure, the main contributing factor is to increase the network lifetime and decrease battery consumption. Thus, the main purpose of this research is to investigate an optimal node placement and clustering scheme in LWSN for prolong network lifetime and increases data packets sends to base station .

1.4 Problem Formulation

Node placement, clustering and routing have been extensively investigated in context of WSN, however, they do not consider peculiarities of LWSN and hence, may not be feasible [8]. The energy efficiency is one of the most challenging problem in optimal node placement schemes, clustering and routing. Energy consumption and network lifetime highly depend on node placement, clustering and routing. Maximizes network lifetime and balance network load through energy-efficient node deployment schemes in LWSNs discussed in [9]. In [10] authors investigated clustering techniques and some issues related on cluster head selection. In [12] discussed some routing protocols issue such as energy efficiency, throughput and network lifetime in LWSNs. In [13] authors investigated cluster head selection scheme and for routing used random topology, randomly throwing nodes over thousands of miles may not be either feasible or practical in linear infrastructures. We address the problem if any node fail there is no any alternative path for data transmission. Although, random deployment is only feasible choice in some circumstances, however, such placement may not satisfy essential design considerations such as coverage and connectivity especially in case of linear configuration . Thus, we can say autonomous monitoring of lifeline (oil, water and gas etc. pipeline) is very challenging due to different environmental conditions and wide geographic desperation and also due to unavailability of alternative paths, handling node failure is a real challenge. Therefore, there is a dire need to investigate an optimal node placement and routing schemes which improves the linear wireless sensor network lifetime using minimizes the consumption of energy and increases number of data packets sends to base station.

1.5 Research Questions

1. Does the existing routing protocol provide energy efficient routing in case of linear configuration of WSN for monitoring of lifeline infrastructure?
2. Does conventional clustering schemes suitable for LWSN?
3. Does the existing nodes deployment schemes suitable for LWSN?

1.6 Research Objectives

This research investigate the performance of LWSN in terms of energy efficient network lifetime operation for lifeline monitoring and maintenance. The main objectives of this research can be categorized into following aspects:

1. To investigate optimized node placement, clustering and routing schemes in LWSN, which increased network lifetime and data packets send from cluster head to base station.
2. To investigate the existing WSN clustering algorithms in context of LWSN and modify a clustering protocol in terms of energy consumption to prolong network lifetime and reduce data packets losses.

1.7 Contribution of the Thesis

The contributions of the research work presented in this thesis can be summarized as following.

1. LWSN can be used in various applications. In this thesis we discussed a list of potential applications for LWSN. We have also described the importance of each application in LWSN, and compared with traditional method in order to find the problem in traditional method for monitoring to life line infrastructure.
2. In this thesis we also investigated issues in context of LWSN i.e. Nodes placement schemes, conventional clustering and routing schemes.
3. Moreover we also investigated linear sequential, linear parallel and grid based node placement schemes in LWSN. The main contribution of this research is the investigation of existing clustering algorithms based on WSN architecture in context of LWSN. The performance of each node placement scheme is analyzed afterward. The results clearly indicate that, node placement and clustering scheme significantly affect LWSN lifetime.
4. We have investigate nine different node placement schemes which can be generally categorized mainly in three linear node deployment schemes such as Linear Sequential, Linear parallel and Grid.
5. At the end we have modified TDEEC based on Grid-Triangular Node placement which comprises of multiple paths with shortest distance for sense data transmission to the base station.

1.8 Thesis organization

This thesis consist of five chapters that are given as follows:

Chapter 1 presents the inspiration to the LWSN, problem formulation, objectives of the research, motivation, research questions, research contribution and summary. Chapter 2 describes recent relevant literature on node placement schemes and also clustering and routing schemes in LWSN. Also this chapter describes some prominent applications of LWSN and highlight their peculiarities compared to generic WSN applications. Then chapter 3 presents categories and proposed node placement strategies that are suitable for disparate applications. Also this chapter briefly describe three prominent clustering protocols and discusses their working in case of LWSNs. Chapter 4 describes simulation results .Finally, chapter 5 presents conclusions and future research direction.

1.9 Summary

This Chapter analyzed the impact of node placement and clustering schemes on LWSN lifetime. The main objective of the nodes placement and routing schemes is to increase network life time and reduce energy consumption for monitoring and maintenance of lifeline infrastructures. The next chapter presents a comprehensive literature review of the existing linear wireless sensor network nodes placement, clustering and routing schemes also discussed various topologies for disparate applications. Then, highlight the peculiarities of LWSN applications and discussed their unique characteristics.

CHAPTER 2

RELATED WORK

2.1 Overview

This chapter presents a comprehensive literature of the existing node placement, clustering and routing scheme. Also this chapter briefly describes some prominent applications of LWSN and highlight their peculiarities compared to generic WSN applications. This will help the reader in better understanding the topology of LWSN. Moreover, the purpose is to demonstrate the feasibility and suitability of LWSN for real-time monitoring of critical infrastructures.

2.2 Literature review

Most of applications require Linear WSN (LWSN) to stay operational for a longer period of time. A trivial approach might be to employ rechargeable nodes or sensors with unlimited battery power. However, it may not be feasible or practical due to higher cost and limited battery capacity. Therefore, non-replenishable limited battery-power of sensor nodes do not allow them to meet these expectations. Consequently, shorter network lifetime is one of the most prominent barriers in deploying LWSN for large-scale deployment. In LWSN, network lifetime primarily relies on node placement, clustering and routing can cause non-uniform energy consumption and thus, shorter network lifetime. Efficient node placement may further enhance energy efficiency in order to maximize the lifetime of a network. Similarly selection of routing protocol which is compatible with the node placement scheme increases overall performance of the network. Node placement [5] is considered most important component that can cause non-uniform energy consumption. Most of the existing WSN node placement schemes can be categorized into random, uniform and non-uniform deployment. Unlike conventional WSN applications, random node distribution in

LWSN might not be feasible for large-scale deployment especially in case of static sensors [6]. Uniform placement schemes deploy nodes at equal distance. However, nodes near the BS rapidly deplete their energy due to additional data forwarding overhead from far sensors. Therefore, to prolong network lifetime, an appropriate node placement and routing schemes are required to balance energy consumption in LWSN.

Similarly, clustering and routing protocols proposed for conventional WSNs may not be suitable for linear WSNs because of various peculiarities. Due to limited transmission range of sensors and energy constraints, direct data transmission from sensors to the BS may not be practical or feasible. Therefore, multi-hop communication is an inherent choice in which sensors transmit collected data to neighboring nodes towards the BS. However, unlike WSNs, alternative routing paths towards the BS [7] may not be available in LWSN especially in case of node failures, which may significantly affect overall network performance. This situation occurs mainly because sensors near the BS deplete their energy quickly due to consistent data forwarding overhead of far nodes. Hence, the network becomes dysfunctional due to non-uniform energy consumption. Therefore, routing is another major concern in LWSNs in addition to node placement [8].

The protection of critical infrastructures is a growing concern and various technologies are employed to monitor lifeline infrastructure for example gas, oil and water pipe lines, road infrastructure, accident monitoring, street light monitoring, international border monitoring etc. In this regard, the authors in [11] investigated the technologies that can be adopted specifically for pipe and structural health monitoring. However, the scope of our work is broader in terms of LWSN applications and we specifically focused on linear configuration or placement of sensor nodes which are specifically used for the above mention lifeline infrastructures. In LWSN the main issues are such as energy efficiency, throughput, data loss and network lifetime [12]. In our research work the main focus is to improve the network lifetime and data packets sends to base station by addressing the node placement and clustering issues in LWSN. Although, both of these have been extensively investigated in [13-16] in context of WSN, however, they are still in infancy in context of LWSN according to their experimental results. In [17] the authors purposed a linear wireless sensor and actor network framework for autonomous monitoring and maintenance of lifeline infrastructures. However, the proposed framework neither deals with specific issues of node placement, routing and clustering. Moreover, some of the existing schemes are generic and do not consider suitable for LWSN and hence, may not be feasible. Although there are some efforts in LWSN in various aspects but node placement, clustering and routing require further investigation.

2.2.1 Node placement strategies in LWSN

Node placement dominates the performance and network lifetime of LWSN in various terms such as throughput, coverage and connectivity. Various node placement strategies have been proposed in context of LWSN. For example, the authors in [18] investigated an unbalance data traffic distribution problem which results in network disconnection and proposed a solution by optimizing the positions of sensor nodes which extend the network lifetime. To balance energy consumption, a decreasing distance node deployment strategy has proposed for linear sequential WSN in [6]. The proposed strategy gradually reduces the distance between nodes towards the BS. On the other side, we analyze the performance of routing algorithms in various topology configurations such as linear parallel and grid. Authors in [19] discussed uniform node placement scheme and finding that the nodes near the BS die more quickly as compare the nodes which are far from base station the main reason behind is that the sensor nodes near the BS have extra load of data forwarding. To optimize energy utilization and improve network lifetime, a node deployment scheme was presented in [20] that calculates the distance between sensor nodes based on path loss. To improve network lifetime, a linear node placement scheme for oil pipeline monitoring was presented in [21]. The authors formulated equal-power placement as a mixed integer linear programing problem and shown that it can outperform equal-distance deployment scheme. To improve coverage and network lifetime a node placement optimization for WSN was presented in [22] for a linear topology. Unlike [22], focus of our work is on maximizing network lifetime through routing and optimal node deployment. The authors in [23] investigated the issues of uniform node deployment in LWSN and proposed an analytical model that provides reliability analysis. Unlike most of the existing studies that only focus on node placement, we also consider routing issues in context of LWSN.

Table 2.1 compares the strengths and weaknesses of existing node placement schemes specifically in LWSN.

Table 2.1. Comparison of different node placement schemes with strengths and weaknesses in LWSN.

Node placement	Strengths	Weaknesses
PALWSN, 2014 [6]	• Increased network lifetime through uniform energy consumption, by analyzing the performance of linear sequential node placement. Moreover the overall the performance of network is improved by placing the gateway the middle of the region.	• Only sequential node placement schemes are investigated. • Alternative paths are not available for data transmission to BS.
NPLWSN, 2013 [18]	• Three different network connectivity cases are used which increased total volume of data traffic and extend network lifetime.	• Used two sink node which increased network cost. • For higher degree of data connectivity required additional power consumption per transmission.
ICMTMA, 2010 [19]	• Using Multi hop communication which increase network lifetime and stability period of network.	• Only Investigated uniform node placement scheme which results in unbalanced network traffic load.
PENPS,2016 [20]	• Reduced the energy consumption per node. • Overall increased network lifetime.	• Alternative paths issue for data transmission.

CBNPO, 2016 [22]	• Overall improve network coverage. • Increase network lifetime and reduce cost.	• Packet loss issue

2.2.2. Clustering in LWSN

An effective clustering protocol should strive to balance energy consumption of sensor nodes. To reduce the exhaustion of energy is performed by cluster head. Therefore, most of the existing WSN clustering protocols may not be applicable in most of the LWSN applications. To increase network reliability and communication efficiency, A Low Energy Adaptive Clustering Hierarchy (LEACH) was presented in [24]. To reduce energy consumption and increase network lifetime LEACH elected a few sensor nodes as cluster heads randomly on the basis of probability. However, LEACH is not implemented linearly enhanced network. The authors in [25] presented a clustering scheme for energy efficiency clustering protocol. In this scheme cluster head selection is based on threshold value of nodes. Each node generates a random number, if the number is lesser than or equal to threshold value and node has not become cluster head for last round, the node is marked to become a cluster head. A new linear clustering technique is presented in [26]. In this technique each node has an equal chance to become a cluster head for the current round. Moreover, this technique used multiple static sinks between communication distance and cluster head for prolong network lifetime. Every time CH collects data and sends it to the nearest sink. Another energy efficient routing protocol Link Aware Clustering mechanism (LCM) has been proposed [27] to support the node and cluster formation, it gives an idea of Predetermined Count of Transmissions (PTX). (PTX) is used to determine priority of each CH. LCM selects the CH on the basis of derived priority. A survey presented in [28] a Routing and clustering optimization technique in WSN. In [29] authors proposed a clustering protocol EPCDREA (Enhanced passive clustering algorithm based on distance and residual energy), in this approach authors elect cluster head on the base of distance between sensor nodes and remaining residual energy which overall extend network lifetime and balanced cluster head election. A recent study [30] presented chain-based routing schemes for single, two, and four chains of cylindrical underground sensor networks. However, node deployment was not considered in this study. In [31] authors investigated clustering protocols include Distributed Energy-efficient Clustering (DEEC). In this protocol the probability of cluster-head selection is primarily based on the ratio between remaining energy of each sensor and the average network energy, nodes have more initial and residual energy in a current round have more chance to be a cluster head. In [32] authors proposed another clustering algorithm include Developed Distributed Energy-Efficient Clustering (DDEEC). To balance energy consumption and increase network lifetime in DDEEC all nodes advance and normal nodes have same chance or probability to be a cluster head in each round. When election of cluster head will be balanced hence, resulting in an increased network lifetime. An Energy Efficient Scheme for Clustering Protocol Prolonging the Lifetime of Heterogeneous Wireless Sensor Networks (TDEEC) was presented in [33] for prolong network lifetime. In TDEEC, authors adjusted the value of the threshold, based on which a node decides to become a cluster head or not. Therefore, nodes having more residual energy within a round have more chances to be cluster head. These are few examples of existing WSN clustering protocols which work on the basis of energy efficiency and maximum network lifetime. Here we discussed some clustering schemes in wireless sensor network, later in chapter 3 we described three prominent clustering protocols [a-c] and discuss their working in case of LWSNs. As we discussed already, conventional clustering schemes may not be suitable for LWSN. So it is more difficult to find a full-fledged LWSN clustering base routing protocol that could be used for different conditions and applications. A Clustered LWSN architecture depicted in figure 2.1.

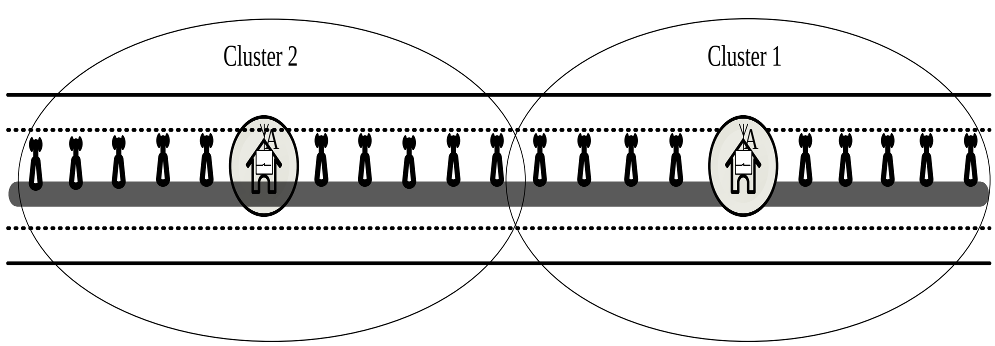


Figure. 2.1 Clustered LWSN architecture [17]

Table 2.2 .Compares different clustering protocols in WSN based on strengths and weaknesses.

Table 2.2. Summary of strengths and limitations of protocols based on clustering in WSN

Protocols	Strengths	Limitations
LEACH (24)	• Good throughput • Reduced latency • Using TDMA and CDMA protocol respectively collision and interferences are overcome. • Low complexity algorithm	• Due to distributed cluster head formation algorithm, it cannot ensure the coverage of entire network. • 1 hop • Distribution of cluster heads is Non-uniform. • Cluster head dies more quickly due to heavy load than new cluster head election was required.
ACH [25]	• Increase energy of cluster head close to the station for inter communications cluster-head. • A uniform distribution of energy consumption for cluster head. • Avoid clustering in each round. • Increase stability period and throughput of a	• Coverage problem in wireless network.

	network over its rivals LEACH, SEP, TEEN and DEEC.	
LCM [27]	• Good preformed for packet delivery ratio, delivery latency and residual energy. • Suitable for time-critical applications. • Reduce high overhead for choosing cluster head selection compared to LEACH.	• Low stability period. • Unsuitable for large-scale networks.
EPCDREA [29]	• Uniform distribution of cluster head. • CH selection is depend on the residual energy.	• 1-Hop
DEEC [31]	• Scalability for multi-hop communication. • The cluster-heads election are by a probability based on the ratio between residual energy of each node and the average energy of the network. • Multi hoping • Good performance compare to SEP and LEACH.	• Just advanced nodes to be a cluster head. • Advance nodes become cluster head continuously then cluster head die quickly. • Non-uniform distribution of cluster heads.

TDEEC [33]	• Adjusted the value of the threshold, according to which a node decides to be a cluster head or not. • Increased stability period • Multi hoping • Overall increased network lifetime as compared to DEEC and DDEEC.	• Used super node thus, Cost effective • If two nodes have same highest energy than which node will be a cluster head it do not determine.

2.2.3. Routing in LWSN

Unlike most of these studies, the focus of our work is specifically on LWSN routing as it is one of the most imperative design issues that significantly affect network lifetime. Due to circumscribed communication range of sensor direct routing to the base station may not be suitable in large scale applications. So for long distance communication the sensor more efficiently drawn out from energy. An effective routing protocol should strive to balance energy consumption of sensor nodes. However, topological constraints in LWSN makes it a challenging problem as alternative paths toward the BS may not be available. Therefore, most of the existing WSN routing protocols may not be applicable in most of the LWSN applications. To increase network lifetime and increase energy efficiency, the authors in [34] presented a framework and a routing protocol for LWSN. This study also analyzed various issues related to linear topology. A Minimum Energy Relay Routing (MERR) protocol was presented in [35]. To minimize energy consumption and prolong network lifetime, MERR select an optimal path for data transmission from sensor node to BS. In [36] authors presented an efficient energy consumption routing scheme, which decrease the maximum distance between two sensor nodes and increases communication hop count A routing Performance and Usage Aware protocol proposed for monitoring of tunnel in [37].Performance and Usage –aware routing is more suitable to monitor the sensor nodes having long distance and linear structure. In [38] a special linear network is proposed in this algorithm sensor are arranged in a linear manner. This routing protocol used for road monitoring in real time and extend network lifetime using minimum distance between different sensor nodes. The simulation results consider this routing algorithm consume less power and more efficient as compare to general-purpose routing protocols. Another LWSN large scale routing protocol proposed in [39] used for high-voltage transmission data. These are few examples of existing LWSN routing protocols which work on the base of energy efficiency and maximize network lifetime. As we discussed already, conventional routing schemes may not be suitable for LWSN. In this it is more difficult to find a full-fledged LWSN routing protocol that could be used for different conditions and applications. Figure.2.2 shows Multi-hop routing in cluster-based WSN with linear configuration.

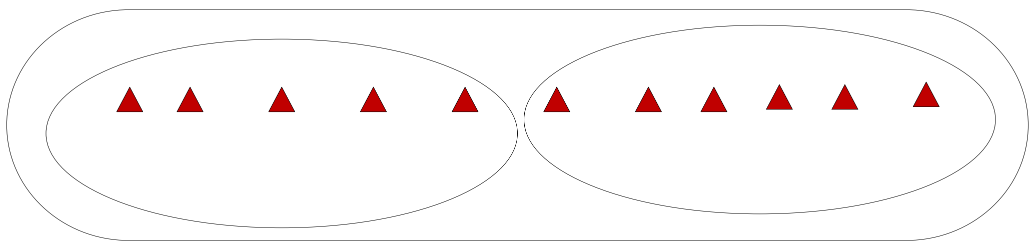


Figure. 2.2 Multi-hop routing in cluster-based WSN with linear configuration.

2.3 Application of Linear Wireless Sensor Network

This research briefly describes some prominent applications of LWSN and highlight their peculiarities compared to generic WSN applications. This will help the reader in better understanding the topology of LWSN. Moreover, the purpose is to demonstrate the feasibility and suitability of LWSN for real-time monitoring of critical infrastructures. Some of these applications are described below.

2.3.1. Pipeline (Oil, Gas and Water) monitoring

Now a days the progress and economy of many countries is highly dependent on their oil, water and gas pipelines [40]. In numerous countries long pipelines are utilized for various purposes. For example, long pipelines are utilized to exchange water from desalination plants, which are usually close to ocean, Metropolis that are not close from the ocean. Riyadh the capital and most famous city of Saudi Arabia is totally dependent on water which are transferred through a network of water pipes which are longer than 3,800 km from the Shuoiba Desalination Plan [41]. In [42] authors reported that Saudi Arabia highly relies upon more than 4000 kilometers of pipeline to transport water from many desalination plants scattered all over the kingdom. The authors in [43], formulated a Langeled pipeline that prolongs for 1,200 km and is extended from Ormen Lange field Norway to the Easington Gas Terminal in England, while England fulfills its 20% needs of gas through this pipeline. This paper reported another longest pipeline which is utilized in Qatar and UAE. This pipeline is 367 km long and fulfills a high level of UAE gas needs. The authors in [44] investigated the gas and oil pipelines extended around the United States about 80000 kilometers. In this manner, these oil and gas pipelines highly effect the economy of United States. However, these gas and oil pipelines need regular measurement and monitoring in order to make proper working and fault free transmission. Finding the fault (assuming any) in these pipelines manually at an exact location is more difficult and time taking process. Some example of these measurements are liquid leakages, bursts, pipeline corrosion detection, pipeline protection cameras, temperature, flow**,** and other anomalies measurements [45]. So using LWSNs, sensor nodes can detect all faults that can occur in a pipeline infrastructure very easily and rapidly through real time monitoring. Example of monitoring oil pipeline using sensor is depicted in figure 2.3.

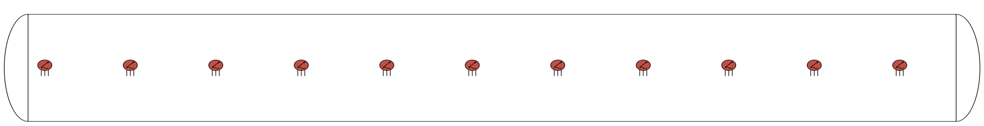


Figure.2.3 monitoring oil pipeline using wireless sensors.

2.3.2. Railroad/subway and bridge monitoring

Observing, supervision and control of railways and metros is another task for linear wireless sensor networks. For long distance travel in sense of expense, capacity and use of space for travels and luggage, rail transportation is one of the most effective, affordable and convenient route. The growth of population needs more deployment and services of railway tracks and bridges across the world that has already been scattered over long distances. In the United States of America, the railroad streets length was 228,513 kms in 2010, regardless of different tracks [46]. Patrolling is a traditional way of monitoring the railways. In Patrolling there is duty of few members of staff for observing a particular distance of railroad for a specific time period. It may be impossible to monitor railroad tracks that are scattered thousands of miles, and continuous monitoring is not feasible with the help of traditional way. Therefore, there is a need to improve the current monitoring systems to make them more relentless, reliable, integrity and efficient, this can be accomplished by using WSNs. Therefore sensor nodes can be deployed for efficient monitoring of railroad tracks. Wireless sensor networks can be utilized for monitoring of the railroad infrastructure, for example, cracks in rail tracks, railway beds, and track equipment alongside obstruction discovery. The use of WSNs in railway monitoring gives a persistent perception for the railway track, regardless of its length. In this manner the cost of network will be diminished because of the utilization of wireless communication, the lesser power, cheaper and smaller size of the sensor nodes. On the other hand the use of sensor nodes decrease human investigation necessities through automated monitoring and enhance safety and reliability. A railroad security framework is proposed in [47], in term of wireless sensor nodes which uses electromagnetic and ultrasonic sensors, the collected data have been sent to control centers and security is set up by taking appropriate activities. In [48] authors monitor the railway condition through self-powered ZigBee sensor nodes. In [49], the authors reported the distribution of fiber optic sensors on critical components in the railroad bridge superstructure of a railroad connection.

2.3.3. Monitoring of vehicular activities

Now a days the number of vehicles has expanded quickly, however, the bedrock capability of streets and transportation frameworks have not developed in an equal approach to easily manage the quantity of vehicles roaming around. Because of this, road jamming, alarming rise in the number of accidents and traffic, pollution has tremendously increased that consequently has a major impact on economy, environment and human. Roadway framework in any metropolis plays an essential part in determining the physical structure of the metropolis, moreover, this highly determine how people move from one to another station. That counts for traffic congestion which is one of the most burning challenge in numerous urban areas because of rapid development of running vehicles. Traffic congestion brings many problems in life of people. Traffic congestion can result in economic losses as well as increased air pollution. Therefore, traffic monitoring is more important to avoid traffic congestion. Compared to other alternative networks, the WSN is inexpensive because of their faster exchange of data, simpler deployment, lesser power consumption and easy maintenance. As a result of WSNs, traffic jamming, congestion and accidents become significantly reduced. Sensors can detect many features such as speed, accidents and flow of a vehicle continuously. For traffic monitoring a petrol control algorithm is proposed in [50]. The authors in [51], has presented a comprehensive review on WSN based ITS for real-time traffic monitoring .The authors [52] reported vehicle real time monitoring based on Intelligent Transportation Systems, ITS, used for detection of vehicle activities . Here the vehicle detection is based on WSN using an isometric Magnetic Resistive (AMR) sensor. The aim of (AMR) is to achieve a less expensive, easy to coordinate, robust, flexible and low maintenance wireless solution for vehicle detection.

2.3.4 Border monitoring

For illegal activities like terrorism, drugs, illegal immigration, smuggling of goods and unauthorized border crossing, International border monitoring is very important. In this regard border monitoring is another application of LWSNs. Borders are extremely vulnerable and prone to terrorist attacks. The protection of long stretches of countries borders has posed a number of challenges. A traditional method for inspection border consists of security checkpoints. Different checkpoints are mounted on international roads to investigate the movement of cross border vehicles and persons. This traditional method for border monitoring demands high expenses along with time consumption and effort, especially on long borders or in sensitive environments. One of the example is a Canada-USA border, which is one of the longest international border of about 8,891 kms length [46]. In such cases implementing the traditional method is more difficult to incessantly monitor all the border regions. Effective and continuous monitoring of a border requires the implementation of multi-surveillance technologies that work as an integrated unit to meet the desired goals such as Wireless Sensor Networks (WSN). WSNs are inapplicable to LWSNs. LWSNs can be used to cover the limitations of the existing monitoring techniques. Sensors are used to monitor the environmental conditions. Through sensor nodes it is very easy to continuously monitor the border and this will reduce the border patrolling time, stuff and effort. The paper [53] investigated some sensor deployment issues for monitoring border and designed a cross-layer routing protocol which is used to continuously monitor the border in an efficient manner. [54] Design a routing protocol for border surveillance.

2.3.5. Streetlight monitoring

Streetlight play an important role in citizen lives. Without street light the infrastructure of a city not appear able. On the time of accident or any crime streetlight play important role as a safety. Street lighting also improves safety for drivers, riders, and pedestrians. To improve the image of the city and management of level, city's light must be upgraded, so the regularly streetlight monitoring is a big challenge. To control and maintain complex street lighting system more economically, through traditional system monitoring a street light it is very difficult because it is more time consuming and involves much human labor. In a traditional method street light were off when sunrise and switched on at sunset manually, that increase much human staff due to this cost increased. In [55] investigated a modern method which automatically street light on and off when sunrise or sunset. But this method have same problem when weather effected like streetlights may be covered with dust or snow, then sensing capacity reduced and resulting same problem. Another zigbee technology which is used for control street light maintenance investigated in [56] zigbee coordinator collects all data according to street light and send it to main control center through GSM module. Simulation results analyzed this method is less expensive, easy to install and maintenance. But this technology has a disadvantage communication failure due to signal attenuation and noise take place. It clearly shows that wireless sensor network can help monitoring and controlling streetlights through sensor which installed on each lamp. Through sensor maintenance energy consumption cost will be reduced. And increase availability of street lighting. It automatically adjust the light intensity to save energy and maintaining user satisfaction. In [57]

Authors discussed wireless communication by LED street lamps monitoring and control system based on Zig-Bee technology working with 2.4GHz, this intelligent control system has main two components luminance sensing and temperature sensing. In [58] authors proposed a model which develop a mechanism to save energy consumption for street light utilizing wireless communication. This mechanism is low cost, power save continuous street lights monitoring. It save energy consumption which caused due to manually switches on and off street lights when it is not essential.

2.2.6. AC power line motoring

Another region of interest where LWSNs can be utilized is in observing overhead and underground AC power lines [59]. The gathered data would be valuable by the service organization to expect outages that can happen because of defective equipment and over-burdening of AC power lines. Due to the result of these outages of services many customer losses and financial cost increase due to maintenance of these losses. It is very difficult to find a fault and its maintenance through a traditional method. Real time monitoring through sensors become very easy and cost effective. These sensors sense electrical parameters which include power, voltage and current. Using the power line itself sensor can communicate their data back to the control region. Using the power line itself sensor can communicate their data back to the control region. Here some research questions take place in term of linear structure of these nodes in order to election of right communication protocols, infrastructure, throughput, architecture, data aggregation and framework that would exploit some advantage of the linear deployment of sensors in sense of reduce installation as well as maintenance costs, increase reliability also security and increase network life time and network performance. AC power line monitoring one of the challenging issue for human.

Comparisons of the linear application monitoring traditional method vs. Real time monitoring using sensor.

Table 2.3. Compares linear applications using traditional methods vs real time based on time consumption, economic losses and staff reduction. From this table it can be seen that linear application monitoring techniques [46].

Table 2.3. The Comparison of liner application monitoring

Applications	**Strengths of real time monitoring through sensor**	**Weaknesses of real time monitoring through traditional method.**
Pipeline (Oil, Gas and Water) monitoring	• Sensor nodes detects all fault that occur in a pipeline infrastructures like liquid leakages, bursts. • Pipeline corrosion detection are very easily and rapidly.	• Impossible measurements of liquid leakages, bursts, pipeline corrosion detection, pipeline protection cameras, temperature, flow**,** and other anomalies measurements.
Railroad track monitoring	• Sensor gives a persistent perception monitoring for the railway track. • The cost of network monitoring is reduced.	• A traditional method is patrolling this method is not feasible to monitor railway tracks that are scattered for long distance. • Immense economic losses in terms of goods, lawsuits and liability issues
Road monitoring or monitoring of vehicular activities	• Using sensor traffic jamming, congestion and accidents have been reduced.	• Through traditional method traffic jamming and congestion increased.

	• Sensor can detect many features such as speed, accidents and flow of a vehicle continuously. • Reduced monitoring cost. • Easy to maintenance.	• Increased economic losses as well as air pollution from vehicle emissions.
Border monitoring	• Sensor are used monitor the environmental conditions. • Easy to continuously monitor the border. • This will reduce the border patrol's time, stuff and effort.	• A traditional method for inspection border consists of security checkpoints. • Costs effective • Lot of time consuming and effort, especially on long borders.

2.4 Research Gap and Directions

Lifeline infrastructures span thousands of miles and pass through inhospitable terrains. Optimal Node placement schemes is one of the most challenging issues that affect the design of lifeline monitoring and maintenance systems [17]. Therefore, appropriate node placement mechanism should be investigated for various environments and different lifeline configurations. On the other hand clustering is another one of major problem in linear environment clustering has investigated [30-33] in context of WSN but not in LWSN so, we described these three prominent clustering protocols and discuss their working in case of LWSNs in next chapter. As stated earlier In LWSN, network lifetime primarily relies on node placement, clustering and routing as all of them can cause non-uniform energy consumption and hence shorter network lifetime. Efficient node placement may further enhance energy efficiency in order to maximize the lifetime of a network.

Similarly selection of routing protocol which is compatible with the node placement scheme will increase overall performance of the network. But still there needs investigate a full flag optimized node placement schemes, clustering and routing in LWSN. So our main focus deploy three prominent clustering protocols [30-33] and discuss their working in case of LWSNs, and investigate optimal node placement scheme in linear configuration. In order to develop an optimized clustering scheme, there is a dire need to investigate the existing clustering schemes in context of linear configuration of wireless sensor networks which can effectively use for lifeline infrastructure.

2. 5 Summary

This chapter presented a comprehensive study of the existing node placement, clustering and routing scheme in context of WSN and also LWSN. A comparative study of existing techniques is presented, in terms of energy efficiency base on node placement and clustering schemes with pros and cons. Furthermore this chapter briefly describes some prominent applications of LWSN and highlight their peculiarities compared to generic WSN applications. This will help the reader in better understanding the topology of LWSN. Moreover, the purpose is to demonstrate the feasibility and suitability of LWSN for real-time monitoring of critical infrastructures. As mentioned earlier, LWSN lifetime primarily depend on node placement. So Chapter 3 elaborates various node placement strategies with diagram that are suitable for disparate applications. Also in chapter 3 describe three prominent WSN clustering protocols and discuss their working in case of LWSNs.

CHAPTER 3

PROPOSED GIRD-TRIANGULAR BASED THRESHOLD DISTRIBUTED ENERGY EFFICIENT CLUSTERING AND ROUTING PROTOCOL

3.1 Overview

This chapter elaborates detail nodes placement schemes in LWSN in order to find the best optimal node placement scheme to minimize energy consumption and prolong network lifetime. The selection of a suitable node placement scheme improves the network lifetime and reduce energy utilization. Also this chapter investigates node placement schemes in term of alternative paths when one node die. On the other hand three prominent clustering protocols namely DEEC, DDEEC and TDEEC are discussed in reference to LWSN. These clustering schemes are further investigated through simulation studies using linear sequential, linear parallel and Grid based topologies. Based on extensive simulation studies with different topologies, we have identified that, Grid –Triangular based node placement scheme perform better in TDEEC based on many alternative paths selection if any failure occur. The main contribution of our proposed Grid-Triangular based node placement is the selection of alternative minimized paths, when a node near to die. The results clearly indicate that, node placement and clustering scheme significantly affect LWSN lifetime and conventional clustering schemes may not be suitable for LWSN.

3.2 Node placement schemes

As mentioned earlier, LWSN lifetime primarily depend on node placement. This chapter describes various node placement strategies that are suitable for disparate applications. Fig. 3.1 presents a taxonomy of node deployment in LWSN. Depending upon the geometry of the applications, node placement schemes can be categorized into linear sequential, linear parallel, and grid. Each of them is described in the following.

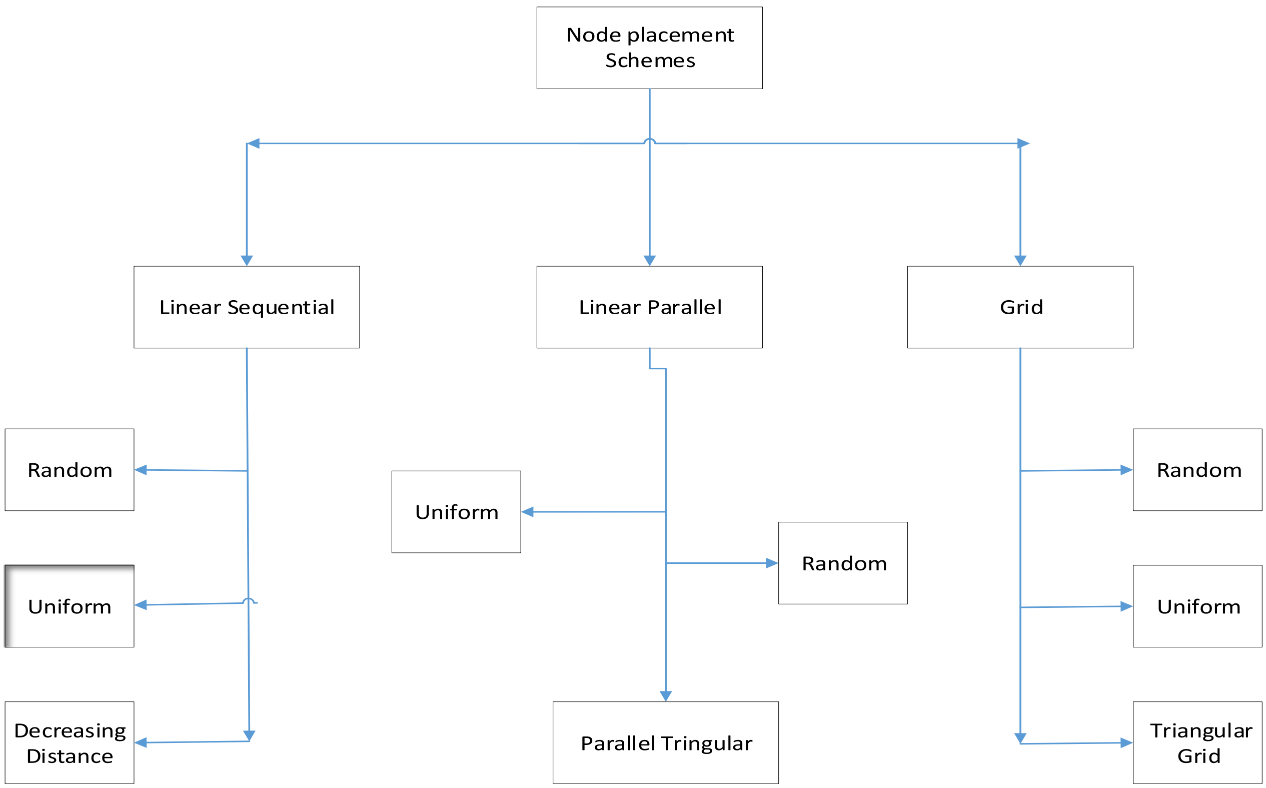


Figure. 3.1 Overview of LWSNs Node placement schemes

3.2.1 Linear Sequential Deployment

Some applications of LWSN such as monitoring of borders, bridges, and pipelines need linear sequential deployment of sensor nodes. Sensor nodes in these applications are placed along the infrastructure a single line. From different perspectives such as node deployment, network lifetime, and routing, linear sequential deployment is one of most challenging task. For example, due to unavailability of alternative paths, handling node failure is a real challenge. Generally, three different strategies are possible to deploy nodes in linear sequential applications, Figure. 3.2 demonstrates the linear sequential deployment of sensors in various configurations.

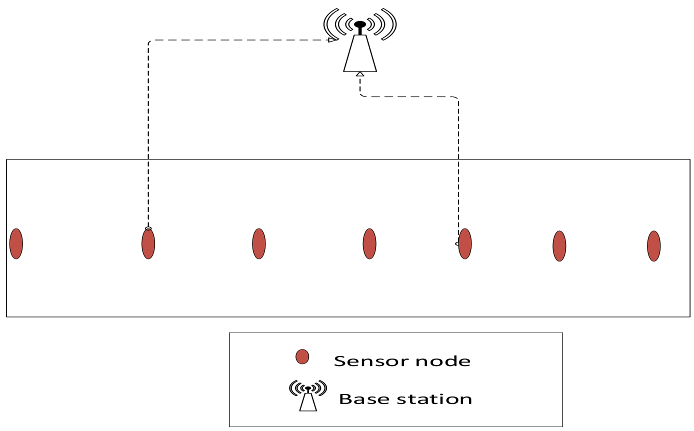


Figure. 3.2 Linear sequential WSN architecture

(a) Random

Most applications of LWSNs are hostile in nature and the sensor nodes have to be deployed in inhospitable terrains. Such applications may include oil and gas pipelines, railway tracks, highways, and border monitoring. Most of these applications are the prime target of insurgents to sabotage critical economic infrastructures and disrupt lives of inhabitants. In these applications, planned deployment of sensors over thousands of miles is a real challenge as it may not only involve risk but is also a cumbersome task. Random placement of sensors in such circumstances is a viable option. It may involve moving vehicles, robots, and drones to randomly place sensors in the deployment region. Starting from one edge of the network segment, position of next sensor is determined randomly on horizontal axis. To ensure connected coverage, the next node should be within the communication range of previous sensor. This procedure is recursively executed until all the nodes are placed. Figure. 3.2 (a) depicts a linear sequential random deployment scheme. Although, random deployment is only feasible choice in some circumstances, however, such placement may not satisfy essential design considerations such as coverage and connectivity especially in case of linear sequential configuration.

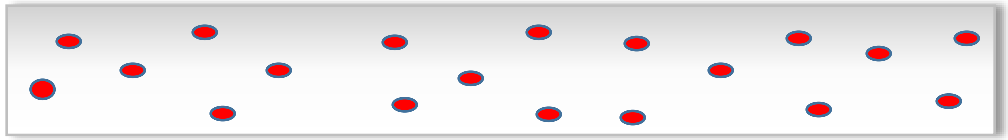


Figure. 3.2 (b) Linear sequential Random deployment scheme

(b) Uniform

The uniform node placement deploy sensor nodes at equal distance from each other. In other words, nodes are evenly distributed in a single line across the deployment region. Despite various merits of uniform deployment, it also suffers from uneven energy consumption especially nodes near the BS drain their energy quickly due to extra load of data forwarding. This scheme is feasible for pre-planned and controlled deployment. Figure. 3.2 (b) depicts a linear sequential uniform deployment scheme.

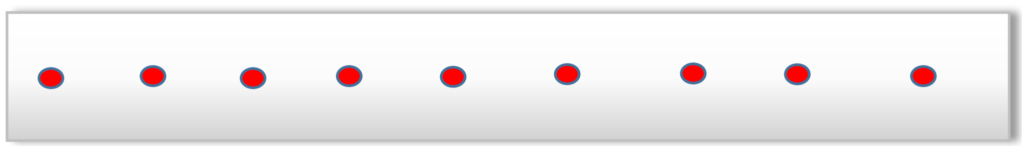


Figure. 3.2 (b) Linear sequential uniform deployment scheme

(c) Decreasing Distance

To cope with the problem of uneven energy consumption near the base station [5], linear sequential decreasing distance node placement scheme was proposed. The idea is to gradually decrease the distance between sensor nodes towards the BS. The design rationale is that increased node density near the BS will not only reduce the data forwarding overhead but also allows require these sensors to transmit at shorter distance which can lead to energy conservation. Although, this scheme is effective for LWSN, however, finding the optimum decreasing distance is a big challenge. Figure. 3.2 (c) depicts a linear sequential decreasing distance deployment scheme.

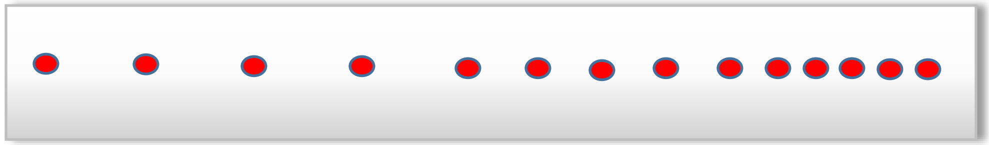


Figure. 3.2 (c) Linear sequential decreasing distance node placement scheme

3.2.2 Linear Parallel Deployment

Some linear applications, like railway track monitoring, high way road monitoring need the sensor nodes deployment in parallel manner. In this nodes deployment scheme if any failure occur there is an alternative path for data forward. The main advantage of this scheme is alternative route for data transfer. The figure. 3.3 demonstrates the linear parallel deployment of sensors in various configurations.

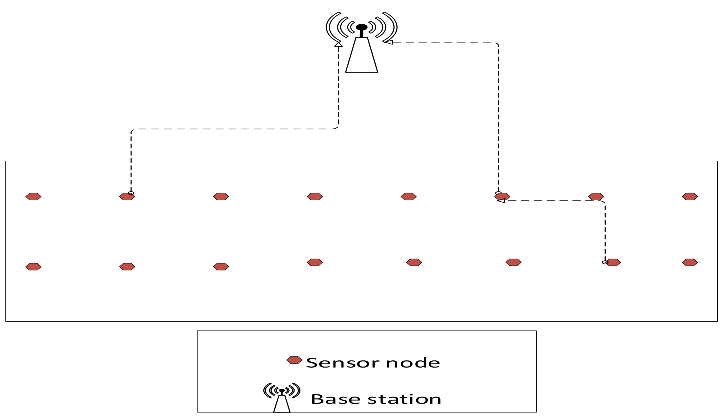


Figure. 3.3 Linear parallel WSN architecture

(a) Random

In linear parallel random deployment the sensor nodes are deployed randomly in such a way that, they lie in communication range to each other and if any fault occur there is an option for alternative route for data forwarding. Although, random placement is easier, however, it results in non-uniform deployment i.e., node density in some part of the segment is higher than the others.

This results in uneven energy consumption because some nodes have to transmit data at larger distance than others. Moreover, nodes near the cluster head have to relay additional data from far sensors. So the node near the base station die quickly. This scheme is suit able for vehicles activities monitoring on high way roads. Figure. 3.3 (a) depicts a linear parallel random deployment scheme.

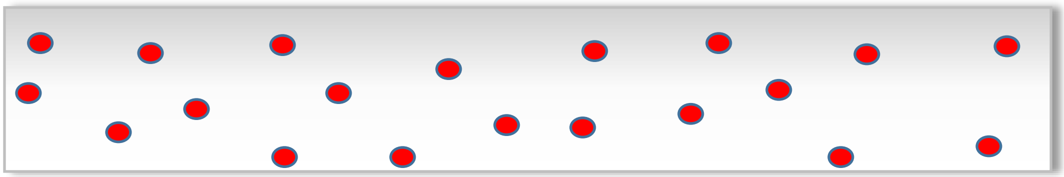


Figure. 3.3 (a). Linear parallel random deployment scheme

(b) Uniform

At stated earlier the uniform node placement in a LWSN segment where all the nodes are placed at equal distance from each other. In linear parallel uniform node placement scheme, there are two parallel lines, and node are placed at equal distance from each other. In this manner there is an alternative path if any node fail other nodes share its load. Parallel uniform node deployment feasible for railway track monitoring. Figure. 3.3 (b) depicts a linear parallel uniform deployment scheme.

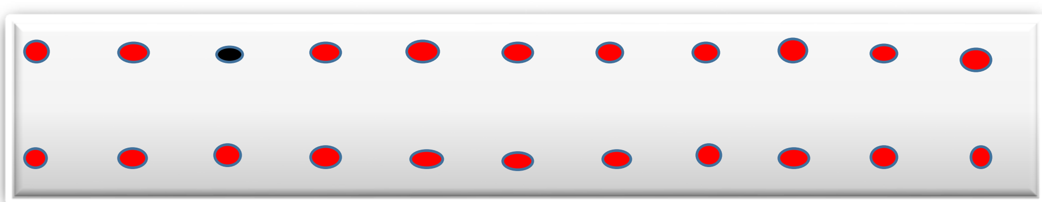


Figure. 3.3 (a). Linear parallel random deployment scheme

(c) Triangular

Sometime Random and uniform schemes are unable to balance energy consumption and hence prolong LWSN lifetime. To overcome this problem there is another scenario in which node are placed in triangular manner. In parallel triangular nodes placement scheme one node occur on the middle of the next corresponding node. If any fault occur there are many alternative paths for data transmission. It maintain strongly network connection. Figure. 3.3 (c) depicts a linear parallel triangular deployment scheme.

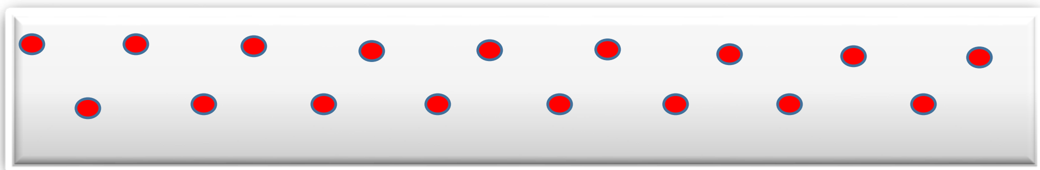


Figure. 3.3 (c) Linear parallel triangular node placement scheme

3.2.3 Grid deployment

In this type, each node is connected to neighboring nodes along more than two dimensions. For data transfer there are many alternative routes if a failure occur .Paddy field monitoring systems is an example of this type of node deployment scheme. The figure 3.4 demonstrates the grid deployment of sensors in various configurations.

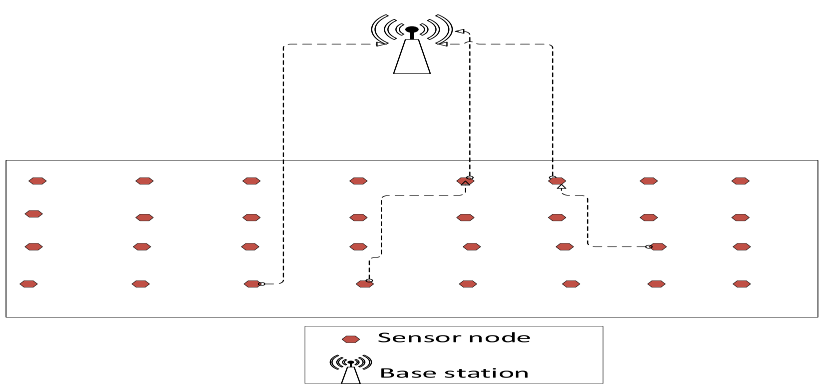


Figure. 3.4 Grid LWSN architecture

(a) Random

In grid random deployment the sensor nodes are deployed randomly in such a way that, they lie in communication range to each other and if any fault occur there are many alternative paths for data forwarding. This scheme is suit able for battlefield monitoring. Figure. 3.4 (a) depicts a grid random deployment scheme.

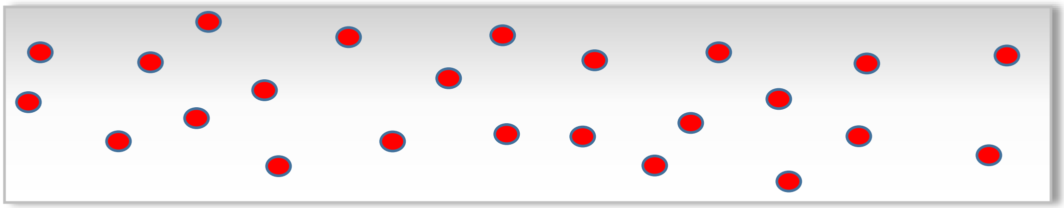


Figure. 3.4 (a). Linear Grid random node placement scheme

(b) Uniform

In this type, each node is connected to neighboring nodes along more than two dimensions with equal distance. Crop monitoring systems belong to this type of node placement scheme Figure. 3.4 (b) depicts a grid uniform deployment scheme.

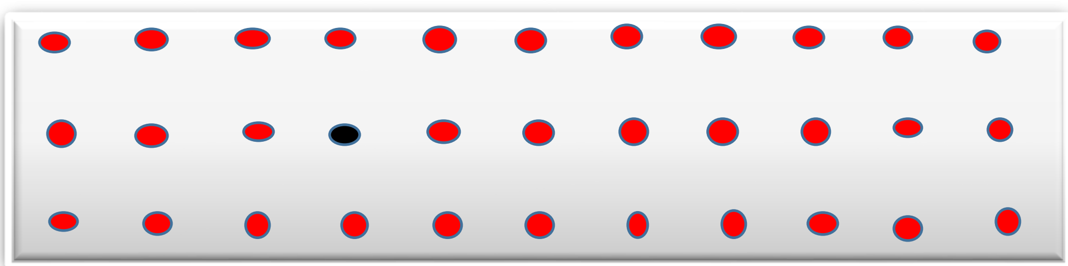


Fig 3.4 (b). Grid uniform node placement scheme

3.3 Clustering Protocols for LWSNs

As mentioned earlier, clustering protocol plays pivotal role in lifetime of LWSN. In this section, we describe three prominent clustering protocols and discuss their working in case of LWSNs. A brief description of these algorithms These clustering protocols include Distributed Energy-efficient Clustering (DEEC) [31], Developed Distributed Energy-Efficient Clustering (DDEEC) [32] and Energy Efficient Scheme for Clustering Protocol Prolonging the Lifetime of Heterogeneous Wireless Sensor Networks (TDEEC) [33]. We briefly discussed theses algorithm in chapter 2 in case of WSN.

3.3.1 DEEC

DEEC is a distributed energy-efficient clustering algorithm for heterogeneous WSN. The main idea of this algorithm is to limit the energy consumption of sensors by adopting an optimal approach. The sensors continuously have to report data to a remotely placed base station. DEEC roughly calculates the expected network life time based on the energy dissipated by each sensor during a round. It employs nodes having two different energy levels i.e., *E0* refers to initial energy of normal nodes and *E0 (1 + a)* denotes starting energy of advanced nodes. The probability of cluster-head selection is primarily based on the ratio between remaining energy of each sensor and the average network energy. To achieve optimal count of cluster heads, the probability threshold that each sensor *si* use to calculate for becoming a cluster-head in each round is as follows[60]. Equation 3.1 is used for cluster head selection.

$$T(Si)=\begin{cases} \frac{pi}{1-pi(rmod\frac{1}{pi})} & if\ si\ \in\ G \\ 0 & otherwise \end{cases} \qquad (3.1)$$

Here, *G* is the group of sensors which are qualified to be cluster heads in round *r*. Each round *r* requires a sensor *si* to choose an arbitrary value amid 0 and 1 if it determine its eligibility to be a cluster head. In case the value is lower than the threshold T*(si*), the sensor *si* becomes a cluster-head during the present round. The cluster head dissipates more energy compared to other sensors.

This is the prime reason that DEEC rotates the role of cluster heads and prefer to delegate it to the sensors that had more initial and residual energy. Hence, resulting in an increased network lifetime.

3.3.2 DDEEC

Unlike DEEC that continuously engage the advanced sensors to be cluster-heads until their remaining energy almost equate with the normal sensors hence, resulting in early death of the advanced nodes. To cope with this issue, DDEEC strives to balance the cluster head selection process across the network based on the residual energy of nodes. Here authors used two type of nodes normal nodes and the advance nodes ,normal nodes denoted with *(1-m)N* ,with initial energy *Eo* also advance nodes denoted with *mN* which initial energy is equal to *Eo(1+a).* So the equation 3.2 determine the accumulative initial energy of the network [60].

$$E\ total = N(1-m)\ E0 + Nm\ E0(1+a) = NE0(1+am) \qquad (3.2)$$

To transmitting an L bit packet over a distance d, to access a Signal to Noise Ratio (SNR) model the energy expended by the radio is given by Equation 3.3 [61]

$$E_{tx}(L,d) = \begin{cases} LE_{elec} + LEfsd^2 \quad if & d < d0 \\ LE_{elec} + LEmpd^4 if & d \geq d0 \end{cases} \qquad (3.3)$$

In this equation *Eelec* represents energy consumption per bit required for transmitter (ETX). This variable depend on many variable such as coding digital signals, conversion of signals and filtering signals for the transmission. Efs and Emp energy required amplifier model and distance between sender and receiver represented with d.

In DDEEC for cluster head election the average energy of rth round is given by Equation 3.4.

$$\bar{E}\ (t) = \frac{1}{N}\ Etotal\ (1- \frac{r}{R}) \qquad (3.4)$$

Where total number of round used in network lifetime denoted by *R.*

So as mention earlier DDEEC strives to balance the cluster head selection process across the network based on the residual energy of nodes. So in DDEEC advance and normal all nodes ones, must have same chance to be a cluster head. Its mean all nodes have same probability to come a cluster head in each round. When election of cluster head will be balanced hence, resulting in an increased network lifetime.

3.3.3 TDEEC

TDEEC is an extension of the DEEC with an advance feature of introducing normal nodes, super nodes and advance nodes. The similarity in both algorithms are its energy estimation. In TDEEC, the authors adjusted the threshold values and based on its threshold value, a node become a cluster head depends on its residual energy. The nodes having more residual energy within a round becomes the cluster head. The main difference between DEEC and its extended version TDEEC is the use of three different types of nodes such as normal nodes, super nodes and advance nodes. Super nodes have more energy as compared to advance nodes and similarly compare to normal nodes, advance nodes have two time more energy as compared to normal nodes. Simulation results shows that the network lifetime improved in TDECC as compared to DEEC. The accumulative initial energy of the network is given by Equation 3.5 [62].

$$E_{total}=N(1-m).E_o+m.N.(1+a)(l-m_o).E_o+N.m.m_o.E_o(1+b)=N.E_o(1+m(a+m_o.b)) \quad (3.5)$$

In these algorithms only random topology used for simulation result, our main contribute we deploy these algorithms in linear environment and investigate the performance of different topologies.

3.4 Proposed Gird-Triangular based Enhance Threshold Distributed Energy Efficient Node Placement Scheme

In triangular node placement scheme all node place in triangular manner. This scheme efficient for long-length LSNs because it has many alternative paths for data forward if any failure occur. In triangular node placement scheme all node place in triangular manner. This scheme efficient for long-length LSNs because it has many alternative paths for data forward if any failure occur. Through this scheme all nodes share the traffic load since network lifetime increase. When random and uniform scheme unable to balance energy consumption then we can apply this scheme for prolong network lifetime. Figure. 3.5 depicts a grid triangular node deployment scheme. Its shows sensor node deploy in a grid with triangular shape.

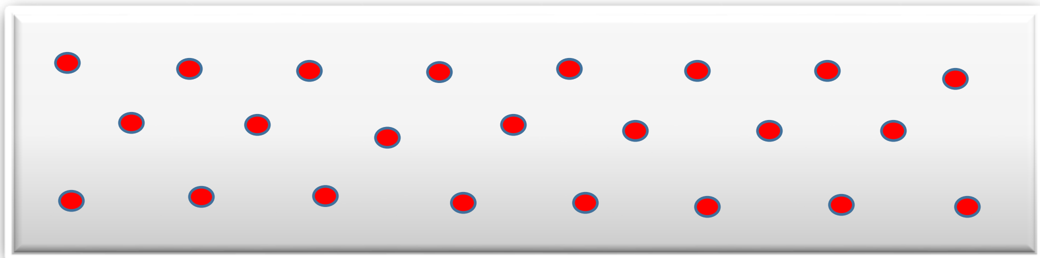


Figure. 3.5 Grid triangular node placement scheme

TDEEC is an extension of the previous algorithm DDEEC, which was an extension of DEEC, the main difference between these two algorithms is the use of super node and also the threshold value of cluster heads are fixed in order to act as cluster head. The main focus of our research work is to investigate an optimal node placement scheme for monitoring the lifeline infrastructure, and for this, we need clustering algorithm which are suitable for linear configuration. In this regard, we have investigated the existing conventional algorithms DEEC, DDEEC and TDEEC with reference to LWSN. We proposed a grid triangular node placement scheme which is suitable for lifeline infrastructure monitoring.

In grid triangular node placement scheme after the energy dissipated in a given node reached a set threshold value, that node will be consider dead for the remainder of the simulation, and nearest node will be chosen for data transmission. our contribution in this regard are two fold, first different node placement schemes are implemented on DEEC, DDEEC and TDEEC in context of LWSN and the second one is when a node near to die mean it residual energy become near to 0.5 it select minimum path from neighbor nodes and send data to more nearest node, through this the number of losses data packets will be reduce and number of data packets will be improve that are received by the base station. Second fold is implemented on only TDEEC.

After extensive simulation studies and implementation of DEEC, DDEEC, and enhance TDEEC with three difference topologies i.e Linear Sequential, Linear Parallel, and Grid based topologies as described in Figure. 3.1 Other than this, we have also simulated Linear Sequential with Random, Uniform, and decreasing distance, also Linear Parallel with, Random, Uniform and Triangular. Other than this, we have also simulated and analyzed Grid with random, uniform and Triangular topologies. After extensive simulation studies, we considered alive nodes and expired nodes, when the first node die after transmitted data to the base station, and number of packets sent to the base station as a performance parameters. We have concluded that, grid triangular node placement scheme LWSN due to many alternative paths if any failure occur. The following section explain TDEEC with grid node placement scheme.

Algorithms

Results: Cluster, CH formation, minimum path selection

Node placement Format

1. Q ← 0 // where Q is network region
2. Apply100*10 then Q ← 100*10 m^2
3. X= 100m and Y = 10m
4. Set nodes=100;
5. $N == 2^e$ // initial energy of node
6. Set level1= 25;
7. Set level 2= 50;
8. Set level 3= 75;
9. For i=1 to n
10. If i<= level 1,

11. set posx= (4*i)-2;
12. Set posy= 2;
13. Else if i>level 1 AND i<= level 2
14. Set posx= 4*(i- level1)
15. Set posy=4;
16. Else if i>level 2 AND i<= level3
17. set posx= 4*(i-level 2)-2;
18. Set posy= 6;
19. Else if i>level 3
20. Set posx= 4*(i- level3)
21. Set posy=8;
22. End if
23. If $n(N) == 0.5^e$ then
24. Nearest n ← All data send by $n(N) == 0.5^e$

Our main contribution in this regard is investigate optimal node placement scheme for monitoring lifeline infrastructure and proposed a grid based triangular node placement scheme for autonomous monitoring lifeline infrastructure. In next chapter simulation result shows impact of optimal node placement scheme on DEEC, DDEEC and TDEEC in context of LWSN.

3.5 Summary

This chapter discussed various node placement schemes in detail in context of LWSN. Also the existing conventional clustering schemes are discussed in detail. The Next chapter presents simulation studies of DEEC, DDEEC, and TDEEC with the help of various node placement schemes as discussed in this chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Overview

This chapter presents simulation studies of the conventional clustering algorithm with a new prospective in terms of linear deployment of sensor nodes in order to monitor lifeline infrastructure. Therefore, in chapter 3, we have proposed different node placement schemes which is suitable for lifeline infrastructure. As discussed earlier, we have selected DEEC, DDEEC and TDEEC. The main idea is to analyze its performance through our proposed linear node placement schemes in order to choose the most suitable clustering and routing scheme in terms of network lifetime for monitoring lifeline infrastructure.

4.2 Simulation Setup

In order to analyze the performance of the DEEC, DDEEC, and TDEEC in LWSN, we used MATLAB for simulation. The deployment region is considered (100 x 10) m. Simulation experiments involve 100 sensor nodes using linear sequential, linear parallel and Grid and base station placed at the center of the region. During deployment, we ensured connectivity of all sensor nodes. All simulation parameters remains same throughout the experiments unless stated otherwise. All sensor nodes have initial energy of 2 joules. A sensor is considered dead if its energy level becomes 0.5 joules. Table 4.1 shows various simulation parameters similar to [31].

Table 4 simulation parameters

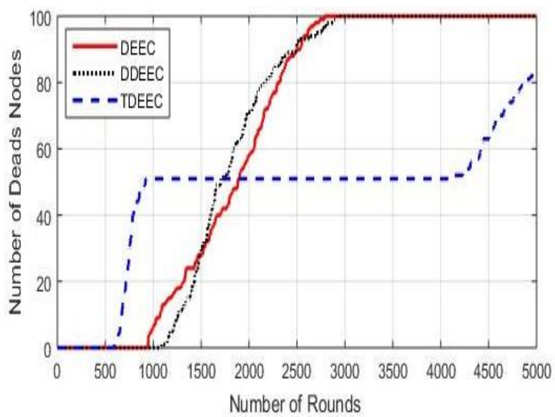
Parameters	**value**
Network field	100m×10m
Number of nodes	100
Energy dissipated	5nj/bit
Multipath loss	0.0013pj/bit/
Initial energy	2 joules
Data Aggregation Energy	5nj/bit/message
Message Size	4000 Bits
Probability of cluster heads	0.1

To evaluate the performance of DEEC, DDEEC and TDEEC different performance metrics are used i.e., number of dead nodes, number of alive nodes, and also number of messages send from cluster head to the base station similar to the performance parameters used in [31]. The network lifetime as per previous researchers depends on the nodes which dies early during the transmission process are considered weak network lifetime. In this regard, the network lifetime is analyzed through number of alive nodes and packets send from cluster head to base station, the more number of alive nodes in a round and more data packets send to the base station indicates the increased network lifetime. The total number of rounds were kept 5000 during all experiments and also base station is center in the region. The next section discusses simulation results of different node deployment schemes which used in DEEC, DDEEC, and TDEEC.

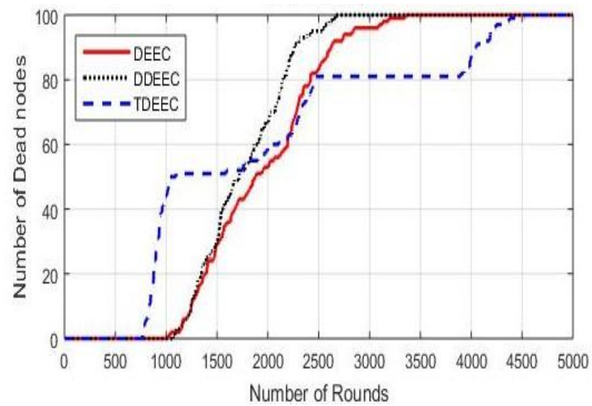
4.3 Linear Sequential deployment scheme

In linear Sequential as discussed in chapter 3, the nodes are deployed linearly (in one line) i.e randomly, uniform and decreasing distance. Some applications of LWSN such as monitoring of borders, bridges, and pipelines need linear sequential deployment of sensor nodes.

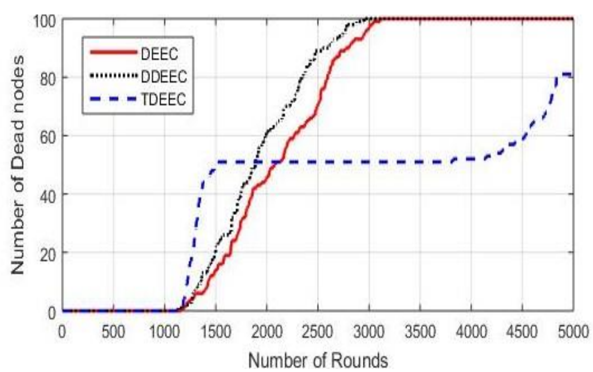
4.3.1 Comparative analysis using dead nodes



(a)



(b)



(c)

Figure 4.1 Number of dead nodes as a function of rounds with various linear sequential deployment schemes a) Random, b) Uniform, and c) Decreasing distance.

Figure 4.1 demonstrates network lifetime achieved by DEEC, DDEEC, and enhance TDEEC when different deployment schemes (i.e., random, uniform, and decreasing distance) in linear sequential were employed. Overall, the results of three routing protocols are almost similar for the three different topologies with few exceptions that will be explained later in this section. This is mainly because there is only one path from each sensor to the BS in all three topologies.

4.3.1.1 Random

Figure. 4.1 (a) shows that first node died in round 946 DEEC and 1088 DDEEC and all sensors became dead in 2788 rounds in DEEC and 2923 rounds in DDEEC. On the other hand, 82 nodes were died in 5000 rounds in case of enhance TDEEC. This clearly indicates the performance supremacy of enhance TDEEC over other two protocols. Due to election of cluster head. And on the other hand in random deployment scheme many be there any shortest alternative path if any failure occur.

4.3.1.2 Uniform

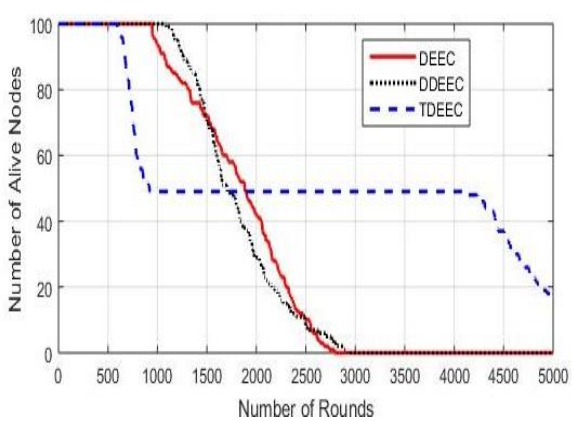
Fig. 4.1 (b) shows the result of linear sequential uniform nodes deployment. Here in DEEC first dead node is 1118 and all nodes to be dead in round 2469 probably. In case of DDEEC first node to be dead in 1075 rounds and all nodes become dead in round 2671 probably. In case of TDEEC first node die in 869 rounds and all node dead in 4769 rounds. As we mentions earlier in sequential uniform node placement there are no any alternative path for data transmission except only that line in which nodes are placed, if any fault occur then a node which are chosen for data transmission may be very far from defected node. So number of dead nodes depends on data forwarding distance. Here if we compare linear sequential random and linear sequential uniform the simulation results clearly indicates linear sequential random perform better in all algorithms.

4.3.1.3 Decreasing Distance

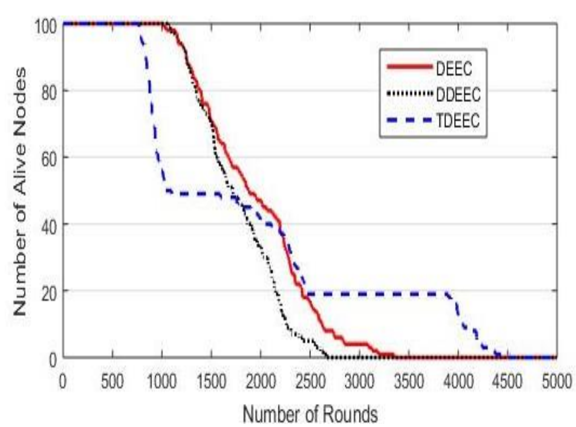
Also we observe the performance of these three algorithms in linear sequential gradually decreasing distance from base station which shown by figure 4.1 (c). In DEEC node start after 1160 rounds while for DDEEC it starts after 1130 rounds. Last node for DEEC and DDEEC dies at 3110 and 2950 rounds. While for TDEEC it starts after 1170 rounds. In TDEEC 77 nodes die for 5000 rounds. It clearly indicates that by introducing linear sequential decreasing distance node placement scheme and the position of base station in center of the region satiability period and lifetime is increases as compare to two schemes which we discussed earlier this is because increased node density near the BS and reduce the data forwarding overhead and also allows require these sensors to transmit at shorter distance which can lead to energy conservation.

4.3.2 Comparative analysis using alive node

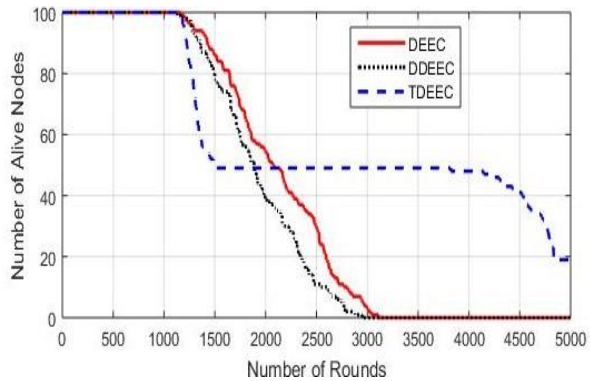
Figure 4.2. Demonstrates total remaining alive nodes over time i.e. Number of rounds. LWSN lifetime achieved by DEEC, DDEEC, and enhance TDEEC when different deployment schemes (i.e., random, uniform, and decreasing distance) in linear sequential were employed.



(a)



(b)



(c)

Figure 4.2 Number of alive nodes as a function of rounds with various deployment schemes a) Linear sequential random, b) Linear sequential uniform, and c) Decreasing distance.

4.3.2.1 Random

The figure 4.2 (a) shows that there is no more alive node in DEEC and DDEEC for 5000 number of rounds but in enhance TDEEC total number of alive nodes are 18 in 5000 rounds. Enhance TDEEC perform better it is because we stated earlier in figure 4.1 (a).

4.3.2.2 Uniform

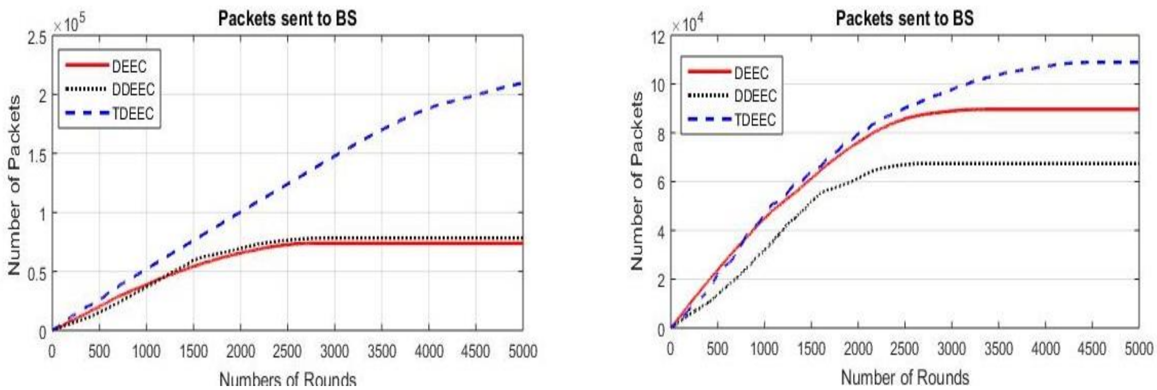
Figure 4.2 (b) shows that there is no more alive node in DEEC and DDEEC and enhance TDEEC for 5000 number of rounds. In other words, nodes are evenly distributed in a single line across the deployment region. Despite various merits of uniform deployment, it also suffers from uneven energy consumption especially nodes near the BS drain their energy quickly due to extra load of data forwarding. When any failure occur there is no any alternative route for data received at the base station.

4.3.2.3 Decreasing Distance

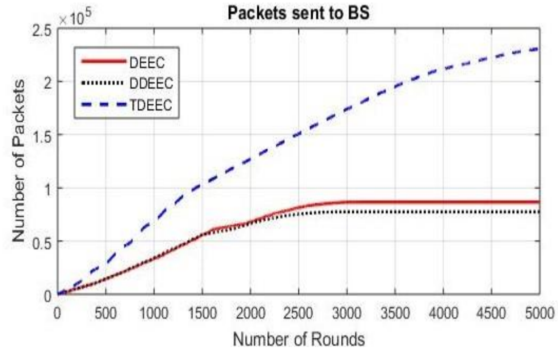
Figure 4.2 (c) demonstrates the performance of linear sequential decreasing distance. The graph shows that there is no more alive node in DEEC and DDEEC for 5000 number of rounds but in TDEEC total number of alive nodes are 23 in 5000 number of rounds. Here clearly show decreasing distance deployment scheme perform better than uniform node deployment scheme this is why? The reason is mention earlier in figure 3.2 (c). our main focus is compare node placements schemes and find out which node placement perform better in case of linear shaped structure . Thus, by introducing a node placement period with linear sequential decreasing distance, lifetime increased as compared with the two other schemes because of increased node density near the BS and reduced the data forwarding overhead. This process also requires these sensors to transmit at a shorter distance, thereby leading to energy conservation.

4.3.3 Number of Packets sends from cluster head to base station

Figure 4.3 demonstrates the comparison in term of number of messages send by cluster head to base station.



(a) (b)



(c)

Figure 4.3 Number of packets send from cluster head to base station with various deployment schemes a) Linear sequential random, b) Linear sequential uniform, and c) Decreasing distance.

4.3.3.1 Random

Figure 4.3 (a) demonstrates the number of packets received at base station. The graph shows the number of packets send from cluster head to base station in DEEC are 73819 and in DDEEC 78398 packets are received at base station. Comparison graph clear indicates enhance TDEEC has more numbers of data packets received at base station in comparison to DEEC and DDEEC. Total number of packets received at base station in enhance TDEEC are 209790 probably, due to node transmitting data its residual energy near to zero means this node near to die, the nearest node will be calculated having shortest path, and will be chosen for data transmission. Respect to this packets lose due to node failure reduced.

4.3.3.2 Uniform

In figure 4.3 (b) we can see the number of packets sends from base station to cluster head in uniform node deployment scheme enhance TDEEC has more packets as compare to DEEC and DDEEC. In DEEC packets received at base station are 41620 and in DDEEC these packets are 67552 probably. But in our algorithm these packets which received at base station from cluster head are 108926 probably. If we compare linear random and linear uniform nodes placement scheme in context of data send at base station thus, it's clearly indicate linear random perform better.

4.3.3.3 Linear decreasing distance

Figure 4.3 (c) demonstrates packets send to the base station using gradually decreasing distance node placement scheme we can see using this scheme number of packets received at base station increased as compare to linear sequential random and linear sequential uniform nodes deployment schemes. This is because increased node density near the BS and reduce the data forwarding overhead. This scheme perform better than which we discussed earlier in graph 4.3 (a) and 4.3 (b). We can see DEEC sends 86677 packets to base station and DDEEC forwards 77453 also enhance TDEEC algorithm forwards 221009 packets to base station from cluster head.

4.3.4 Network life time

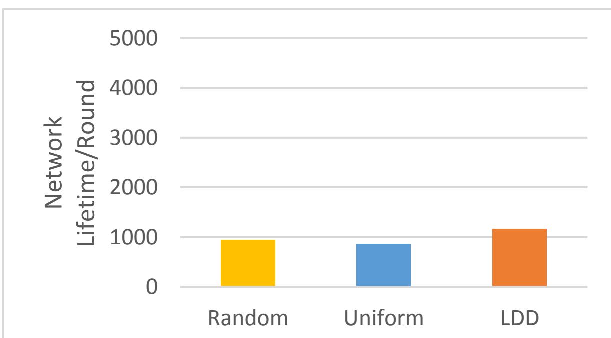


Figure 4.4 Network lifetime with various deployment schemes a) Linear sequential random, b) Linear sequential uniform, and c) Decreasing distance.

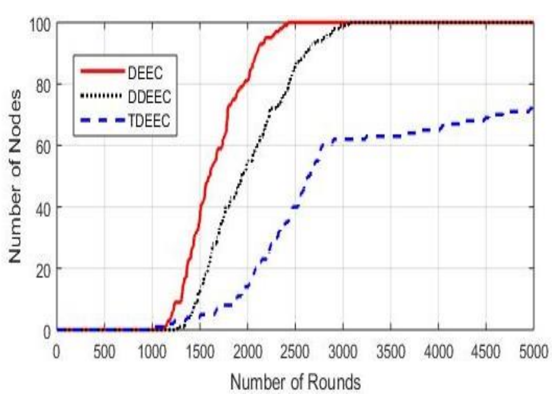
Figure 4.4 shows the network lifetime per rounds for linear sequential random, linear sequential uniform and gradually decreasing distance node placement schemes. Figure 4.4 clearly indicates that linear decreasing distance node placement scheme significantly increase network lifetime compared to linear random and linear uniform. This is mainly because linear sequential decreasing distance LDD balances the data forwarding overhead by placing more nodes towards the base station. In addition, reducing the distance towards the base station also prevents nearby nodes to deplete out their energy more quickly, hence prolong network lifetime. The design rationale is that increased node density near the BS will not only reduce the data forwarding overhead but also allows require these sensors to transmit at shorter distance which can lead to energy conservation.

4.4 Linear Parallel Deployment

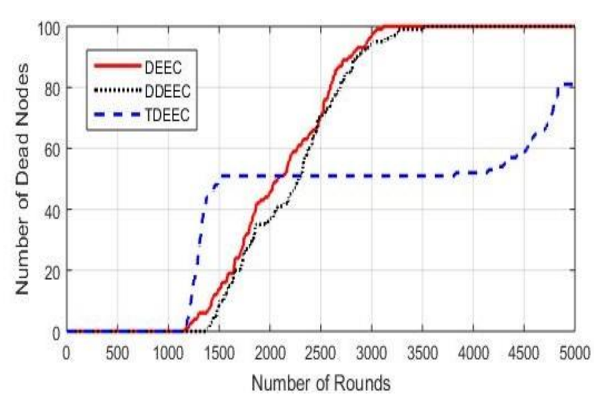
In linear parallel nodes deployment scheme if any failure occur there is an alternative path for data forward. The main advantage of this scheme is alternative route for data transfer. Here we discussed simulation results using parameters number of dead and alive nodes.

4.4.1 Comparison using parameter number of dead nodes

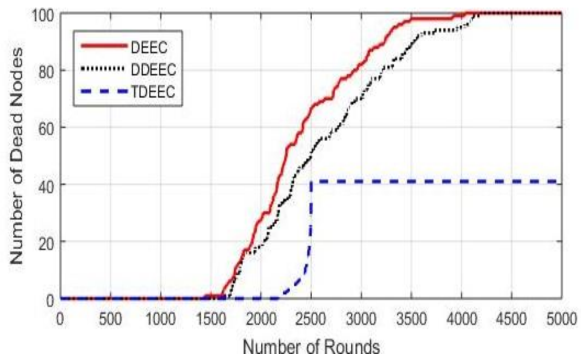
Figure 4.5 demonstrates network lifetime achieved by DEEC, DDEEC, and TDEEC when different deployment schemes (i.e., random, uniform, and triangular) in linear parallel were employed.



(a)



(b)



(c)

Figure 4.5 Number of dead nodes as a function of rounds with various deployment schemes a) Linear parallel random, b) Linear parallel uniform, and c) linear parallel triangular.

4.4.1.1 Random

Fig 4.5 (a) represents the performance of these three algorithms under linear parallel random node deployment. In DEEC nodes start die after 1049 rounds and in DDEEC number of death nodes starts after 600 rounds. And last node for DEEC and DDEEC dies at 3170 and 3390 rounds probably. While for enhance TDEEC first node die at 610 rounds and total died nodes are 76 in 5000 rounds. It indicate that through linear parallel random node placement scheme lifetime of DEEC, DDEEC and enhance TDEEC is longer as compared linear sequential nodes deployment scheme due to alternative paths.

4.4.1.2 Uniform

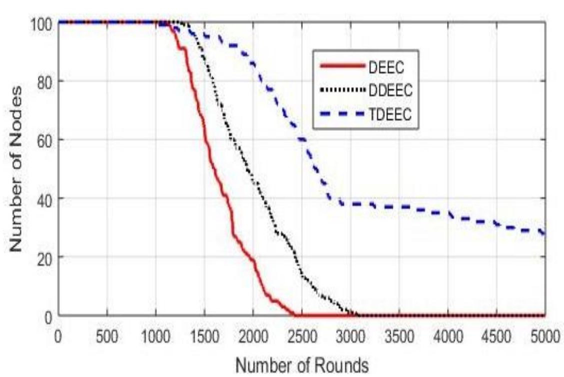
Fig 4.5 (b) demonstrates the comparison in linear parallel uniform distance according to number of death nodes. In DEEC first node dead after 1260 rounds and all nodes die after 3070 rounds while in DDEEC first node dead after 1380 and all nodes dead after 3500 rounds. In TDEEC first node dead 1200 and 54 nodes dead in 5000 rounds. It is clearly indicate that linear parallel uniform node deployment scheme perform better then linear sequential uniform node deployment scheme this is because there is alternative paths node to node for data transfer.

4.4.1.3 Triangular

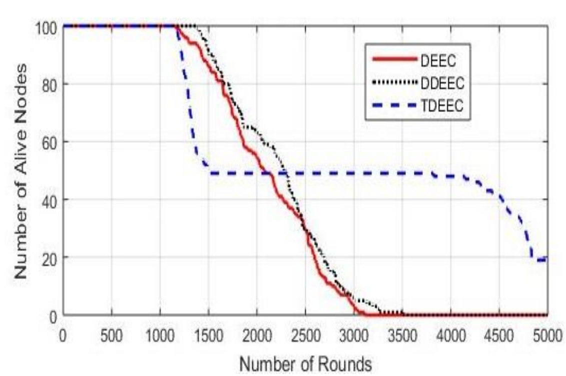
The figure 4.5 (c) describe the dead node in parallel triangular nodes deployment scheme. In DEEC, the first node died after round 1400, and all nodes died after around 4030. While in DDEEC, first node died after 1615 rounds and all nodes likely died after 4190 rounds probably. In TDEEC, first node died after round 2174 and 41 nodes dead within 5000 rounds. The comparison results clearly indicate linear parallel triangular scheme perform better than do the linear sequential and linear parallel uniform node deployment schemes because in the linear parallel triangular scheme, the data transfer alternative paths increase. Simulation results show the same conclusion.

4.4.2 Comparison using parameter number of alive nodes

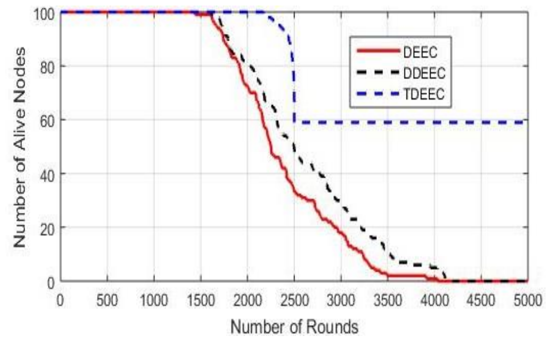
Figure 4.6. Demonstrates total remaining alive nodes over time i.e. Number of rounds. LWSN lifetime achieved by DEEC, DDEEC, and TDEEC when different deployment schemes (i.e., random, uniform, and decreasing distance) in linear sequential were employed.



(a)



(b)



(c)

Figure. 4.6 Number of alive nodes as a function of rounds with various deployment schemes a) Linear parallel random, b) Linear parallel uniform, and c) linear parallel triangular

4.4.2.1 Random

Fig 4.6 (a) Shows the total number of alive nodes in case of linear parallel random deployment environment. There is no more alive node in 5000 rounds for DEEC and DDEEC whereas that for enhance TDEEC, 59 nodes are alive for 5000 rounds. Due to cluster head selection the comparison graphs shows the performance of enhance TDEEC is longer than other two protocols. Also in linear parallel there is alternative path if any failure occur.

4.4.2.2 Uniform

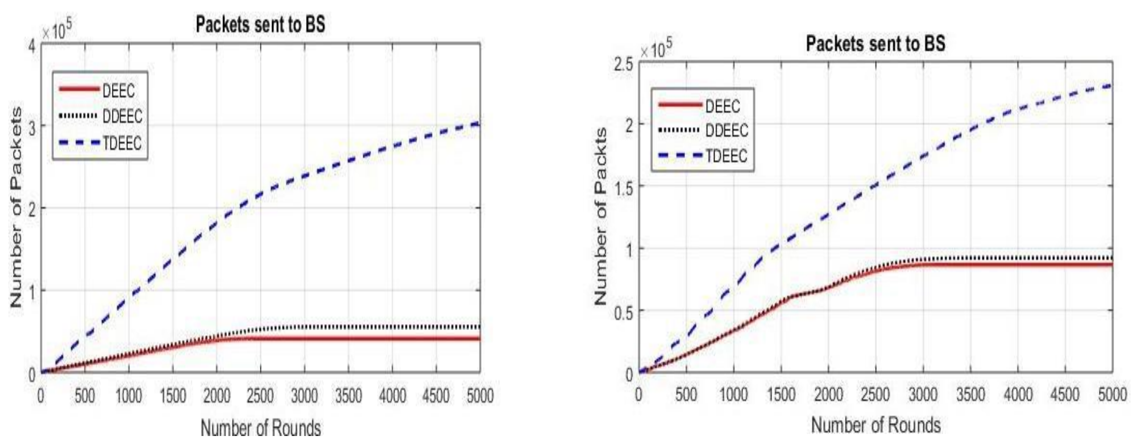
Also the figure 4.6 (b) shows the performance of linear parallel uniform nodes deployment. The results clearly shows there is no more alive node in DEEC and DDEEC for 5000 number of rounds but in TDEEC alive nodes are 46 in 5000 number of rounds. It shows that enhance TDEEC increase the network life time through balance cluster head selection and using optimal nodes placement scheme. This result clearly indicates the linear parallel uniform node deployment scheme performs better than the linear sequential uniform node deployment scheme because of the alternative cluster head paths to the BS.

4.4.2.3 Triangular

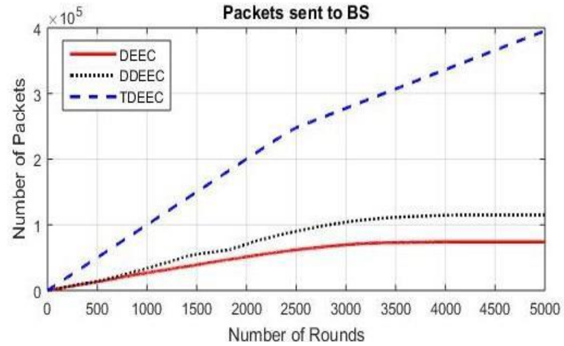
On the other hand figure 4.6 (c) shows the results of alive nodes in linear parallel triangular nodes deployment scheme. It define there is no more alive node in DEEC and DDEEC for 5000 number of rounds while in TDEEC total no of alive nodes are 59 in 5000 number of rounds. The comparison results clearly indicate the linear parallel triangular scheme performs better than linear sequential and linear parallel uniform node deployment schemes because in the linear parallel triangular scheme, the data transfer alternative paths increase. Simulation results show the same conclusion.

4.4.3 Number of Packets sends from cluster head to base station

Figure 4.7 demonstrates the comparison in term of number of messages send by cluster head to base station. This comparison shows using linear parallel random, uniform and triangular node placements schemes.



(a) (b)



(c)

Figure 4.7 Number of packets send from cluster head to base station with various deployment schemes a) Linear parallel random, b) Linear parallel uniform, and c) Linear triangular.

4.4.3.1 Random

Figure 4.7 (a) demonstrates the number of packets received at base station. The graph shows the number of packets send from cluster head to base station in DEEC are 94710 and, whereas for DDEEC 135713 packets are received at base station. Comparison graph clear indicates enhance TDEEC has more numbers of data packets received at base station as comparison to DEEC and DDEEC. Total number of packets received at base station in enhance TDEEC are 215127 probably, due to node transmitting data its residual energy near to zero means a node near to die, the nearest node will be calculated having shortest path, and will be chosen for data transmission. The data packets transfer cluster head to base station increase.

4.4.3.2 Uniform

In figure 4.7 (b) we can see enhance TDEEC, send more number of data packets from cluster head to base station in parallel uniform nodes deployment scheme. Using this node deployment scheme DEEC send 55266 packets at base station and DDEEC, transfer 92153 packets at base station. Whereas enhance TDEEC, these packets which received at base station from cluster head are 393168 probably. This is why? The reason is mention earlier.

4.4.3.3 Triangular

Figure 4.7 (c) demonstrates packets send to the base station using linear parallel triangular node placement scheme. We can see using this scheme number of packets received at base station increased as compare to linear sequential and linear parallel uniform nodes deployment schemes. We can see DEEC, sends 73943 packets to base station, whereas DDEEC, forwards 114971 packets at base station. Also in TDEEC, algorithm forwards 3931690 packets at base station from cluster head. Because in the linear parallel triangular scheme, the data transfer alternative paths increase. Simulation results show the same conclusion.

4.4.4 Network life time

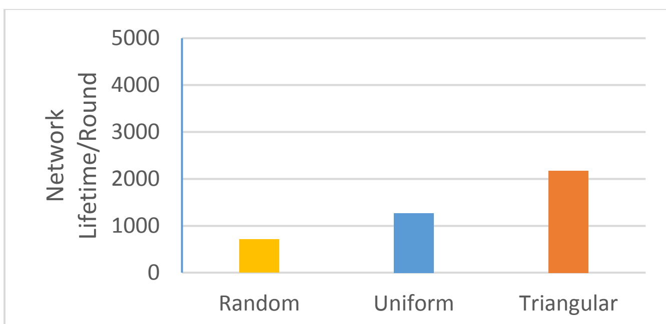


Figure 4.8 Network lifetime with various deployment schemes a) Linear parallel random, b) Linear parallel uniform, and c) Linear parallel triangular.

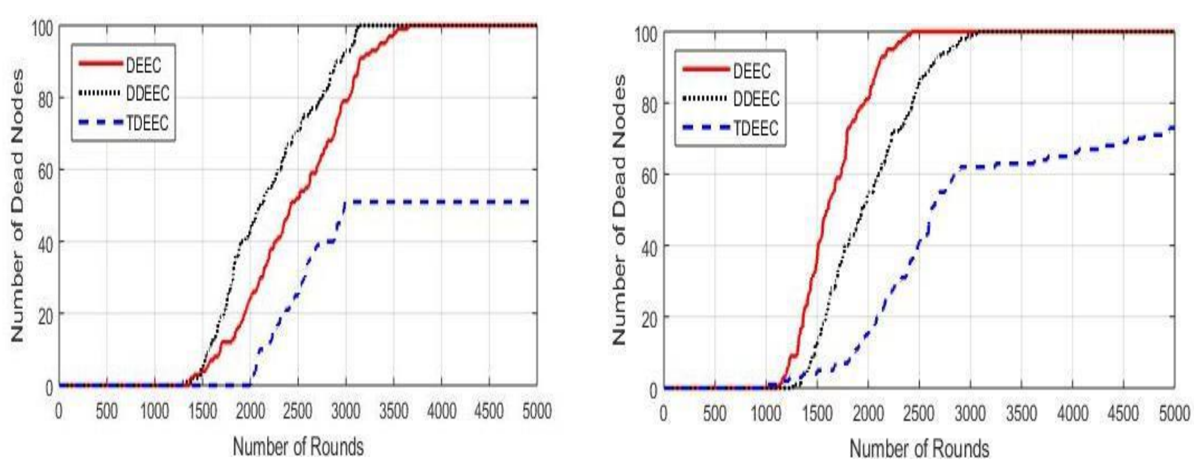
Figure 4.8 shows the network lifetime for linear parallel random, linear parallel uniform and linear parallel triangular node placement schemes. Figure 4.8 clearly indicates that linear parallel triangular node placement scheme significantly increase network lifetime compared to linear random and linear uniform schemes because in the linear parallel triangular scheme, the data transfer alternative paths increase. In parallel triangular nodes are places in two parallel lines so the data forwarding load balanced hence, the lifetime of a node increase. Simulation results show the same conclusion.

4.5 Grid deployment

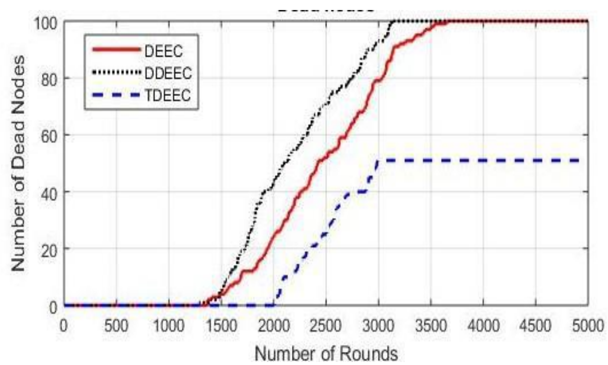
As we stated earlier in this type, each node is connected to neighboring nodes along more than two dimensions. For data transfer there are many alternative routes if a failure occur .Paddy field monitoring systems is an example of this type of node deployment scheme. Here we discussed simulation results using parameters number of dead and alive nodes.

4.5.1 Comparison using parameter number of dead nodes

Figure 4.9 demonstrates network lifetime achieved by DEEC, DDEEC, and TDEEC when different deployment schemes (i.e., random, uniform, and triangular) in grid were employed. Grid deployment increase lifetime of network due to many alternative paths if any failure occur. There is less chance to loss of data if any node fail it data can be sent to the base station through multiples alternative paths.



(a) (b)



(c)

Figure 4.9 Number of dead nodes as a function of rounds with various deployment schemes a) Grid random, b) Grid uniform, and c) Triangular Grid

4.5.1.1 Random

Figure 4.9 (a) shows the performance of these three algorithms under grid random node deployment. In DEEC, nodes start to die after round 1350, whereas in DDEEC, node death starts after round 1200. Total died nodes in DEEC, are 75 and in DDEEC, died nodes are 70, respectively within rounds. In TDEEC, node death started after round 2000. In enhance TDEEC, 41 nodes died within 5000 rounds. This result clearly shows that by introducing grid random node placement, the lifetimes of DEEC, DDEEC, and enhance TDEEC become longer than the linear sequential and linear parallel node deployment schemes due to alternative paths.

4.5.1.2 Uniform

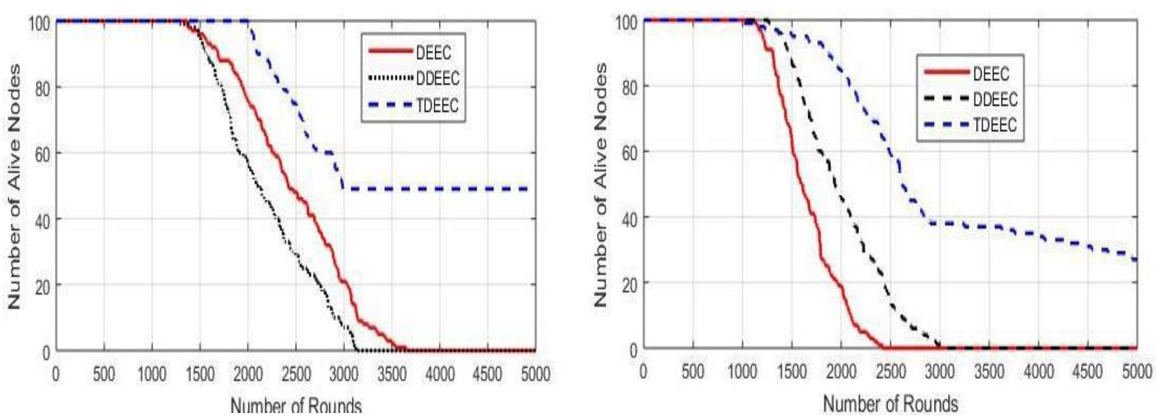
The figure 4.9 (b) shows that in DEEC, number of dead node starts in 1001 rounds probably and total number of node drawn out from their energy are 73 in 5000 rounds. In DDEEC, first node drawn out from energy in 2250 rounds while total number of death nodes are 70 in 5000 rounds. Therefore in TDEEC, the first node likely died within 2980 rounds, and 78 nodes died within 5000 rounds. We achieve grid node deployment scheme reduce number of death node and increase network life time through many alternative paths for data transmission to BS.

4.5.1.3 Triangular

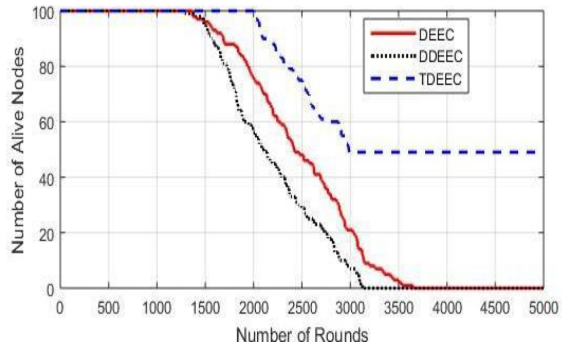
Figure 4.9 (c) reflects the total numbers of node that depleted out their energy and becomes dead in grid triangular deployment scheme. Grid triangular distance node deployment approach maximize network lifetime by reducing the number of dead nodes. The comparison graph shows in DEEC number of death node starts from 3550 rounds and total nodes drawn out from their energy 66 within rounds also in DDEEC, first node die in 2400 rounds whenever total number of death nodes are approximately 69 in 5000 rounds. In enhance TDEEC, the first node likely died within 3319 rounds, and 11 nodes died within 5000 rounds Thus, the grid triangular node deployment scheme performs better than the other schemes because in this scheme, if any node fails, data can be transmitted to the BS using many alternative paths. Grid triangular have more alternative paths other all schemes which we discussed earlier.

4.5.2 Comparison using parameter number of alive node

Figure. 4.10. Demonstrates total remaining alive nodes in total number of rounds. LWSN lifetime achieved by DEEC, DDEEC, and TDEEC when different deployment schemes (i.e. uniform, and triangular) in grid were employed.



(a) (b)



(c)

Figure. 4.10 Number of alive nodes as a function of rounds with various deployment schemes a) Grid random, b) Grid uniform, and c) Triangular Grid

4.5.2.1 Random

Figure 4.10 (a) Shows the total number of alive nodes in case of grid random deployment environment. There is 25 alive node in 5000 rounds for DEEC and for DDEEC, alive nodes are 30 in 5000 rounds. In enhance TDEEC due to balanced cluster head selection the comparison graphs shows lifetime of TDEEC is longer than other two algorithms and on the other hand optimal path selection for data transmission to BS achieve by grid deployment scheme due to many alternatives paths which chosen when any fault occur. So in TDEEC, 61 total alive node within rounds.

4.5.2.2 Uniform

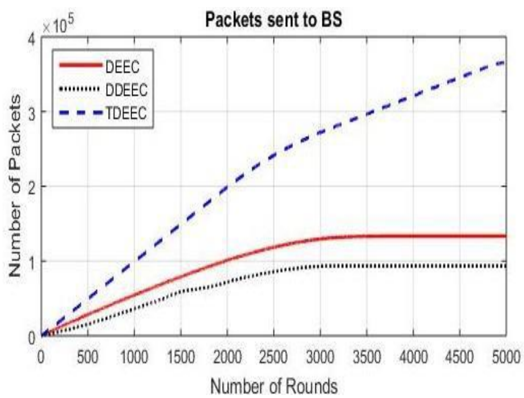
Figure 4.10 (b) Shows the total number of alive nodes in case of grid uniform deployment environment. The graph shows there 23 alive node within 5000 rounds in DEEC, while there are 30 nodes alive in DDEEC for 5000 rounds. Also in TDEEC there are 78 alive nodes in 5000 rounds. The comparison results shows grid uniform deployment scheme perform better then linear sequential uniform and linear parallel uniform node deployment schemes. Hence network stability and lifetime increases by using optimal node placement scheme.

4.5.2.3 Triangular

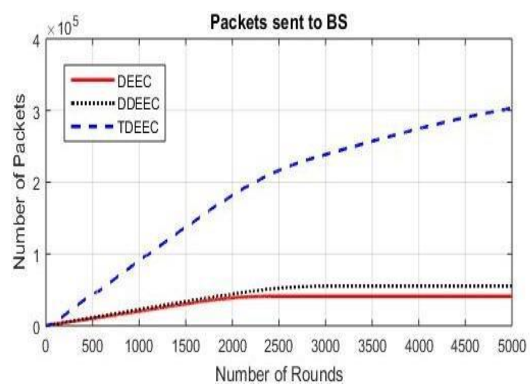
Figure 4.10 (c) represent the total alive nodes during the lifetime of the network in grid triangular node deployment scheme. We can see likely 34 alive nodes in DEEC, whenever in DDEEC, 31 alive nodes within rounds. Also in TDEEC there are 89 alive nodes in 5000 rounds. The comparison results shows grid triangular deployment scheme perform better in all algorithms. Hence network stability and lifetime increases due to network traffic load balanced and many alternative paths. Why triangular node placement perform better all other node placements schemes which we discussed earlier? So In grid triangular nodes placement scheme if any fault occur there are many alternative paths available for data transmission to base station, and on the other hand number of alive nodes increase because the number of died nodes depend on data sending distance. In grid triangular this data sending distance reduces so number of died nodes reduces. Thus, the grid triangular node deployment scheme increase network lifetime.

4.5.3 Number of Packets sends from cluster head to base station

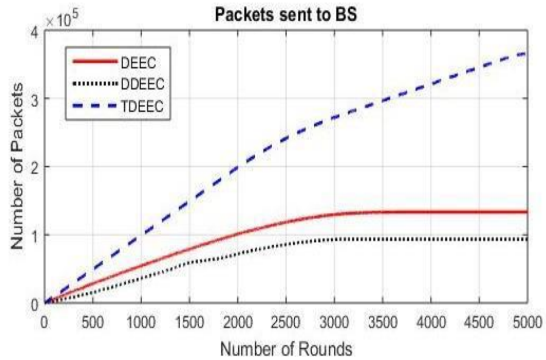
Figure 4.11 demonstrates the comparison in term of number of messages send by cluster head to base station. This comparison shows using grid random, uniform and triangular node placements schemes.



(a)



(b)



(c)

Figure 4.11 Number of packets send from cluster head to base station with various deployment schemes a) Grid random, b) Grid uniform, and c) Grid Triangular.

4.5.3.1 Random

Figure 4.11 (a) demonstrates the number of packets received at base station. The graph shows the number of packets send from cluster head to base station in DEEC, are 362154 and, whereas for DDEEC, 222746 packets are received at base station. Total number of packets received at base station in enhance TDEEC, are 407915 probably Comparison graph clear indicates enhance TDEEC has more numbers of data packets received at base station as comparison to DEEC and DDEEC. Due to node transmitting data its residual energy near to zero means a node near to die, the nearest node will be calculated having shortest path, and will be chosen for data transmission. The data packets transfer cluster head to base station increase. Simulation results show the same conclusion.

4.5.3.2 Uniform

In figure 4.11 (b) we can see enhance TDEEC, send more number of data packets from cluster head to base station in Grid uniform nodes deployment scheme. Using this node deployment scheme DEEC, forward 303344 packets at base station and DDEEC, transfer 365000 packets at base station. Whereas enhance TDEEC, these packets which received at base station from cluster head are 457716 probably.

4.5.3.3 Triangular

Figure 4.11 (c) demonstrates packets send to the base station using grid triangular node placement scheme. We can see using this scheme number of packets received at base station increased as compare to linear sequential and linear parallel nodes deployment schemes. We can see DEEC, sends 362154 packets at base station, whereas DDEEC, forwards 222746 packets at base station. Also enhance TDEEC, algorithm forwards 472744 packets at base station from cluster head. The messages delivered by enhance TDEEC are more than that of DEEC and DDEEC.

We can see maximize number of alternative routes and selection of alternative minimum path if any node near to deplete their energy the network lifetime increases and the data packets delivered are more. Simulation results show the same conclusion.

4.5.4 Network lifetime

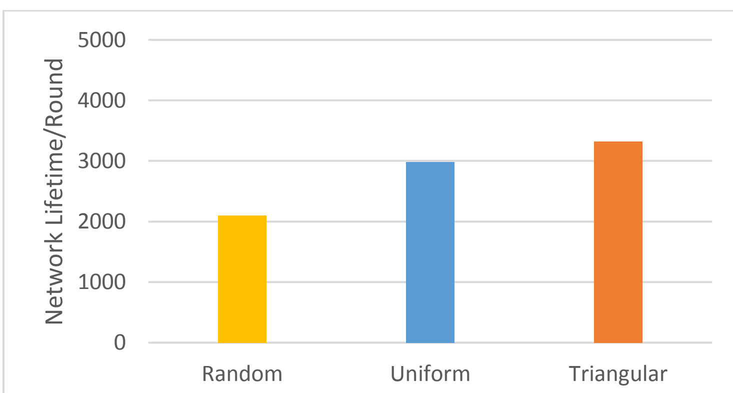
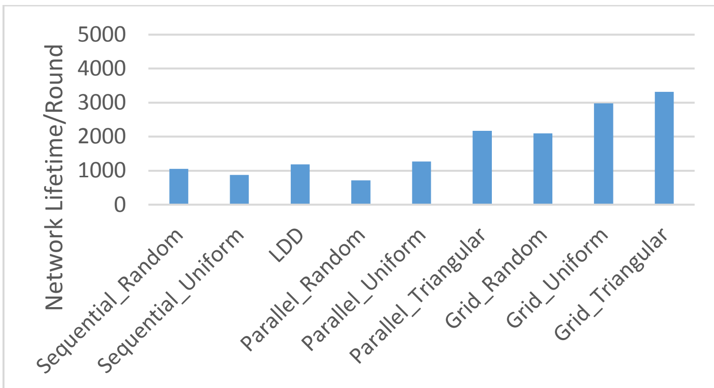


Figure 4.12 Network lifetime with various deployment schemes a) grid random, b) grid uniform, and c) grid triangular.

Figure 4.12 shows the network lifetime under 50000 rounds for grid random, grid uniform and grid triangular node placement schemes. Figure 4.4 shows that grid triangular node placement scheme increase network lifetime compared to grid random and grid uniform schemes because in the linear parallel triangular scheme, the data transfer alternative paths increase. In parallel triangular nodes are places in two parallel lines so the data forwarding load balanced hence, the lifetime of a node increase. Simulation results show the same conclusion



4.13 Comparison between different node placement schemes in terms of network lifetime.

Figure 4.13 shows the network lifetime for different node placement schemes. Figure 4.13 clearly indicates that grid triangular approaches significantly increase network lifetime compared to other node placement schemes. This is because network traffic load balanced through multi hoping.

4.6 Summary

In this chapter we analyze the comparative performance of the DEEC, DDEEC, and TDEEC used different node placement schemes in context of LWSN also this chapter describes the experiment setup, performance metrics, and analysis of experimental results. When analyze the performance of different node deployment schemes in LWSN environment, we ensure connectivity of all sensor nodes. Experimental result analyze on the base of number of dead node and number of alive node remaining during 5000 rounds. Also analyze packets messages sends from cluster head to base station.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Overview

This chapter summarizes the brief overview of the research work carried out to address the issue of monitoring lifeline infrastructures including oil and gas pipelines, monitoring of roads using wireless sensor networks. In wireless sensor networks, node placement, clustering and routing algorithms are used to sense the information and transmit the sense data to their base station. One of the main issue in wireless sensor network is the energy consumption and network lifetime so that, the required data should be processed accordingly. Here it is important to mention that, Linear Wireless Sensor Network (LWSN) refers to the placement and distribution of sensor nodes in linear fashion. In case of linear deployment of sensor nodes, the conventional node placement, clustering and routing algorithms are not suitable for LWSN. So the main issue we have addressed in our thesis is to design a node placement scheme which is suitable for LWSN. The following section summarizes the conclusion of the research work conducted in this regard.

5.2 Conclusion

In this thesis, we investigated the optimal node placement scheme and clustering in linear wireless sensor networks and analyzed their performance. We have also discussed some prominent applications of LWSN and highlight their peculiarities compared to generic WSN applications. Then we discussed some node placement schemes (linear sequential, linear parallel and grid). We analyzed their performance using simulation studies with the help of most popular conventional clustering schemes such as DEEC, DDEEC and TDEEC with reference to LWSN. The main contribution of our thesis is, the extensive analysis of node placement schemes using linear sequential, linear parallel, and grid based node placement schemes. Here, it is important to highlight that in each node placement scheme i.e Linear sequential we further categorized each one with random deployment, uniform and decreasing distance based node deployment. We have also simulated each algorithm i.e DEEC, DDEEC, and TDEEC for each main and sub category of linear deployment. Moreover, we have concluded that, the TDEEC performs better in Grid based node placement scheme. After complete analysis and validation of results, we introduced shortest path in case the energy dissipated in a given node reached a set threshold value, that node was considered dead for the remainder of the simulation, and send the data to the near neighbor node The detailed simulation result clearly shows that performance of grid based node placement is better than linear sequential and linear parallel due to multiple alternative paths for data transmission. We have also concluded from simulation results that, efficient node placement and clustering scheme significantly affect LWSN lifetime and conventional clustering and routing schemes are not be suitable for LWSN.

5.3 Thesis contribution

The main problem in wireless sensor network is the energy efficiency and network lifetime. In case of linear wireless sensor network in which the nodes are deployed in linear order for various applications, efficient node placement scheme which leads to efficient clustering and routing algorithms. In order to achieve the network lifetime and energy consumption, in this regard our contributions are as under.

1. Complete analysis of conventional clustering and routing schemes with reference to LWSN.
2. Implementation of existing clustering schemes with (3x3) nine different node placement schemes specific to linear deployment of sensor nodes.
3. Analysis of DEEC, DDEEC, and TDEEC with the above mentioned node placement schemes.
4. After complete analysis and validation of simulation results shows Grid-Triangular with selection of shortest path for data transmission to base station enhance network lifetime.

5.4 Limitations

Our research is limited to node placement and routing only. We have not developed a complete clustering and routing algorithm for linear wireless sensor network.

5.5 Future work

In future it is recommended to design a complete clustering and routing protocol and architecture tailored for LWSN which used for real time monitoring lifeline infrastructure such as pipeline (gas, water and oil), railway track and crop field monitoring.

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