
Naveen Garlapati
Mohammed Altaf Ahmed
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Contact Information:
Authors:
Naveen Garlapati
E-mail: naga11@student.bth.se

Mohammed Altaf Ahmed
E-mail: reply2altaf@gmail.com

External advisor:
Michael Brorsson Ganehag
Engineer
NODA Intelligent Systems AB,
Karlskrona

University advisor:
Christian Johansson
Email: christian.johansson@bth.se
School of Computing
Blekinge Institute of Technology

School of Computing
Blekinge Institute of Technology
SE – 371 79 Karlskrona
Sweden

Internet : www.bth.se/com
Phone : +46 455 38 50 00
Fax : +46 455 38 50 57
ABSTRACT

Sensors play a prominent role in the industrialized society of today and a world without sensors is inconceivable as most of the electronic applications are based on it. Various applications including in the fields like military control in battlefield surveillance, industrial automation, health monitoring, security systems and many more utilizes wireless sensors, which reveals its prominence and deployment perspective. Such sensor nodes are becoming more common as the technology for wireless communication is becoming increasingly affordable. This thesis deals with the estimation of battery life for the selected algorithms where a specific industrial application is considered, utilizing wireless battery powered sensor nodes in order to measure indoor temperature in buildings as part of a heating control system. This application can accommodate only two batteries and sometimes it is to be placed in highly restricted areas, which makes it difficult to replace the batteries often. Hence saving the battery life is an intrinsic issue which needs to be overcome by any industrial manufacturer. So far, various algorithms have been implemented to solve this issue but have not succeeded completely. In our research we introduced a new approach to choose the best suited algorithm based on the requirements of specific industrial application. Also, by implementing those algorithms and considering the time interval of 15, 30 and 60 min, the battery life is estimated for any network.

The purpose of the paper is to study and compare different power conservation algorithms for wireless sensor networks in relation to the specific constraints found in this heating control system. The different algorithms are evaluated on the basis of their ability to preserve power while simultaneously fulfilling these specific constraints. Three different algorithms are selected and studied through simulations and their individual operational behaviour in relation to the specific industrial application is shown.

Finally, this report demonstrates the total energy consumed per message, average distance calculations from source node to sink node, by performing simulations in MATLAB (v7.9.0). This paper also exhibits the behavior of PEGASIS, EEAR and SPIN-1 algorithms considering node number variation, node range and different communication intervals as parameters. By performing quantitative analysis of obtained results, at the end one can find the sustainability of the battery life. For 200 nodes network, it is lasting longer when PEGASIS algorithm (high energy efficient) is used. But for the same number of deployed nodes, the EEAR based network sustains smaller than PEGASIS based network (considering two batteries) as EEAR could accomplish self organizing technique, similarly SPIN-1 based networks lasts very small as they could implement both self organizing and self-healing techniques. Hence it is to conclude that, for this specific industrial application, the researchers as well as manufacturers can incorporate these results directly in their application.

**Keywords:** Algorithms, Energy efficiency, MATLAB
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<th>Description</th>
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<tbody>
<tr>
<td>A/D</td>
<td>Analog to Digital</td>
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<tr>
<td>ACK</td>
<td>Acknowledgement</td>
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<td>ADV</td>
<td>Advertisement message</td>
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<td>AWP</td>
<td>Asynchronous Wake Protocol</td>
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<tr>
<td>BS</td>
<td>Base Station</td>
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<tr>
<td>CH</td>
<td>Cluster Head</td>
</tr>
<tr>
<td>DCR</td>
<td>Data Centric Routing</td>
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<td>DD</td>
<td>Direct Diffusion</td>
</tr>
<tr>
<td>EEAR</td>
<td>Energy Efficient Aware Routing</td>
</tr>
<tr>
<td>EECS</td>
<td>Energy Efficient Clustering Scheme</td>
</tr>
<tr>
<td>EEHC</td>
<td>Energy Efficient Hierarchy Cluster</td>
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<tr>
<td>EEUC</td>
<td>Energy Efficient Unequal Clustering</td>
</tr>
<tr>
<td>GAF</td>
<td>Geographic Adaptive Fidelity</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HAL</td>
<td>Hardware Abstraction Layer</td>
</tr>
<tr>
<td>HEDC</td>
<td>Hybrid Energy Distributed Cluster</td>
</tr>
<tr>
<td>LEACH</td>
<td>Low Energy Adaptive Clustering Hierarchy</td>
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<td>MATLAB</td>
<td>Matrix Laboratory</td>
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<tr>
<td>MEMS</td>
<td>Micro-Electro-Mechanical System</td>
</tr>
<tr>
<td>MRPUC</td>
<td>Multi-hop Routing Protocol with Unequal Clustering</td>
</tr>
<tr>
<td>PEACH</td>
<td>Power Efficient Adaptive Clustering Hierarchy</td>
</tr>
<tr>
<td>PEGASIS</td>
<td>Power Efficient Gathering in Sensor Information System</td>
</tr>
<tr>
<td>RAW</td>
<td>Random Asynchronous Wake protocol</td>
</tr>
<tr>
<td>REQ</td>
<td>Request</td>
</tr>
<tr>
<td>SNAP</td>
<td>Synapse Network Application Protocol</td>
</tr>
<tr>
<td>SPIN</td>
<td>Sensor Protocol for Information via Negotiation</td>
</tr>
<tr>
<td>STEM</td>
<td>Sparse Topology Energy Management</td>
</tr>
<tr>
<td>S-WEB</td>
<td>Sensor web</td>
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<td>WSN</td>
<td>Wireless Sensor Networks</td>
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1 **INTRODUCTION**

In today's world of wireless communications, wireless sensor technology is increasing rapidly and has the capability to prevail in the future as well. It is a new network technology which integrates low-power communication, sensor and micro-electro-mechanics [1]. A sensor network consists of a sensing subsystem, processing and power subsystem. Sensor nodes are small devices which are part of this typical wireless sensor network. These can be used in different applications such as industry, building automation, agriculture, military systems and information monitoring systems. Sensor nodes acquire more battery power to transmit the monitored information. As the nodes are distributed in random environments, it is very hard to replace the batteries. Hence energy management is one of the most challenging issues to be solved within the industry [14].

At any instance of node functionality, the hierarchies of energy consumption at node levels are data transmission, sensing the data and processing the data [2], hence there is a requirement of power consumption to save battery usage during communication. For example if these nodes are deployed in air, it is very difficult to replace at some instances like typical geographical areas. Also, issues like node failure, dynamic routing can be solved using self-healing and self-organizing techniques. But, carrying out these techniques simultaneously costs more energy and reduce the network life-time [12]. Hence in this project, a detailed study is carried out to choose energy efficient algorithms for self-healing and self-organizing mechanisms and by summarizing this study, the extension of the most suitable algorithm will be suggested.

1.1 **Aim and Objective**

The aim of this thesis is to evaluate the algorithms related to power conservation and choose the best suited algorithms, which consume less power and has capability to maintain a Wireless Sensor Network (WSN). Also, investigate the possibility for such algorithms to possess self organizing and self healing mechanism.

- To perform a literature study in order to investigate the current research in the field of WSN related to power consumption constraints.
- To collect different types of energy efficient algorithms and evaluate them critically considering power consumption and industrial constraints.
- Calculating the message count based on algorithmic behavior.
- Creating a simulation environment to calculate average energy.
- To identify the best suited algorithm by analyzing the results obtained.
- Investigate the possibility for a power efficient network to possess self organizing and self-healing mechanisms by estimating battery life time.
1.2 Research Question

RQ1. Which are the current state of the art algorithms in regards to wireless sensor networks related to power consumption constraints?

RQ2. Which is the best suited algorithm obtained from RQ1 in relation to performance constraints like power usage, energy efficiency and network life time?

RQ3. Is it possible and if so, to what extent is the proposed algorithm could be self-organizing and self-healing?

1.3 Scope of the thesis

The thesis emphasizes on the evaluation of power conservation algorithms which are applicable in WSNs. The basic concepts of WSNs are explained so as to affirm the required background knowledge and present the state of the art in regards to power conservation algorithms. Evaluation and selection of power conservation algorithm which conserves battery power in WSN is the ultimate goal of this research. Verifying the self organizing and self configuring techniques for the selected algorithms is another outcome of this work. Message calculation of mentioned algorithms such as PEGASIS, EEAR and SPIN-1 are included in the work.

1.4 Thesis outline

Chapter 1 presents the brief introduction of the topic and motivates the need for power conservation algorithms in WSNs. Chapter 2 discusses the background knowledge about the WSNs, followed by some of the challenges to face in WSNs, discussing about important applications, explaining different types of routing techniques in WSN. It further deals with the batteries used in WSN and concludes discussing about related works. Chapter 3 gives an overview of power conservation algorithms. Next chapter explicates the details of selected algorithms. Chapter 5 depicts simulation setup and details the implementation of algorithms. The results are analyzed and presented in chapter 6. Finally, obtained results are interpreted in the last chapter.

1.5 Research methodology

This research includes both analytical work as well as experimental parts through simulations. The process begins with the study of various power conservation algorithms, followed by simulations. This is then complemented with a theoretical analysis in order to estimate the battery lifetime of each algorithm. An overview of the process is shown in Figure 1. The basic steps in the research methodology are as follows:

1. Literature study on state of art based on power consumption algorithms. Initially, a detailed study is carried out to gain sufficient knowledge of current research fields based on the power consumption constraints in WSN. This study also helps to identify the research gap and provide contribution towards the particular mentioned field [15].
2. The search strategy is based on formation of a string by using related keywords, and then the needed relevant conference papers, journal articles and white papers are collected from databases like Google Scholar, Inspec, IEEE Explore, ACM digital library. The needed material is filtered by studying title, abstract and conclusions relevant to our research.

3. By studying various papers as a part of literature review, we gathered different algorithms and protocols mainly belonging to mobile adhoc networks, dissemination protocols, cluster algorithms, duty cycle and sleep awake types and from which, three prominent algorithms will be selected based on constrains such as power conservation, network life time and also relating to industrial specifications as well.

4. Theoretical analysis for calculation of message count that requires to drive data from source to sink for each selected algorithms.

5. Deployment of wireless sensor nodes in virtual environment of MATLAB (version 7.9.0).

6. For the estimation of battery life time which is our ultimate goal, it involves 3 basic and essential steps.
   - Calculation of shortest path from source to destination among the nodes to save energy.
   - Calculation of total energy parameters like average distance and average energy of the nodes involving in shortest paths.
   - Calculations of total energy while transmitting the data from source to sink in every single round.

7. Analyzing the obtained results (from step 6) and estimating the sustainability of battery life when it eventualizes its communication for every 15 minutes, 30 minutes and 60 minutes respectively.

8. Evaluation of most appropriate algorithms in regards to the specific industrial application and also verifying the existence of self healing and self organizing techniques for the specified algorithms by gaining results from RQ1 and RQ2.

9. Interpretation of results in form of graphs.

Figure 1: Research Methodology
2 BACKGROUND

2.1 What is WSN

Wireless sensor networks are gaining lot of attention in research areas as well as in the development of various applications [2]. It has become one of the leading and efficient technologies in wireless communication. These networks are used to monitor different applications such as snow monitoring, home and industry automation, and most importantly in military applications to monitor the information [9]. WSN is a new network technology which integrates low-power communication, sensor and micro-electro-mechanics [MEMS] [1]. It is collection of many number of sensor nodes which communicate themselves to acquire monitored information. In WSN sensor nodes can be deployed in either random (adhoc fashion) or in a manual way depending upon the application. These networks which are grouped with sensors are linked through a wireless medium to perform their required tasks. Communication between these sensors is occurred with the help of infrared devices or base stations or radios [7]. This radio network helps user to access information from any remote location and allows to visualizing and analyzing the sensor data. WSN’s which consists of many number of sensor nodes are able to communicate within themselves and as well as with the base station. Each sensor device consists of transceiver, a micro controller and is equipped with a power source which is usually an AA and AAA batteries. The specifics of each WSN depend on the nature of the application which is discussed further in section 2.4.

2.2 Architecture of WSN node

Sensor nodes are small devices which are battery powered and are a part of this typical wireless sensor network. A typical sensor node consists of four basic components: sensing subsystem, processing subsystem, power subsystem and communication subsystem [16]. The Figure 2 shown below [18] is the architecture of a single node. The explanation of each subsystem is given as follows:

![Figure 2: WSN Node Architecture](image-url)
2.2.1 Sensing subsystem

Sensors play a crucial role in WSN architecture as they establish a link between the real-time world and the computational environment. Sensors are the hardware devices which are used to monitor the data for required applications and to react to the environmental changes. After sensing the environment, the function of the sensor is to collect the sensed data and send it to further system for processing. The energy in sensor nodes is transformed from one form to another form using transducers. Sensor nodes normally include analog, digital and A/D converters and a microcontroller [28]. Sensors are categorized depending on the application and these can act according to the requirements of each application. Also, the factors to choose in a sensor are size and battery consumption.

2.2.2 Processing subsystem

Sensor nodes also consist of a processing unit along with memory units and converters. The communication interface processes the data. Later the collected data can be analyzed to verify the performance of the network. Here, the unit is responsible for adapting the routing information and align the topology if needed. Also performs data gathering, data acquisition and however processes the received data (incoming and outgoing) [29]. This subsystem also involves data fusion where the different packets arriving from the sensor nodes are gathered to form a single packet, thereby reducing the transmission energy between the sensor and user (observer).

2.2.3 Communication subsystem

This subsystem is responsible for the transmission of data. Sensor nodes use radio frequencies to carry the signals from sensors through the base station to the required end user. The role of the base station is to maintain the communication between sensor network and external source (user). In a network, there can be a single or multiple base stations depending upon the requirement, area and number of sensors to monitor. In a network, each individual node communicates and co-ordinate with other nodes. There are two types of communications: infrastructure and application [36].

Communication which is required to build, maintain, optimize a network is referred as infrastructure. Due to environmental changes in the network there can be a varying topology and sometimes nodes can fail. Therefore, these situations can be managed by conventional protocols [36]. Hence even in a static sensor network, there is a need of infrastructure communication and external communication which is required to re-configure the topology [36].

The data which is gathered should be transferred further to the monitoring end and is referred as application [36]. The amount of energy required to transmit a packet to sink is depended on distance and more over the energy required for a node to transmit is fixed. But, if the distance is far then that requires high amount of energy. Hence, this can be eliminated by choosing the shortest path for transmission of data. Also this communication refers to application based. For example, when there is a necessity to communicate, nodes should communicate and data should be sent continuously. Another example is when the application depends on event driven, sensor suppose to act when the event or environment change occurs. Therefore, it is good to decrease communication cost in order to increase life time of a network.
2.2.4 Power subsystem

All the above mentioned subsystems require a power unit to function and perform their individual tasks. Power subsystem provides the supply voltage and the requirements of the power are strict due to energy consumption constraints. It also supplies sufficient levels of current during the radio transmission and reception. A battery can act as energy storage which is generally AA or AAA size and voltage regulator is also included in the power subsystem. In most of the hardware platforms there is a possibility to allow switching of the states i.e. between on, off and idle for each device to minimize the power usage.

These sensors collaborate with each other at certain interval of time to carry out the required task. Data from each sensor is collected and analyzed by a data processor (computer) outside the network [12]. These nodes can be self organized and self healed depending upon the routing topology that is used for the communication between them. Also, it is very difficult to replace a sensor node if they are placed in extreme geographical areas.

2.3 Challenges in WSN

Before formation of the sensor network and deployment of sensor nodes the prior and fundamental understanding about connecting and managing the network in needed to achieve beneficial scalability and efficiency. Even though sensor networks are grouped under the class of adhoc networks but these differs with their characteristics. Both adhoc and sensor networks share the challenges of energy constraints and routing techniques [37]. Generally, in an adhoc networks nodes are considered as mobile where as in the sensor networks nodes are static for most of the applications such as military. Hence, these networks may differ in their traffic patterns [37]. These are some of the most important aspects that the wireless sensor networks should overcome, and they are described below.

2.3.1 Power consumption/ Network life time

Power consumption is one of the crucial challenges required to manage in sensor networks. Many researchers are focusing their efforts to improve energy efficiency in these networks [37]. As many of the sensors are battery powered, energy consumption is a very crucial metric and should be managed wisely in order to extend the network life time. For example in the military applications, it is difficult to replace the batteries in the battle field. Hence the sensors may fail and might not function if the batteries are exhausted. So, efficient routing may overcome this issue and extend the network life time.

2.3.2 Fault tolerance

While processing and communication between the sensors, some sensors may fail to communicate because of link failures, lack of power supply or due to any physical damage or even by environmental interventions. In order to overcome these mentioned problems, accommodation of new links is required. Also, maintaining the transmission power and signaling rates; rerouting of packets and redundancy is necessary to establish a robust and fault tolerant network.
2.3.3 Scalability

Scalability is a critical factor especially for sensor networks which contains many number of nodes and can be responsible for degradation of network performance as well. Topological changes in network such as network size and node density should not affect the performance of the network. Hence, routing protocols employed in WSN must be scalable enough to maintain the sensor states when it changes its state from sleep to ideal or vice versa.

2.3.4 Throughput

Most of the times sensor must transmit its data to the BS, the required number of successful packet transmission of a given node per timeslot is determined as throughput.

2.3.5 Accuracy/latency

Acquiring the exact information without any distortions is the most primary objective in a WSN. Also, there should not be any sort of delay. The routing protocols and network topology will ensure the delivery of the data with minimum delay.

2.3.6 Node deployment

The sensor nodes are placed manually in a random fashion and are deployed depending upon the required application. Another way of deployment is self organizing systems, where the sensor nodes are scattered and topology is formed in an adhoc manner. Uniform distribution of nodes and optical clustering schemes can efficiently maintain the network [17].

2.3.7 Data aggregation

Data aggregation is the combination of data arriving from different sources by using some functions such as suppression (finding and eliminating duplicates), minimum, maximum and average [17]. As sensor node generates the meaningful data, data from multiple nodes can be aggregated in order to reduce the number of transmissions. This aggregation technique is used to reduce the energy consumption and achieve data transfer optimization in the routing protocols [11], [18].

2.3.8 Hardware constraints

Since sensor nodes are very small in size and are operated under low power. These have limited energy capacity, low storage and in addition to these, sensors have low computational capability. Therefore, there is a need of adequate network design for routing protocols that can overcome mentioned challenges.

2.3.9 Security issues

As the routing protocols have limited capability, some of these protocols cannot accommodate all the crucial information acquired by the sensor, challenging the security of data. Data is sent to the end users by getting direct access to the messages present in the sensors through internet services. Hence, there is a need to prevent the data from unauthorized parties or from any malicious actions.
2.4 Applications

WSN have a capability to monitor wide range of applications including physical conditions [38] such as temperature, humidity, light, pressure, noise intensity level, object movement and its characteristics etc. WSN node promises many new applications by implementing concept of micro-sensing and wireless communication [20]. There are many application related to WSN and some of these are explored below:

2.4.1 Military applications

Wireless sensor network helps in surveillance and tracking of information in military command control. The Ad-Hoc deployment of the sensor nodes, self organization and fault tolerance characteristics of WSN, improves the firm sensing capability of this application. Some of the other military applications are “monitoring the friendly forces, ammunition and equipment, attack detection, battle surveillances and targeting” etc. [39]

2.4.2 Environmental monitoring

Applications like snow monitoring which is used to monitor the snow conditions and avalanche forecasting [8]; habitat monitoring which helps to deliver the information about localized environmental conditions of each individual habitat, such as issues affecting animals, plants and humans [19]; humidity and temperature monitoring, wild life monitoring, traffic control, fire detection, flood detection etc also utilizes WSNs. Also another important example that comes under environmental monitoring is disaster management. Sensor networks help in detection of location that could be useful for rescue operations, also used for prevention of potential hazards.

2.4.3 Medical Applications

Sensor networks have also focused its attention on medical application. These are used to monitor the patient's physiological condition, also used to administrate the drug section, monitor the patients and the doctors within the hospital [30]. These are also used to detect the different types of viruses by monitoring the infected area.

2.4.4 Other Applications

For commercial purposes, sensors are widely used in home and industry automations. Also, the commercial buildings and offices are equipped with sensors and actuators to monitor the room temperatures and air flow thereby improving the living conditions. In home automation these applications are used for remote metering and for smart intelligence purposes. Vehicle tracking and detecting is also an application of WSN’s that can help avoid car thefts [20].

2.5 Routing techniques in WSN

There are many routing protocols which are developed for WSN’s. The routing structure is neither fixed nor schematic; rather it is established in an adhoc manner. Considering the power consumption and energy saving schemes, there is a need for routing technique in network layer for WSN’s. Therefore, routing protocols in WSN are divided into two categories. One is according to the nature of the application and

another by its network architecture. Some of the protocols which can be used in WSN are listed below

2.5.1 Location based protocol

In location based protocol, routing technique depends on the location of sensor nodes. This technique is used to calculate the distance between two specific or neighboring nodes in order to estimate the energy consumption. The advantage of location sensor is that, it sends the query to the required sink node i.e. to the known region rather than sending to the whole network, which saves the energy and improves network lifetime. An example of location based routing protocol is, Geographic Adaptive Fidelity (GAF) algorithm. GAF is mainly designed for energy conservation. Here, the sensor network is divided into grids and each sensor is equipped with GPS, for its location information in a particular grid. There is a switching between the states which means that the sensors which are not active are turned off maintaining the constant routing fidelity simultaneously [11].

2.5.2 Hierarchical based protocol

Hierarchical based routing is also known as cluster based routing protocol. The nodes in WSN are grouped into clusters and high energy nodes are elected as cluster heads (CH) while low energy nodes needs to send sensed information to the CH. The role of CH is to aggregate and compress the sensed data which is received from the cluster of nodes and transmit it to the BS. Here it employs the multi hop technique to send the data to sink among the clusters and CHs are used to reduce the number of transmitted messages to the BS. A good example which utilizes this technique is LEACH. LEACH randomly elects the nodes which possess high energy as CHs. The role of CH is distributed evenly among the group of nodes by considering the energy of the nodes thereby balancing the energy load in the whole network. It also preserves energy by reducing inter cluster and intra cluster collisions [18].

2.5.3 Flat based routing or Data centric routing

Flat based routing is required for large WSNs. In this technique each and every node plays equal role. As the sensor nodes are large in number, it is very difficult to assign identity to each single node. This issue can be eliminated by data centric routing. DCR assigns global identity to each and every sensor which is deployed in WSN. BS sends the queries using attribute based naming to the nodes in the network and waits for the response from the sensors. Some examples for this sort of technique are SPIN and direct diffusion. The advantage of the SPIN protocol is that, it can overcome the flooding and overlap problems. In traditional flooding methods, always a node disseminates data to its neighboring node regardless of checking whether the neighbor node possesses the data or not, resulting to the retransmission of data which leads to the wastage of resources; called as Implosion problem. Similarly, if a node receives same data from one or more neighboring nodes of same geographical region, then it leads to overlap problem. These problems are avoided in SPIN protocol. Before transmission of the data, SPIN allows sensors to negotiate with each other, to avoid inappropriate information in the network. It uses meta-data [11] to notate the data which sensors want to disseminate. A technique called Resource adaptation is used in SPIN to transmit the data and consume energy. Another protocol called direct diffusion is a data centric protocol where the data, acquired by sensor nodes is named by attribute –value pairs [18]. Direct Diffusion finds multiple paths to a single destination. The BS requests data by broadcasting interests [18]. Caching and processing the data in proper mode would increase efficiency and improve scalability of the network.


2.6 Batteries used in WSN

Sensor nodes often functioned with the help of power sources such as batteries. Common batteries used in sensors are of AA and AAA types. Both AA and AAA batteries hold the same voltage of 1.5V but the difference between them is that the AA batteries deliver more power and are used in high power consumption devices whereas the AAA batteries are used in low power consumption devices. Moreover they are also of different dimensions. It is very difficult to replace the batteries used in those sensors which are located at extreme locations, hence it is always recommended to use long lasting batteries with high quality in sensors.

![Battery life comparison](image)

**Figure 3: Battery life comparison**

The given Figure 3 [31] above compares the difference between a high quality and low quality battery that is used to operate as power supply for real time wireless sensor networks. The graph shown is taken from the industry specification of the Energizer battery [31]. The blue line in the graph represents depletion of the high quality battery and the grey ones represents step down stage of low quality battery. It can be clearly seen that batteries which are high quality have a more constant performance and degrade with the voltage and maintains the constant power levels for most of its life. As shown in Figure 3, the standard batteries give better service, but once when it decreases the voltage level below 1.2v it gets exhausted very soon. On the other hand, ordinary batteries start depleting consistently from the start. Hence, it is recommended to use high quality batteries that serve to increase the network lifetime in WSNs.

2.7 Related Work

In wireless sensor networks, the energy is consumed at different levels such as during transmitting, receiving, listening, sleeping, and being idle. According to [1], an algorithm that utilizes time division multiple access method as medium access control layer protocol scheduled with different time slots are used to collect data tree, which reduces energy cost and drives with optimum network throughput. In [4], author’s focus on survey of routing protocols for energy consumption, data latency and increase of network lifetime. Different clustering algorithms based on metrics, advantages and disadvantages are used for surveying process.

Energy efficiency and data efficiency are the performance limitations for wireless sensor networks. Cluster head algorithm [5] is a method used to detect energy change

in nodes and also describes the reliability of data. Another clustering algorithm [6] explains the necessity of wireless sensor network in disaster management system. This algorithm manages the network by distribution of cluster heads and decreases the communication cost thereby, reducing complexity.

**Self-organization and self-healing**

The survey in [7] describes several algorithms for self organization of wireless sensor networks. It also includes scalability of static nodes considering energy resources. Signal processing functions are carried out between set of nodes by using the protocol that supports mobility of nodes and energy efficiency. Allipi et al [8] argued that energy consumed while processing and sensing sensor data is less than data transmission. Adaptive sampling algorithm is new paradigm that sets best frequency required for wireless sensors and is used for energy management. A detailed study is also carried out for design of energy efficiency by using adaptive measurement for snow monitoring application [8].

Wireless sensor networks are expected to act according to importance of application and its necessity of monitoring. An efficient algorithm should focus on scheduling of sensors among active and sleep states and should be capable for any network size and application. There has been an attempt to build a model for portion of coverage, quality of data transmission and energy consumption by using of bipartite graph method [9]. In [10], all the nodes except sink node are divided according to its function into terminal and intermediate nodes. Moreover, different sleep and wake up strategies are adopted that are used to build an algorithm based on minimum hop routing protocol for energy consumption.

Sensor nodes should be self-organized during formation of network structure as these are battery powered and is expected to run for a long period of time. One such protocol which provides self organizing characteristics is the hierarchical protocol [11]. This literature present a collection of routing protocols that consumes low energy while maintaining self organizing routing in a network. Hierarchical clustering is adapted for increase in network life time, which depends on the node formation and also utilizes routing information present at the node. One such method towards self organization of nodes is possible by formation of clusters using triangular method [12].

**Technology**

Synapse works on the practical implementation of the WSN for industrial applications. They have developed the SNAP architecture, which is formed with mesh structures using wireless nodes. SnapPy is a virtual machine which is combination of SNAP (Synapse Network Application Protocol) and Python scripting language subsequently deployed in the wireless nodes using HAL. A HAL (Hardware Abstraction Layer) acts as an interface between developed software and physical components like processor [13].
3 OVERVIEW OF POWER CONSERVATION ALGORITHMS

3.1 Clustering Algorithms

Clusters are the sensors grouped together in large WSN’s. It is proved to be the effective approach to offer better data aggregation and scalability for large WSN’s, hence clustering technique is brought into WSN’s [22]. Deliberating clustering techniques are the crucial factor in WSN as these improves performance and enhances the network life time of the network.

The clustering techniques vary widely based on the pursued network architecture, node deployment and bootstrapping schemes, the characteristics of the CH nodes and the network operation model [21]. These schemes provide less communication overheads and give efficient resource allocations thereby reducing the overall energy consumption and decreasing the interferences among sensor nodes.

3.1.1 Clusters

The hierarchical units of wireless networks which build up in multi hop manner are called Clusters. In order to establish a complex free communication from base station to cluster heads, network is broke down to clusters. Clustering concept is most useful in network applications where many ad-hoc sensors are placed randomly for the purpose of sensing.

3.1.2 Cluster heads

Cluster heads (CHs) are the central head of a cluster. CHs need to conduct activities in the cluster very often. The activities could be data aggregation, organizing and relaying the communication schedule of a cluster.

3.1.3 Base Station

The BS acts as a sink in the WSN. It provides link to communicate between sensor network and the end-user.

3.1.4 Issues to be solved in Clustering Algorithms

This concept of clustering mechanism overcomes few constraints in wireless sensor networks such as Limited Energy, Network Lifetime, Cluster formation and CH selection, Synchronization, Data aggregation [32].

Since the nodes are having limited energy, clustering tries to optimize its formation and solve by balancing the energy consumption in sensor nodes. Similarly by reducing the energy consumption in the sensors at the time of communication, clustering scheme is useful for improving the network lifetime.

Clustering algorithms are designed and addressed based on the issues such as minimum cluster size; election and re-election of CHs, and cluster maintenance. The main aim of selecting cluster head and its isolation from other nodes is to maximize energy utilization.
3.1.5 Types of Clustering Algorithms

There are different types of clustering algorithms. The figure 4 shown is the taxonomy of clustering techniques that can be implemented to overcome the issues in WSN’s [22].

![Figure 4: Taxonomy of Clustering Schemes](image)

3.1.5.1 Leach (Low-Energy Adaptive Clustering Hierarchy)

LEACH [18] was one of the first great advancement on conventional clustering approaches in WSN [32]. The algorithm randomly rotates the CH and offers energy balancing in the network. In LEACH CH rotation is probabilistic in nature that is every node has a good chance to be selected as CH though it has a low energy. It also offers a flex that each node will contact to the CH directly by forming one-hop intra- and inter-cluster topology.

3.1.5.2 Energy Efficient Clustering Scheme (EECS):

Energy Efficient Clustering Scheme is an algorithm in which CH candidates should prove its own to rise to cluster head for a given round. As a result it finds a solution to the problem that clusters standing at a longer distance from the base station need more energy for transmission to base station compared to the one that is closer.

3.1.5.3 Hybrid Energy Efficient Distributed Clustering (HEED):

In HEED, based on the intra-cluster communication cost and the distances between the nodes i.e., how closer to the distances, they will choose to join the cluster or not. Also, based on the residual energies in the sensors the highest one will become the cluster-head node which is not the case of LEACH.

3.1.5.4 Energy-efficient unequal clustering (EEUC):

This algorithm is proposed to equalize the consumption of energy among clusters, the EEUC proposed to balance the energy consumption among clusters, it proposes that the size of the cluster near to the sink is smaller as compared to the clusters with long distances from the link node, for the cause to save the much energy among inter-cluster and intra-cluster communications.

3.1.5.5 Energy Efficient Hierarchical Clustering (EEHC):

In EEHC, each CH’s will obtain data from its node and send the combined report (obtained from all its nodes) to the base-station. It is a distributed, randomized clustering algorithm for WSN’s.
3.1.5.6 Multi-hop routing protocol with unequal clustering (MRPUC):

MRPUC is a distributed clustering scheme in which it functions in rounds where, each round is divided into 3 phases: cluster setup, inter-cluster multi-hop routing formation and data transmission. Since the inter cluster communication depends on the residual energy of each nodes, MRPUC is preventing the early death of Cluster Heads.

3.1.5.7 PEACH (Power-Efficient and Adaptive Clustering Hierarchy):

This protocol is mainly proposed for WSN’s to derogate the energy consumption of single node, and increase the network lifetime. PEACH uses characteristics of overhearing in wireless communication where it forms clusters without any separate overhead and also supports adaptive multi-level clustering [23].

3.1.5.8 Sensor Web or S-WEB:

S-WEB follows a hybrid technique where the clusters are formed based on the sensing field where two arcs are considered from two adjacent circles originating from the base station. Each cluster will be identified the order of Signal Strength threshold (_) and in S-WEB many tasks were carried by the nodes except the beacons which are generated from the Base Station.

3.1.5.9 Distance-energy cluster algorithm

DECSA algorithm is based on the distance and residual energy of sensor nodes. This algorithm improves the process of election of CH as well as improves data transmission. Each round in the DECSA protocol is divided into two phases; initialization phase and stable working phase [24]. In the initialization stage, certain TDMA time slots are distributed to each sensors and further cluster is elected. Election of cluster head depends on random number generated by each node which must be less than the threshold value T. The highest probability of node to become a cluster head depends on nodes residual energy. Hence this kind of CH election can prolong network lifetime.

In stable working stage, both CH and base-station CH are elected and messages collected from nodes are transmitted to CH first. Later on CH will not directly communicate with the base station as BS are very far, rather CH sends all the messages to base station CH. Thereafter, BS-CH fusions all the collected data and finally transmit it to BS [24]. As BS-CH is very near to BS more amount of energy can be consumed while transmitting the data.

3.2 Duty cycle or sleep awake Algorithms

Duty cycling is the part of networking subsystem which is most effective in terms of energy conservation. Here, the radio transceiver drives into sleep mode or low power mode when the communication is halted. In this technique the radio device should not be active when there is no data to transmit, hence should be switched off. The nodes switches between the two states; active and sleep states. This phenomenon is referred as duty cycling [2]. As sensors alternate between the states they need to synchronize their sleep and wake times.

3.2.1 On Demand Schemes

On demand schemes needs two different channels to operate; normal data communication require data channel where as awaking nodes require wakeup channel. This scheme avoids disturbance of signals on the wake channel when data is being
transmitted in the neighboring channel. One of the examples of on demand schemes is sparse topology and energy management (STEM), which employs two different radio signals for wake up and data transmission. It also uses the asynchronous schemes for radio to avoid the disturbances in transmission ranges. When node wants to transmit the data it sets the threshold value of time to $T$ and also initializes the wake up radio as $T$-active. It utilizes the streams of beacons on wake up channel to transfer the data from source node to destination node. When the destination node receives the data it sends back the beacon frame and activates the radio to ON mode. During the transmission if any collision occurs on the radio channel, the node which senses the collision will trigger the radio to ON mode. This process continues until the source node gets an acknowledgement from destination node.

3.2.2 Scheduled Rendezvous Schemes

This scheme postulates that all the nodes and their neighbors have same wake up time. These verify the happening of communication between themselves at certain intervals of time. Later on until occurrence of next rendezvous time these nodes switch back to sleep mode. Here, when a single node is awake it means all the nodes are awake that is the major advantage of this scheme. Hence, only one broadcast is needed to all the neighbors to awake those up [2]. Scheduled rendezvous protocols are differentiated depending upon their node sleep/wakeup strategies. One of the examples of this is fully synchronized pattern. In this pattern the time slots are fixed for awake and sleep states. Nodes which are at wake up state are fixed with time slot of $T_{wakeup}$ and remain active for every $T_{active}$ then return to sleep state after occurrence of next event. Because of the low complexity level of this scheme it can be used extensively in practical implementations [2].

3.2.3 Asynchronous scheme

Unlike other schemes, this scheme allows each single node to have different time periods for active session and wake up states. The protocol which implements such scheme is asynchronous wake up protocol (AWP). This protocol doesn’t require a finite time slot to detect the neighbors. The advantage of AWP is it recovers the network topology failure and avoids packet collision. Here each node is associated with wake schedule to generate wakeup schedule event [2]. In order to happen a communication between two nodes these should have same wake up schedule but with different time synchronization slots. With attention to Random Asynchronous Wakeup (RAW) approach nodes are characterized by their respective densities which determine the existence of paths to transmit the data from source to sink. In addition, this protocol is equipped with random wake up scheme and is change with geographical routing changes where packet is sent to destination using nearest neighbors. Each node in random scheme wakes up randomly once in the given time interval of $T$. The random wake up scheme completely relies on local decision and is simple [2]. Although its simple, but it does not ensure the successful packet delivery to destination as some times node cannot search the neighbor in same time slot.

3.2.4 Node sleeping algorithm

It is the energy efficient algorithm which is based on minimum hop routing protocol. It proposes different node sleep and node wakeup strategies [10]. In node sleeping strategy, after network initialization all the nodes except the destination node generate the data packet randomly in a certain time period. Here, all nodes are divided in to intermediate and terminal nodes except destination node. Data acquisition is compensated by terminal nodes where as intermediate node collect data and forwards
it. In this stage, algorithms check the nodes, later if the node type is terminal it enters in to sleep mode until there is some data to wake up. If else the node is intermediate then it sets a counter value to 0 and forwards the data packet. It continues to follow the path; the data packet gets forwarded to make counter value to increment 1. If the node did not achieve $N_i$ in a period of $T$, then the counter is again set to 0.

In node wake up strategy, during communication if nodes are awake, then only data is transmitted successfully. Here, the wake up the node when data transmission is needed. The intermediate node holds a timer with minimum value of 0 and maximum of $T$. when these nodes halt communication, they enter in sleep state until these have some data to transmit. Similarly, terminal nodes enter in to sleep mode after transmitting the data until they transmit the next phase of data. Hence, nodes sleep all the times if these have no data transmit and move to wake up state if required to send data [10].
4 DESCRIPTION OF SELECTED ALGORITHMS

4.1 Selection criteria

Using the evaluation process detailed in Figure 5 we identified three algorithms for further study, namely EEAR, PEGASIS and SPIN-1. The evaluation is done on the basis of their behavior and they are categorized under energy efficiency, clustering and dissemination mechanisms respectively. In addition, these algorithms work efficiently for a small network (typically for less number of nodes and low volume), which meets perfectly with the specifications of our application i.e. measuring indoor temperature in small buildings.

Figure 5: Selection Criteria
The research is motivated by evaluating the algorithms for energy conservation and the estimation of battery life time according to the specific application (measuring indoor temperature in industrial wireless sensor networks). In regards, it is molded to frame two research questions (excluding experimentation part i.e., RQ3) to find the most appropriate algorithms. In relation to RQ1 and RQ2 a literature search was first performed using search strings. Those searches were based on the following strings:

- Network lifetime
- Energy conservation
- Power conservation

The literature study was performed using the following databases:

- IEEE
- Inspec
- ACM Digital Library

The results of this initial search were then scrutinized manually in order to refine the search further.

The study indicates that there are mainly two variations of mobile wireless networks; Infrastructure networks and infrastructure-less mobile networks [41]. Infrastructure types are the fixed networks with wired gateways and base stations. These networks are ignored in this research because the nodes vary dynamically which is not a case with infrastructure type. On the other hand routing protocols, algorithms and mobile adhoc networks (MANETS) for wireless sensor networks which are grouped under infrastructure-less networks comes into focus.

The MANETS follow two kinds of approaches such as table driven protocols and On-Demand Schemes, which includes many traditional and modern protocols like DSDV, WRP, AODV and TORA. But, due to factors like higher packet delivery rate, scalability, toggling between inter-cluster and intra-cluster, multi casting and flooding problems these kinds of protocols are eliminated and protocols/algorithms related to wireless sensor networks are considered.

Because of previously mentioned issues which also relates to industrial application (measuring indoor temperature in heating system), three categories of algorithms are considered. They are:

- Energy Routing Algorithms
- Clustering/Hierarchal Type of Algorithms
- Negotiation Based Routing Algorithms

Among Energy Routing algorithms like Greedy Perimeter Stateless Routing (GPSR), Energy Aware Greedy Routing (EAGR) and Efficient Energy Aware Routing algorithm (EEAR), EEAR algorithm is considered due to its long Network Survivability, Higher Packet Delivery rate and Less Energy Consumption. Similarly, out of many traditional clustering algorithms like Low Energy Adaptive Clustering Hierarchy (LEACH), Threshold-Sensitive Energy Efficient Sensor Network Protocol (TEEN), etc Power-Efficient Gathering in Sensor Information Systems (PEGASIS) is considered because of its meta-data, energy efficiency and efficient life time of the network. For negotiation based routing algorithms, Sensor Protocols for Information via Negotiation 1(SPIN 1) is chosen to avoid Resource Blindness, Overlap, Implosion kind of issues in this research work to maintain efficient communication in a network.
4.2 EEAR algorithm

4.2.1 Overview

EEAR stands for energy efficient aware routing. This algorithm describes a power consumption scheme based on nodes residual energy (remaining energy) in a sensor network [33]. It selects the best path in order to achieve optimized routing strategy by calculating the nearest distance of its neighbor nodes. This algorithm also lets each individual node be aware of information about the neighboring nodes which leads to low packet loss which consumes energy which in turn certainly increases network lifetime.

4.2.2 Algorithm description

EEAR algorithm works on basis of the node information such as geographical location and its energy level of each node in a network. It follows the packet forwarding process from source node to destination node by using the node information. Each node should be aware of their individual information i.e. location and energy levels as well as they need to discover the closest neighboring node and its information [33]. Now, the selected node which needs to transmit the packet will calculate the distance and energy level of the selected neighbor node. The condition for the selected neighbor node among all the neighbors is its energy should be greater than the threshold level or average energy and the distance must be less than or equal to the average distance. The sender node sends the packet with address of the destination included in packet header [33] and each time when node forwards the packet some energy of its own is depleted. Hence, this process repeats at each node and creates the routing path by its own until the packet reaches to the destination. If the packet gets dropped it means that the neighbor node is dead.

Advantages

- The successful number of packet rate will be more comparing to other algorithms.
- Relatively low amounts of energy are consumed during the process, which means increased network life time
- It can be implemented in real time industrial applications.

Disadvantages

- This algorithm cannot support large wireless sensor networks where there are thousands of nodes.
- This also does not hold well, in case of mobile nodes.
- Also, there cannot be a large number of base stations as station itself consumes more amount of energy.

4.2.3 Improved EEAR

Conditions

These are some of the conditions [33], [34]
1) The network size can be changed to verify the performance by varying the number of nodes from 50 to maximum of 250 nodes. As, for real time applications these number of nodes are sufficient.
2) The initial energy of each node in a network can be taken as 1 joule [33].
3) The topology is not fixed as it is adhoc (random).
4) The packet size can be different according to the message length.
5) A very general queue analysis can be considered for incoming and outgoing packets.
6) When the neighbor node is dead, the algorithm should find the other nearest node to transmit the data in order to avoid the packet loss.

**Working Steps**

These are the working steps for EEAR [33], [34]

1. Initialize the network randomly.
2. Find the geographical location of nodes.
3. Find the neighbors by calculating distances and energy for the neighbor nodes.
4. Select the node to send the data.
5. If the node is alive calculate average energy and average distance
6. Calculate average energy and average distance.
7. Else (if node is dead) find the neighbors and their distances.
8. Select the neighbor node that is alive.
9. Send the data to the selected node.
10. Decrement the energy of nodes.
11. Packet is forwarded to destination.
12. If not sent then Packet is dropped.

### 4.3 PEGASIS algorithm

#### 4.3.1 Overview

The implementation of PEGASIS algorithm is based on LEACH. Here each node receive and transmit the data to their neighbors. Also, each time a single node is elected as head node among all other nodes in a network. When the communication occurs, different nodes are elected as head each time. The function of head node is to receive data from the all the surrounding neighbor nodes and transmit the data to the base station. This algorithm helps to distribute and balance the energy load among all the sensor nodes. The nodes follow the routing path using a greedy algorithm [42].

#### 4.3.2 Algorithm description

Power efficient gathering in sensor information system (PEGASIS) is a chain based algorithm where each node plays a role of head for one time to transmit the data for base station. Each node present in the network communicates with only one neighbor node [42]. In data gathering applications, all nodes need to collect and send their own data to BS; this task can be accomplished by each node sending their own data to the BS but the cost of transmitting the data directly to BS increases. Also, this requires more power to transmit the data if the base station is located far away from the node. This algorithm helps to form a network structure in form of chains, where the nodes are randomly located but chained structure is formed between them [43]. In the chained structure a single node is elected as head among all the nodes and data gets collected from each node, get fused and later forwarded to head node. Finally, head transmits the collected data to base station. In this process only one node is transmitting the data to BS which conserves power and balances the energy among the nodes in the network. All the nodes have knowledge about their network is assumed. The routing procedure is same as employed in greedy algorithm. This routing approach lets the farthest node to have close neighbors from the BS [43] as distance will
increase gradually between the nodes during the reformation of chain. The reformation is occurred when the node is dead. A single node in random position is elected as head and it receives the collected data from all other nodes and transmits the data to BS. In each round, the rotation of head is occurred and different nodes take turn to transmit the data to BS.

**Advantages:**
1) Only node transmits the data to BS to consume power unlike the other clustering techniques.
2) Nodes take turn to act as head which balances energy.
3) Each node will communicate only with its neighbor.

**Disadvantages:**
1) If the network is large with many nodes, there might be delay in data transmission.
2) There is a probability for long chain communication to occur.
3) Inappropriate threshold value can lead to complexity in choosing neighbors which are far away.

### 4.3.3 Improved PEGASIS

The improved version of PEGASIS adopts thresholds which reduce the formation of long chains and elect the head by considering the node residual energy and distance between the nodes and BS. The Figure 6 shows the flow chart [42], [43] which describes the PEGASIS algorithm.

**Condition:**
1) The nodes whose neighbors are far apart cannot be made head because they consume more energy to transmit [42].
4.4 SPIN algorithm

4.4.1 Overview

The SPIN algorithm represents sensor protocols for information via negotiation which is categorized under dissemination algorithms. Here the implementation of this protocol is based on data aggregation method. This algorithm works on three stages: advertisement, request and data stage. When data needs to be transmitted between two nodes A and B, node A sends the advertisement message to its neighbor B. Now, if the neighboring node B is interested to receive the data which was advertised by node A, it sends a request to node A. Later, node A sends the actual data as requested by the node B [26].
4.4.2 Algorithm description

The SPIN algorithm is basically proposed for energy conservation in wireless sensor networks. In the SPIN algorithm the data is named using high level data descriptor generally known as Meta data [26]. In the network, to eliminate the transmission of excessive redundant data, this sensor node utilizes meta-data negotiations. Also, these spin nodes take the decision upon the required application and the resources available to them [26]. In addition, SPIN depends on two basic ideas; first each node obtains the needed data and communicates with the other to share the data which it already holds. Each node is depended on the application to conserve energy and make efficient use of battery power. Secondly, if there are any changes in the network topology then each node should monitor the network by itself and use their own energy to adjust to the changed topology to increase the life time of the network [26]. Communication in spin is established by making use of three message formats. Initially, when a SPIN node has some data to share and broadcast, it sends ADV (advertisement message) which consists of the meta-data descriptors. Later, a neighbor node sends the request for actual data to the previously advertised node. Finally, the original data message which includes meta-data as header is sent to the requested node.

Advantages
1) Negotiation between the SPIN nodes overcomes the problems like impulsion and overlap.
2) It also overcomes the problem of resource blindness by adapting resources stored in the SPIN nodes.

Disadvantages
1) SPIN cannot handle the blindly forward and data inaccessible problems.

4.4.3 Improved SPIN

The improved versions of the SPIN algorithm are SPIN-1 and SPIN-2. Here, only SPIN-1 is considered and described. SPIN-1 is the extension of the original SPIN. It overcomes the problems of SPIN such as blindly forwarding and data accessibility [27]. SPIN-1 is also a three way handshake protocol used for dissemination of the data. Basically in SPIN-1 there are three stages which complete the communication process. The working of SPIN-1 can be described by illustrating a Figure 7 given below selected from [17], [26], [27].

![Figure 7: Working of SPIN-1](image)
The following are the steps to explain the SPIN-1 algorithm [26]

1) Firstly, node A ADV packet (advertises) the data to node B as it is neighbor to node A (fig. a).
2) Node B checks the data advertised by node A to verify whether it contains the data with itself which node A wants to advertise.
3) If it does not find the advertise data, it sends the REQ message back to A (fig. b).
4) Now node A receives the REQ packet from B and sends the actual data packet to B (fig. c).
5) Later on node B aggregate its own data with the data received from A and broadcast an ADV messages to all the neighbors (fig. d).
6) Note that Node B will not broadcast ADV to A as it is aware that node A already has the data.
7) Finally, node B sends the actual data to the nodes that request for the data and send the actual data message. Hence, this process goes on (fig. e, fig. f).
5 IMPLEMENTATION AND SIMULATION

This chapter is divided into two parts. The first part deals with implementation of the selected algorithms and the message calculation. The second part describes simulation setup and configuration details.

5.1 Implementation of Algorithms

Based on the literature review, we have chosen three algorithms (PEGASIS, EEAR and SPIN-1) as described in section 4.3. The basis for selecting these algorithms is that each exhibit different properties and follows different approaches for sending data to the destination.

5.1.1 Approach to calculate number of messages for different algorithms

This section describes the approach to calculate the number of messages required to transmit a payload data in order to start communication. Each algorithm has different ways of sending messages to initiate a communication. Here, we predicted that the product of number of messages (per data transmission) and average energy (per message) gives the total energy consumed per message while transmitting data from source node to sink node. The total number of messages involved in the communication is calculated by a detailed study of algorithms and also by mathematical analysis as described in further sub-sections.

5.1.1.1 PEGASIS

In this algorithm, the main idea is to communicate with the closest neighbor node by forming chains and electing a leader node which is nearest to Base-station/sink. The base station is located away from the network but closest to the leader node. This algorithm forms a chain communication between the nodes using a token system. The whole calculation process can be accomplished by using greedy algorithm in which the communication starts at a random node, assuming that every node has the knowledge of its neighbor.

For calculating the number of messages required to transmit the data to the base station, we assume that an event is triggered at the end node and that node needs to send the data to the leader node. Now, the leader node will pass tokens to all the end nodes of a network linked with the surrounding nodes in the form of chains, i.e. for N number of nodes it requires (N-1) number of messages (token passing from one node to other is treated as message) excluding it. Similarly, once the token is reached to the end node, the node either starts sending data (if available) or a blank message to the next neighbor node in the chain. If this node possesses any data, it simply fuses its own data and relays to the next node. This process continues until it reaches to the Leader node, where N number of such nodes consuming (N-1) messages again. From leader node to Base station it consumes one more message.

Therefore, by summating all the messages it requires (2N-1) number of messages to transmit complete data to the base station.
5.1.1.2 SPIN-1

SPIN-1 is a data centric routing algorithm. Whenever a node senses some data, by negotiating to its neighbor nodes, it distributes to the whole network. This process is carried out in three phases or messages for the reliable communication. These messages are ADV message (for advertising purpose), REQ message (for requesting purpose) and DATA message (for sending data to those nodes).

Whenever a node senses data, it passes the ADV message to all the nodes that involves (N-1) messages for that node. Similarly the neighboring node passes ADV message to all the nodes excluding it and its previous node, making (N-2) messages. This process is repeated further by all the nodes. Hence for passing ADV message to all the nodes which is the summation of (N-1) + (N-2) +…….1 gives rise to N*(N-1)/2 messages.

The REQ message is sent the initiator node as a response from that node which needs the data, whereas the nodes which already have the data behave inactive and does not respond. Assuming that half of the total number of nodes send the REQ message in return, requires (N-1)/2 messages. Therefore, for N number of nodes it requires N*(N-1)/2 number of messages.

The Data is sent as a DATA message to all the nodes which needs data (intimated by REQ message). Hence this would also require N*(N-1)/2 number of messages for N number of nodes.

By summating all the three phases, total communication between all the nodes is established. Therefore, it requires 3N*(N-1)/2 number of messages to transmit data to the base station.

5.1.1.3 EEAR

EEAR provides high data packet delivery rate. The mechanism of EEAR lies in choosing the neighboring node. It competes by finding the energies consumed and distances between all the nodes. Also it finds the average energies and average distances among all the nodes. Once the energies and distances are determined, it starts finding its nearest node based on shortest distance and the residual energy. If any node is found with zero energy, this algorithm would ignore that node, even though its distance is very near and further precedes its search for next nearest node. In this way the communication is established from source node to sink.

The node possesses all the required data and if it is ready for communication, it sends a message to the nearest neighbor node as request and in return it receives a response from that node which can be treated as another message. Now the source node starts sending data which can be taken as one more message. Hence to pass data from one node to another, it consumes three messages. Hence for N number of nodes in the shortest path consumes 3N number of messages.

The Figure 8 depicts the step by step process to calculate number of messages in each selected algorithm (EEAR, PEGASIS and SPIN-1). Also, Table 1 given below presents the message calculation of each algorithm.
Table 1: Calculation of Messages

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Message calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEGASIS</td>
<td>2N-1</td>
</tr>
<tr>
<td>EEAR</td>
<td>3N</td>
</tr>
<tr>
<td>SPIN-1</td>
<td>3N(N-1)/2</td>
</tr>
</tbody>
</table>

Where N = amount of nodes; in our case N = 50, 100, 200;
Volume = 100*100*100;
Node range = 35m;

5.2 Simulation setup

Wireless sensor networks consists of many number of spatially distributed sensor nodes. It is very difficult to test these environments in the real time scenarios and also testing the real time network increases cost and takes much time. Therefore, it is necessary to develop different simulation environments to test WSNs and also build different protocol structures, schemes in a very large scale [35]. There are many simulation tools which can simulate WSNs, for example NS-2, OMNeT++, Avrora,

TOSSIM, J-SIM and EmStar. We choose to use MATLAB (version 7.9) as it is a flexible environment and also supports the C language.

“MATLAB is an integrated technical computing environment that combines numeric computation, advanced graphics and visualization, and a high-level programming language” [40].

MATLAB is high-level language and possess an interactive environment for computation purpose. The main attributes of MATLAB are as follows:

- For managing data, files and codes in a development environment.
- For the iterative exploration, problem solving and design purpose it follows interactive tools.
- It possesses 2-D and 3-D graphics for visualizing purpose.
- It provides option for graphical user interfaces using custom tools.
- It provides functions for integrating algorithms with the external applications and other languages such as C, C++, Java, and Microsoft® Excel® etc.

The main advantage to use this tool is it supports to calculate and analyze mathematical values such as energy and distance calculation in our case. Also, we consider a 3-D plane which is better visualized in MATLAB and a node can be plotted in a coordinates system, where distance can be calculated between nodes easily. Hence, this tool is considered in this research work.

5.2.1 Simulation procedure

In order to perform the simulation experiments we gathered the required industrial specifications. These requirements are specified in section 5.2.2. The general simulation process is defined as follows:

1. Randomly deploy nodes.
2. Calculate and identify shortest path. This is done by calculating the distances and energies between all neighbor nodes.
3. Calculate the average distance and energy from source to sink node involved in shortest path.

This process is then repeated until statistical confidence is achieved. The following sections in this chapter details the individual steps in this process.

5.2.2 Industrial specifications

In this thesis we have considered an industrial application used in order to measure the indoor temperature in buildings as part of a heating control system. The energy of the battery is 15552 joules for 2 AA batteries (see Appendix). This value is obtained by taking into account the drop in voltage below 1.2V and 0.8 as the installation setup factor. These values are found after interviewing the external advisor working for NODA Intelligent Systems AB in Karlshamn.

5.2.3 Node deployment scenario

As our first step, we have deployed the WSN nodes and built a WSN network. We have considered the 3D plane rather than a 2D plane as in order to simulate a real time environment such as deploying nodes in a building. So, the nodes have been deployed in 3D plane. Here, the nodes are placed randomly in plane. The dimension of the volume is 100*100*100 m³. As shown in the Figure 9 below, the mentioned volume is
considered and number of nodes viewed in the Figure 9 are 100. These nodes are randomly generated.

**Figure 9: Node Deployment Scenario**

5.2.4 Distance calculation between neighbor nodes

Each node is placed in the plane with the help of x, y and z-coordinates. These coordinates are chosen randomly with the help of ‘rand’ command in the MATLAB. All these nodes are distributed randomly in the whole volume. The distance between two nodes is calculated using the two point distance formula of the basic geometry. Similarly, all the distances were calculated among all the nodes which are distributed in the 3-dimensional plane.

Let the node No1 and No2 are the coordinates of x, y and z and their surrounding nodes N2, N3 and so on respectively. These refers to the points (x1, y1, z1) and (x2, y2, z2) respectively. Also, the distance between No1: N2, No1: N3, No1: N4 and so on is calculated using

Distance between 2 nodes: \( \sqrt{(x2 - x1)^2 + (y2 - y1)^2 + (z2 - z1)^2} \)

Figure 10 indicates five nodes scenario where initial volume of 20m*20m*20m is considered. Calculate the distance between the two neighbor nodes and also calculating distances to its all other neighboring nodes. Also, it is clear that the distance to its node is zero. The first row in the matrix indicates the node N1 is distant to its corresponding nodes N2, N3, N4, and N5 respectively. Similarly all the distances are calculated to their corresponding nodes respectively.

**Figure 10: Distance Calculation of all nodes**

Considering 3D pictorial view of distance calculation of all nodes is shown in Figure 11. Nodes ‘No: 1, No: 2’ are represented as nodes identification number to differentiate between the each individual node. Also ‘N: 1, N: 2’ represents the identification of the corresponding neighbor nodes. The distance between the each other nodes is denoted as ‘D’. Now for instance if the example of ‘No: 4, N: 3, D: 8.0301’ is considered as shown in figure, it symbolizes that the node 4 has node 3 as the nearest neighbor and the distance between the two nodes (4, 3) is of 8.0301 metres.

![Distance Calculation of all nodes](image)

<table>
<thead>
<tr>
<th></th>
<th>nodes</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>0</td>
<td>No1</td>
<td>0</td>
<td>17.4893</td>
<td>9.8946</td>
<td>28.4993</td>
</tr>
<tr>
<td>d</td>
<td>No2</td>
<td>17.4893</td>
<td>0</td>
<td>18.1867</td>
<td>19.1513</td>
</tr>
<tr>
<td>e</td>
<td>No3</td>
<td>9.8946</td>
<td>18.1867</td>
<td>0</td>
<td>23.5962</td>
</tr>
<tr>
<td>g</td>
<td>No4</td>
<td>28.4993</td>
<td>19.1513</td>
<td>23.5962</td>
<td>0</td>
</tr>
<tr>
<td>f</td>
<td>No5</td>
<td>21.8527</td>
<td>13.9538</td>
<td>22.0022</td>
<td>13.9534</td>
</tr>
</tbody>
</table>

![Distance Calculation between Neighbor Nodes](image)
5.2.5 Energy between neighboring nodes

To calculate the energy between the neighboring nodes, we will consider some assumptions taken from [25]. The formula given in [25] to calculate the energy between the neighboring nodes is given as

\[ E(i) = [(n - i + 1)(E_{elec} + E_{amp}d_i^\alpha) + (n - i)E_{elec}] \]

\( E(i) \) is the energy (in joules) consumed by each node to send data packet, where \( i^{th} \) node is the node that transmits the data. It is assumed that energy is transferred from each node to the sink node through the closest downstream neighbor [25]. The parameters used in the above equation are the general standard parameters taken from [25]. These are described below as follows:

- \( n \): number of nodes
- \( i \): data transmitting node
- \( E_{elec} \): Energy consumed in transmission
- \( E_{amp} \): Energy consumed in amplification
- \( \alpha \): Attenuation constant
- \( d_i \): Distance between \( i^{th} \) node and its neighboring node of shortest path

Where the values for corresponding parameters are:

- \( E_{elec} = 50nJ/\text{bit} \)
- \( E_{amp} = 100pJ/\text{bit} \)
- \( \alpha = 2 \)

![MATLAB Code Output](image)

Figure 12: Energy between Neighbor Nodes

As shown in the above Figure 12 there are respective nodes and neighbors. Also there is an energy calculation among the corresponding nodes. For example if we consider the first case in figure node 6 is the neighbor for node 1 and the energy required to transmit node 1 and node 6 is 6.0755e-007 J. Hence the remaining values are calculated as shown in the above figure.

5.2.6 Shortest path calculation

Shortest path calculation is established by using Greedy Algorithm based on node residual energies and the optimal distances. The red colored line in Figure 13 indicates the shortest path from source to destination. In this process, all the distances between the nodes and the residual energies of each and every node are calculated using the distance and energy formulae [24]. Suppose n1, n2 and n3 are the nodes in a sequence. A node n1 carrying the data transfers to its surrounding node n2 ascertaining with the two conditions such as least intermediate distance (n1↔n2), minimum threshold energy to hold the data and transfer to its next corresponding node (n2→n3). Similarly the next node calculates its neighbor node as well. In this way a link or the shortest path is established from source node to the sink/destination node.

Since, the nodes are plotted in the 3D coordinate axis and all the nodes with their intermediate distances can be represented in the matrix form (where exactly Matlab is used). During data transmission from source node to destination node, most of energy will be wasted whenever an intermediate node travels to its previous nodes (n1→n2→n3→n1). This leads to repetition of loops which consumes more energy. Hence, to avoid this loop problem, a control over the network should be performed which regulates as a protocol i.e., in the matrix with all intermediate distances between nodes, the lower triangular matrix is eliminated which represents the repetition of nodes from source to destination.

Example for avoiding loops:

<table>
<thead>
<tr>
<th></th>
<th>n1</th>
<th>n2</th>
<th>n3</th>
</tr>
</thead>
<tbody>
<tr>
<td>n1</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>n2</td>
<td>5</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>n3</td>
<td>2</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

\[ n1 \rightarrow n2 = 5; \quad n2 \rightarrow n1 = 5 \]

After elimination of lower triangular matrix to avoid loops:

<table>
<thead>
<tr>
<th></th>
<th>n1</th>
<th>n2</th>
<th>n3</th>
</tr>
</thead>
<tbody>
<tr>
<td>n1</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>n2</td>
<td>0</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>n3</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>

\[ n1 \rightarrow n2 = 5; \quad n2 \rightarrow n1 = 0; \]

Hence the node n2 ignores n1 and chooses next neighboring node and similarly, n3 ignores n2.

5.2.7 Average distance calculation from source to sink

Average distance is the average of distances between the nodes involved in the shortest path. Figure 14 indicates the nodes (2, 7, 4, 9) involved in the shortest path and their corresponding distances (2↔7=36.05, 7↔4=57.18, 4↔9=24.9). The average of all these distances among the nodes of the shortest path establishes the average distance from the source to sink.
Figure 14 represents the identification of boundary nodes and the distance from origin to the final node (end of the coordinate axis) for a single simulation run. In the 3D space region nodes are deployed in the network and the nodes away from both transmission and reception nodes with respect to origin are ignored for energy consumption among them i.e.,

- **Origin or Base axis O = (0, 0, 0)**
- **Transmission node n1 = (x1, y1, z1)**
- **Reception node n2 = (x2, y2, z2)**

In both cases like O<n1<n2 or O<n2<n1, the nodes away from these two nodes(n2 & n1) are ignored for calculation of shortest path since they are not going to take part in carrying the data as they are away from both transmission and reception nodes. Hence, the nodes which are farther from origin (either n1 or n2) are considered as end node. Later shortest path is calculated among nodes from origin to destination node.

### 5.2.8 Average energy calculations from source to sink

In section 5.2.6, the individual energies are calculated among all the nodes to its neighbors. After calculating the shortest path from source to sink, the average of energies corresponds to these nodes (involved in the shortest path) represented in figure 14, gives the “Average energy” consumed by the nodes in a network to transmit a message from source to sink.
5.2.9 Energy cost for maintaining communication

The network is deployed in the adhoc manner, but initially it is presumed that all the nodes have the information about their surrounding ones according to their base papers. For instance, SPIN -1 utilizes Meta-Data descriptor which consist a unique ID of the node helps in the communication to other nodes [26], EEAR utilizes Mapping Tables in which it stores the Geographical location of a node. It also uses node residual energy, minimum distance and node coordinates to communicate with its neighbor nodes [33]. Similarly, in PEGASIS for the formation of chains, it assumes all nodes have knowledge of their surrounding nodes in a network which employs greedy algorithm [42]. Though these algorithms uses different approaches, the chosen application requires too small overhead for communication which can be ignored. Hence, considering this particular scenario, the cost to maintain communication is ignored and is only focused on the message transmission. Also, ones the network is deployed, it is going to sustain for long years so maintenance of network is also not considered.
6 RESULTS

In this section we present the results of our work in relation to the research questions specified in section 1.2. First, we present the results relating to average energy and distances, and then we present the total energy usage in relation to the individual algorithms for each experimental scenario using different amounts of nodes. In order to achieve statistical confidence we repeated the simulation experiments for 35 times. Finally we present the battery life time for each algorithm in relation to each communication interval scenario.

6.1 Average energy and distance

The average energy consumption and distance is presented in Table 2.

Table 2: Average Energy and Distance Calculation

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Average energy/message</th>
<th>Average distance/message</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.00006J</td>
<td>19.66m</td>
</tr>
<tr>
<td>200</td>
<td>0.00021J</td>
<td>16.34m</td>
</tr>
<tr>
<td>300</td>
<td>0.00029J</td>
<td>13.58m</td>
</tr>
</tbody>
</table>

The average energies and average distances per message are calculated for different amount of nodes i.e., 100, 200 and 300 nodes respectively, indicating the density of the nodes deployed over 100x100x100 m³ volume of a cube.

6.2 Calculation of total energy

Table 3: Representation of Total Energy

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Total energies for different amount of nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 nodes</td>
</tr>
<tr>
<td>PEGASIS</td>
<td>0.0121J</td>
</tr>
<tr>
<td>EEAR</td>
<td>0.018J</td>
</tr>
<tr>
<td>SPIN-1</td>
<td>0.907J</td>
</tr>
</tbody>
</table>
Table 3 shows the amount of energies consumed while transmitting a message from source to destination. Total energy is calculated by multiplying the number of messages (based on algorithms) and the average energy consumed per message (obtained from simulations). Hence the total energies of PEGASIS, EEAR and SPIN-1 are calculated for 100, 200, 300 nodes respectively.

Also Table 3 indicates the comparison of energies consumed by different algorithms; maximum energy is consumed by SPIN-1 algorithm as it should also implement self-organizing and self-healing techniques along with data transmission. But, the other algorithms sustain for longer time, consuming very little energy and providing efficient data transmission. Hence these values show that the battery life of SPIN-1 algorithm will drain faster compared to PEGASIS and EEAR.

### 6.3 Calculation of battery life time

**Table 4: Battery Lifetime for PEGASIS**

<table>
<thead>
<tr>
<th>PEGASIS</th>
<th>Battery life for the communication intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15min</td>
</tr>
<tr>
<td>100 nodes</td>
<td>20 years</td>
</tr>
<tr>
<td>200 nodes</td>
<td>5 years</td>
</tr>
<tr>
<td>300 nodes</td>
<td>2 years</td>
</tr>
</tbody>
</table>

**Table 5: Battery Lifetime for EEAR**

<table>
<thead>
<tr>
<th>EEAR</th>
<th>Battery life for the communication intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15min</td>
</tr>
<tr>
<td>100 nodes</td>
<td>20 years</td>
</tr>
<tr>
<td>200 nodes</td>
<td>3 years</td>
</tr>
<tr>
<td>300 nodes</td>
<td>1 year</td>
</tr>
</tbody>
</table>

Table 6: Battery Lifetime for SPIN-1

<table>
<thead>
<tr>
<th>SPIN-1</th>
<th>Battery life for the communication intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15min</td>
</tr>
<tr>
<td>100 nodes</td>
<td>6 months</td>
</tr>
<tr>
<td>200 nodes</td>
<td>10 days</td>
</tr>
<tr>
<td>300 nodes</td>
<td>3 days</td>
</tr>
</tbody>
</table>

Table 4, 5 and 6 show the final results from the calculations considering total energy (15,552 Joules) of the battery. The energy calculation is made for every 15 minutes as communication interval, which are calculated to find the life span of a battery. Similarly 30 minute and 60 minutes communication interval is calculated for 100, 200 and 300 nodes respectively. The values for the communication interval were found through an interview with the external advisor at NODA.

The mentioned tables are framed considering the amount of nodes against communication interval for the three algorithms PEGASIS, EEAR and SPIN-1 respectively resulting in battery lifetime. It infers that, while deploying 100 nodes, both PEGASIS and EEAR algorithms based network sustain for 20 years while SPIN-1 algorithm based network remains only 6 months of battery life. Similarly when 200 nodes are deployed, PEGASIS based network lasts for 5 years, while EEAR network lasts for 3 year 4 months, but the SPIN-1 algorithm based network exists only for 10 days.

By depicting the values for 100 and 200 nodes scenario considering 15 minutes communication interval time as shown in Table 4 and Table 5, the battery life time obtained is for 20 years for both PEGASIS and EEAR algorithms. When communication interval is varied from 15 minutes to 30 minutes then the battery life should also be doubled and quadrupled in case of 60 minutes, instead the values (20 years each) are same for all the cases (15, 30, and 60).

The life time of a selected standard AA battery used for measuring indoor temperature lasts for maximum of 20 years (according to industrial advisor). It means irrespective of communication interval the battery will physically lift for maximum of 20 years and also network will sustain to that period itself. Therefore, the values which are obtained greater than 20 years are rounded off to at maximum of 20 years due to the mentioned reasons. Hence, there is a linear correlation between network life time and amount of messages. Theoretically, the lifetime of the network should be doubled when the communication interval is doubled for 30 and 60 minutes.
7 DISCUSSION

This work is concerned mainly with the sustainability of battery life. This is carried out in a distinctive approach, where quantitative analysis is done for the obtained results. This is subjected to validation by taking 10 trails of each experiment and deducting average values of the energies and distances.

The main results of our thesis are discussed considering 100x100x100 m$^3$ in 3D volume of network maintaining 15 minutes of communication interval. This is described as follows:-

When 100 nodes are considered, PEGASIS and EEAR excluding SPIN-1, proves to be energy efficient algorithms. These algorithms mainly concentrates on the minimization of energy consumption offering the existence of 20 years battery life, where the actual average battery life is 20 years, hence for its whole time the network is going to functionalize. This is taken under 15 minutes communication interval. When 200 nodes are considered, the EEAR based network lasts only for three years which shows that, EEAR algorithm is implementing self organizing technique where maximum energy is utilized to regulate its network. Similarly, when 300 nodes are considered in the same network, SPIN-1 based network is functionalized only for 10 days which indicates that, most of the energy is consumed only to implement the self-organizing and self healing techniques. Hence it should be powered with alternate energy source in this case. This process is then repeated for the 30 and 60 minute communication interval scenarios respectively. We found that PEGASIS sustains longer than compared to EEAR. Whereas, SPIN-1 is also improved its performance by a factor of 2 and 4 for the mentioned communication intervals.

We can also infer from the tables that, total energy consumption per message is increased while increasing number of nodes, which shows that energy consumption not only depends on the type of algorithm but also on the density of the network [25].

We have assumed that each algorithm starts communication to its neighbor in the pattern of token, request, advertisement, broadcast and data are considered as a single message. We formalize this by thorough understanding of each algorithmic behavior.

During calculation of the shortest path, we limited the number of nodes by using the node range, transmitter range and receiver range. These specifications are considered as per industrial requirements.

In order to validate our experimental results, we have repeated the simulations for a large number of times in order to obtain the average value and distance for the nodes 100, 200 and 300 as shown in Table 7, Table 8 and Table 9 (see Appendix). We have also estimated the standard deviation and 95% confidence interval to validate the calculated average value and distance. (see Appendix)
8 **CONCLUSION**

This thesis work is mainly intended to solve the proposed research questions. Firstly, we studied and described the pros and cons of wireless sensor technology. Later we highlighted the crucial problem faced by industrial manufacturers and tried to solve this by introducing a new approach of calculating the approximate span of battery life. To analyze the core process and also for proposing new approach, we answered the formulated research questions.

RQ1 deals with the study of algorithms related to power consumption and it is fulfilled by gathering all the related data of wireless sensor networks from various IEEE papers, journals, conference papers etc through various databases. As a result of our literature study, we have found many such algorithms which consume battery power and increase the network life time in wireless sensor network.

RQ2 deals with the selection of algorithms in consideration to various parameters like power usage, energy efficiency, network life time, node variations etc which is resolved by choosing three prominent algorithms like PEGASIS, EEAR and SPIN-1 based on their different mechanisms. We conclude that PEGASIS and EEAR are most appropriate algorithms inconsideration with performance constraints of specific industrial application i.e. measuring indoor temperature in buildings.

RQ3 is the challenging issue of our research work which deals with the verification of self healing and self organizing techniques to the selected algorithms and this is solved by the describing the network considerations and the results incurred from our experiments using MATLAB.

For experimental purposes, we considered a sensor network with 100x100x100 m$^3$ as volume while deploying 100 nodes, both of the algorithms such as PEGASIS and EEAR based networks are going to sustain for 20 years. But SPIN-1 exists for only 6 months. It shows that as per industrial requirements any of the PEGASIS and EEAR algorithms can be used under specifications, while SPIN-1 is best suited when only small size networks are considered. Similarly for 200 nodes, both the algorithms like PEGASIS and EEAR lasts for seven years and four years respectively, but the SPIN-1 drastically falls down to 5 days of battery life. It suggests that, as the node number is more for the SPIN-1 algorithm, it is better to provide alternate energy source instead of batteries as a source. Finally, for 300 nodes the results follows previous case by dropping the values further. Also, based on our new approach it shows that this algorithm exhibits self-organizing and self-healing mechanisms, since it consumes very high energy and drains the complete battery rapidly i.e., most of the energy of battery is consumed in exhibiting these two mechanisms.

The data calculation is done for every 15, 30 and 60 minutes of communication intervals while maintaining industrial specifications, indicating that these results can be used by manufacturers based on different applications and requirements of industries.

Though a lot of research has previously been done regarding the chosen algorithms, our research introduces a distinctive approach for the calculation of battery life, which many times is a major constraint in real life industrial applications.
9  FUTURE WORK

As a part of future work, our evaluation process can be extended by considering other types of algorithms and following our approach leads to a few more conclusions which might be useful in other areas as well. Since this work was done on static networks, these can be replaced with mobile networks and following this approach may provide different results as well. In addition to this, our work is confined to only one specific industrial application. It can be extended by considering specifications of few more applications and similar experiments can be carried out. Also, it would be interesting to implement and test the same in real time industrial applications.
REFERENCE


APPENDIX:

Total Net Energy Calculation:

The single battery consumes 16200 joules of energy. As this application utilizes two batteries, the total energy consumption is 32400 joules. The specific industrial application considered in this work requires at least 1.2V in order to maintain functionality. The net voltage is 1.8V. As 32400 joules is consumed for 3volts, for 1.8volts it requires 19,440 joules of total energy to the network. Also, this energy is multiplied with the installation setup factor (0.8) to obtain the total energy supplied to the node.

Validity for Average energy and distance:

Table 7: Validity for 100 nodes

<table>
<thead>
<tr>
<th>Average energy</th>
<th>Average distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000045</td>
<td>18.37</td>
</tr>
<tr>
<td>0.000063</td>
<td>13.90</td>
</tr>
<tr>
<td>0.00018</td>
<td>24.28</td>
</tr>
<tr>
<td>0.000135</td>
<td>22.37</td>
</tr>
<tr>
<td>0.00119</td>
<td>18.78</td>
</tr>
<tr>
<td>0.00029</td>
<td>19.54</td>
</tr>
<tr>
<td>0.00020</td>
<td>21.60</td>
</tr>
<tr>
<td>0.00063</td>
<td>16.50</td>
</tr>
<tr>
<td>0.00057</td>
<td>22.54</td>
</tr>
<tr>
<td>0.00149</td>
<td>21.65</td>
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**Average value**

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**Standard deviation**

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**95% CI**

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Table 9: Validity for 300 nodes

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Average value

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Standard deviation

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95 % CI

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