Adaptive Energy-Aware Transmission Scheme for Wireless Sensor Networks

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ABSTRACT

A Wireless Sensor Network is composed of a large number of sensor nodes that are densely deployed either inside a phenomenon or very close to it [1]. A WSN enables wide range of applications; as a result it is receiving increasing research interest. The main challenge to researchers in the field of WSNs is to maintain a useful network lifetime under constrains imposed on the limited energy reserves that are inherent in the small, locally-powered sensor nodes. This research addresses this challenge through the development and evaluation of an information control, energy management and, transmission range adaptation algorithm which leads to an increased network lifetime.

The contribution of this research is the development of an AIRT (**A**daptive **I**nformation managed energy-aware algorithm for sensor networks with **R**ule managed reporting and **T**ransmission Range Adjustments) or AIRT. The AIRT scheme increases the network lifetime at the possible sacrifices of often trivial data and further increase network lifetime through adapting transmission ranges based on nodes energy reserve level and message importance. The wireless sensor network environment was simulated using C Programming Language, where several runs of the simulation were performed in other to get reliable performance results. The performance results showed the advantage of the proposed AIRT scheme. Two different set of network statistics were measured; nodes energy resource depletion time and network connectivity. The results of each statistics of our technique were compared to the results of the statistics of similar works of recent researchers and our

results show a significant improvement in network lifetime and connectivity (though not the focus of this research)

Keywords: Energy-aware; wireless sensor networks; adaptive transmission ranges; priority balancing.

ÖZ

Kablosuz sensör ağı çok sayıda bağlantı noktasının bir olgu içinde bir araya gelmesinden oluşur. Bu ağların uygulama alanları çok geniştir ve halen büyüyen bir araştırma alanıdır. Kablosuz sensör ağlarını araştıran araştırmacıların üzerinde yoğunlaştıkları bir konu, kullanılabilir ağ yaşam süresini belli kısıtlamalarla düzenleyip (limitli enerji kaynakları gibi) küçük bölgesel olarak güçlendiren sensör bağlantı noktalarıyla çalışmasını sağlamaktır.

Bu araştırmanın katkısı uyan IRT algoritmasını geliştirmek ve AIRT algoritmasını bulmaktır. AIRT, ağ yaşam süresini arttırır, paketin önemlilik derecesine ve bağlantı noktasının enerji kaynağına göre transfer alanını ayarlar. Çalışmada, kablosuz sensör ağının simulasyonu C programlama dili kullanılarak yapıldı. Program, daha gerçekçi sonuçlar vermesi için birkaç kez çalıştırıldı. Üç değişik ağ istatistiği ölçüldü. Bunlar, bağlantı noktasının enerji kaynaklarını tüketme zamanı, ağ bağlantısı ve paket başarısıdır. Elde edilen sonuçlar diğer çalışmalarla karşılaştırıldı ve bu çalışmanın sonuçlarının ağ yaşam süresi, bağlantı ve kaybolan paketlerde önemli bir gelişme gözlendi.

Anahtar kelimeler: Enerji-koruması, kablosuz ağ bağlantısı, adaptif tarnsfer alanları, öncelikli dengeleme.

To My Parents

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ABBREVIATIONS

WSN: Wireless **S**ensor **N**etwork

AIRT: Adaptive **I**nformation managed energy-aware algorithm for sensor networks with **R**ule managed reporting and **T**ransmission range adjustments

RMR: Rule **M**anaged **R**eporting

IDEALS: Information manage**D** **E**nergy-**A**ware a**L**gorithm for **S**ensor networks

TRA: Transmission **R**ange **A**djustments

MP: Message **P**riority

PP: Power **P**riority

DB: Data **B**ase

T: Threshold

P: Periodic

D: Differential

MAC: Medium **A**ccess **C**ontrol

OSI-BRM: OSI Basic **R**eference **M**odel

Sim: Simulator

Chapter 1

INTRODUCTION

Wireless Sensor Networks (WSNs) are composed of sensor nodes that are deployed typically to examine and communicate examined information to the end-user. WSNs were motivated by military, industrial and consumer applications and they are receiving a lot of research interest in the academic institutions as well. Communication is regarded as the largest consumer of energy in a sensor node and therefore a considerable volume of research has been concentrated on how to utilize the energy depletion and therefore increase the life span of a wireless sensor node and the network as a whole [2].

Energy harvesting (for example, solar energy) is employed to extend the life span of a sensor network; however great attention was not given to it due to its limited efficiency. Besides energy harvesting, there are numerous ways to increase network life span. The most commonly used technique to increase the life span of a sensor network is the use of energy-aware algorithms whereby the majorities constitute routing or media access control [2]. Secondly, information-aware techniques are also employed to extend network lifetime whereby usefulness of information is considered before transmission [3]. For example, if information is of less important, it is not transmitted therefore, this leads to decrease in the amount of transmissions hence, increase network lifetime. Thirdly, alternating sensor nodes between sleep and

active mode is also used to extend sensor node lifetime [4, 5]. Finally, adjusting of transmission range of sensor nodes is employed to extend network lifetime [6, 7].

In this thesis, a scheme to extend the lifetime of a wireless sensor network called AIRT (**A**daptive **I**nformation managed energy-aware algorithm for sensor networks with **R**ule managed reporting and **T**ransmission range adjustments) was proposed. It combines the energy-aware, information-aware, and transmission range adjustment power saving techniques mentioned above.

1.1 Research Aims

The research of this thesis aims to investigate a method to reduce the energy expenditure, hence providing a considerable increase in the lifetime of a wireless sensor network. This is achieved through the combination of energy management, information control and, transmission range adaptation. The developed system is analyzed and validated through simulation. Simulation is performed using the C Programming Language. WSN environment to be simulated is a network consisting of a few sensor nodes, and it is suitable for small-scale industrial and commercial applications. Few sensor nodes are chosen for the simulation, as scalability (the ability of the network to operate efficiently when the number of nodes increases) is not our primary concern in this research.

To investigate our energy management, information control and transmission range adaptation scheme, we will simulate it and validate our simulation results by having several runs of our simulation algorithm. Node energy depletion time and network connectivity (though not the primary concern) are the two set of network statistics that will recorded during the simulation.

To prove that this research correctly increase the network lifetime, the performance measurement results derived from the different sets of network statistics will be compared to the simulation results of other recent researchers whose aim was also to improve network lifetime using energy management techniques.

The themes of the research of this thesis are:

Information-Aware Operation: The research considers the information aware operation of the nodes as well as the whole network. This involves determining the relevance of the 'information' contained in each message a sensor node generate or receives, by assigning priority to the it.

Energy-Aware Operation: The energy-aware operation of the individual sensor nodes and of the network as a whole is considered.

Transmission Range Adaptation: Its operation is applied to each and every node nodes in the network as well. The nodes message transmission range adaptation takes advantage of information-aware operations and energy-aware operations of the nodes and adapts a suitable transmission range based on them.

1.2 Major Research Contributions

The major research contributions are:

AIRT: The primary contribution of this thesis is the AIRT (**A**daptive **I**nformation managed energy-aware algorithm for sensor networks with **R**ule managed reporting and **T**ransmission range adjustments) technique. This technique decreases the energy depletion and hence increase the duration of life span of a WSN through possible loss of low-information messages. Additionally, AIRT further increases the duration of life span of a WSN by adapting a suitable transmission range of nodes by taking

into consideration message importance and level of nodes energy resource. RMR (**R**ule **M**anaged **R**eporting) is an operation in AIRT that uses some defined system of rules to check if the information contained in a message warrants it to be transmitted and then give priority to the message. IDEALS (**I**nformation manage**D** Energy aware **AL**gorithm for **S**ensor networks) is also an operation in AIRT that compared its nodes residual energy level to the importance of message from RMR, then determined if the message should be transmitted or not. Finally, TRA (**T**ransmission **R**ange **A**djustment) in AIRT determines a suitable transmission range for a node based on the message priority from RMR and nodes residual energy level from IDEALS and finally the message is transmitted with a suitable range.

The remaining part of the thesis research is organized as follows:

Chapter 2 presents some critiques of the state-of-the-art in the field of WSNs with respect to energy management, information control, and transmission range adaptation. Chapter 3 introduces the details of our AIRT algorithm developed in this research. Chapter 4 provides the result obtained from the simulation of a WSN using our developed AIRT algorithm. Chapter 5 concludes the report and outlines possible future research.

Chapter2

CRITICS OF WIRELESS SENSOR NETWORKS STATE-OF-THE-ART

In is important to note that WSNs are continuously receiving research interests in academic as well as in many industrial and consumer applications till date. This chapter provides an overview of some background information in the field of WSNs with respect to energy management, information control, transmission range adjustment, communication protocol, and simulation and energy modeling.

2.1 Introduction to Wireless Sensor Networks (WSNs)

Networks of wireless sensors are advantageous for both application and economical reasons. They are beneficial for application reasons because they made possible the applications that were previously not possible to achieve with wired sensors, some of such application are monitoring environments under harsh weather conditions, and monitoring hostile enemy territory. Additionally, the economic benefit of WSNs is the lack of cabling between sensors. The cost of installing wiring for a single sensor in a building is estimated to average $200 [8], or as much as $150 per meter for critical applications in risky industrial environments [9]. It is suggested that a typical industrial scenario can see a reduction of over 80% in the total system cost (for both materials and installation labor) by using commercially available WSNs [10]. Hence, introduction of wireless communication in sensor networks show a considerable cost savings.

Definition: Wireless Sensor Network (WSN)

"A sensor network is composed of a large number of sensor nodes (small, inexpensive, low-power devices with sensing, data processing, and communicating components) that are densely deployed either inside the phenomenon or very close to it, so as to detect and communicate detected event wirelessly using multi-hop routing."[11]

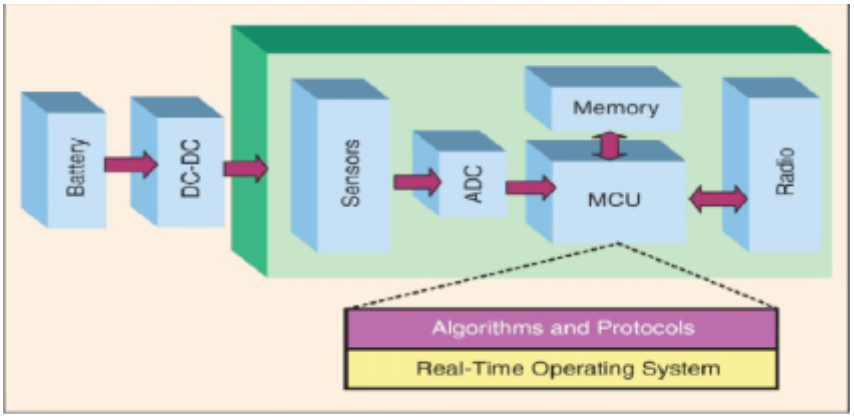


Figure 2.1: Architecture of a typical wireless sensor node [12].

WSNs (also referred to as smart dust, Sensor Webs, embedded networked sensors, and wireless integrated network sensors) fundamentally consists of multiple wireless sensor nodes (also known as 'motes', and referred to hereon as 'nodes'), an architecture of which is illustrated in Figure 2.1. The primary power source of WSNs is battery for example, the Berkeley mote [13] powered by two AA batteries, this power source happens to be the most critical resource bottle neck in WSNs. Secondary power source (solar panel) harvest power from the environment so as to be applied to the sensor node depending on the willingness of the designer [14]. Nodes sense information using their sensors in the surrounding environment in which they are deployed, these sensed information are processed by their processors and

because sensor nodes have limited memory size and are naturally deployed in harsh locations, a radio transceiver is implemented for wireless communication to transfer the data to a base station (which could be a laptop) in accordance to a communication protocol [15]. Wireless sensor nodes in the network forward and receive packets among themselves so as to perform packet routing (deciding the path that a packet should follow). The sensor network structure used in the simulation of the proposed AIRT scheme can be seen in Figure 2.2, it comprises of a sink node (or base station) and a considerable number of sensor nodes which are distributed in a large geographic region (sensing area).

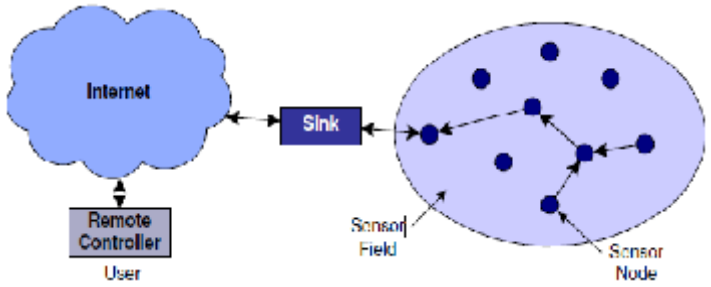


Figure 2.2: Sensor Network Structure [15]

The development of WSNs was first motivated by military applications such as enemy tracking and battle field surveillance. In the early days wireless sensor networks were solely used for academic research purposes. In the present days, wireless sensor networks are used in lots of industrial and as well as consumer application, such as healthcare applications, traffic control applications, monitoring and control of industrial process, monitoring of machine health, monitoring of environment, and home automation application [15], overview of these applications are broken down in to two categories as can be seen in Figure 2.3. A lot of such applications require secure communications. This is because of the wireless nature of

the network that often put the network at risk of cruel attacks, for example interception for deceiving due to the wireless nature of the network, impersonating of information, masking so as not to be seen. As a result, security is a very vital factor in WSN, although it is not our focus in the research of this thesis [16].

WSNs have virtually limitless range of diversity of applications, requirement, designs and platforms [17]. This is as a result of rapid growth and evolution of technology. Hardware platforms range from relatively large and powerful devices (such as Personal Digital Assistants [PDAs] or PC104-based system) to smaller, low-power devices using embedded microcontrollers (such as smart dust). The research in this thesis is targeted to smaller network that required few sensor nodes which perform self-sufficient operation; the research could be used for academic purposes and the logic may be used in industrial and commercial environment.

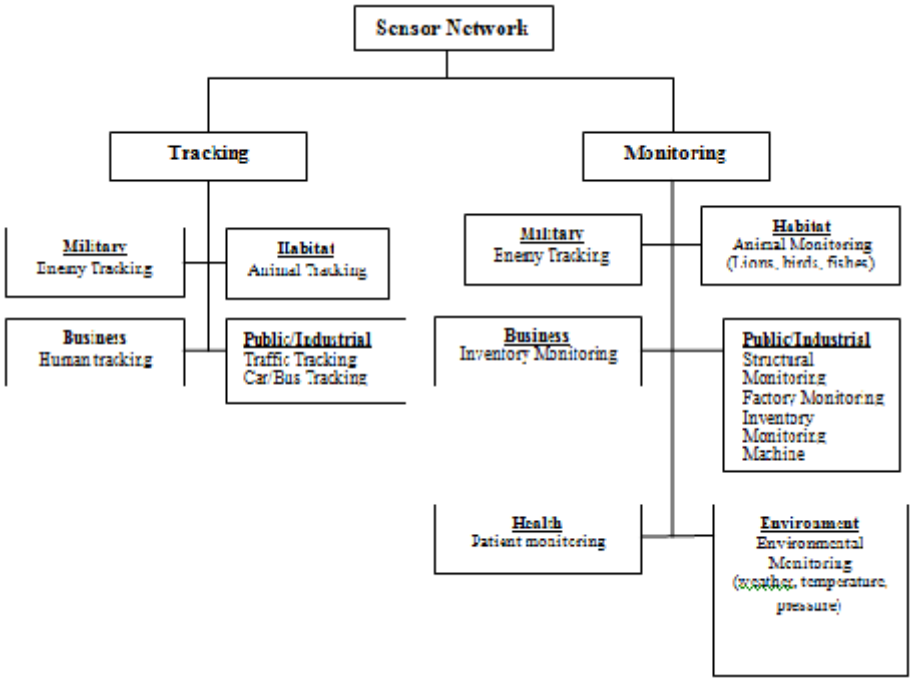


Figure 2.3 Outline of sensor network applications [14].

2.2 Research facts

Radio communication is regarded as the most power demanding operation in a sensor node [11]. Wireless communication strength is reliant on how the sensor nodes are organized. As we might guess, sparsely organized sensor nodes may lead to long-range transmission and higher energy usage whereas densely organized sensor nodes may lead to short-range transmission and less energy expenditure [14].

There are always tradeoffs in wireless sensor networks depending on the application. However, power consumption still remains one the most important constraints in WSNs. For that reason:

"Protocols must focus primarily on power conservation. They must have inbuilt trade-off mechanisms that give the end user the option of prolonging network lifetime at the cost of lower throughput or higher transmission delay." [11]

Therefore in order to increase network lifetime of a wireless sensor network, energy harvesting (e.g. solar energy) is an attractive option. Conversely, energy harvesting management for WSNs has not received research interest comparable to that of other related field; as it was disregarded as a research and development priority for the Office of the Communications (OFCOM) in 2007 [18]. For this reason, it is not used in this thesis as a mechanism to extend the network lifetime.

In this thesis, usefulness of data is a priority as oppose to treating all data as having equal or homogeneous usefulness. "Transmitted information would have different levels of usefulness/importance to the end user. For example, the information of a car

tire pressure sensor detecting a fast puncture requiring urgent action is more important than knowing that everything okay" [19] .

2.3 Energy Management

Based on the numerous experimental studies in the field of wireless sensor networks where low-power radio transceiver communication is in use, wireless radio communication is often the most power-demanding operation in a sensor device [20]. This radio communication leads to rapid consumption of energy resource in each and every sensor node and the network as a whole. For this reason, a considerable volume of research has been reported investigating a wide range of methods for reducing and controlling energy consumption [11, 20, 22]; some of which are discussed in this section.

Techniques for dropping the energy depletion of a sensor node may include Dynamic Voltage Scaling (DVS) and Dynamic Frequency Scaling (DFS). The former decreases the voltage to conserve power, while the later decreases the frequency to conserve power [21, 22]. As a result of this decrease, performance in traded; however this trade is acceptable in many WSNs.

In a duty cycle operation, the majority of the cycle is spent in the low-power sleep state following this cycle; *sleep-wakeup-sample-compute-communicate* [23]. For the duration of the sleep period of a duty cycle operation in a WSN, vital events can be missed, and also some applications and sensors require continuous sampling (for example accelerometers) which restricts duty-cycle operation from being easily achievable [24]. For these reasons, careful thought is given to duty-cycle-operation.

Authors in [25] proposed a technique to increase the time it takes for a sensor node to completely deplete its network lifetime by scheduling between sleep and active mode and adjusting node transmission range. And their simulation results show a considerable increase in network lifetime compared to techniques that used either duty-cycle or transmission range adjustments only.

Energy harvesting although it is not used in this thesis, we felt it is important to mention that, as harvesting is continuously receiving research interest because it helps to increase the energy source from zero energy to low energy. In the subsections below, energy harvesting and energy-aware operations for WSNs will be investigated.

2.3.1 Energy Harvesting

Energy harvesting can be defined as a process of obtaining energy from an external source (e.g., solar power) to power small devices like sensor nodes. The motivating factor behind using energy harvesting is to address the issue of limited energy store inherent in small locally powered sensor nodes. Energy harvesting enables applications that might not to possible achieve, for example in WSNs systems such as Zigbee's, when the battery of wireless node is deployed at a remote site is unreliable or unavailable, energy harvesting can supply power. Additionally, locally powered nodes that are sustainable through energy harvesting are useful in applications where no wired infrastructure exists (for example, environmental monitoring applications).

There are a wide variety of different energy sources appropriate for powering wireless sensor nodes [8]. Table 2.1 and 2.2 shows a comparison of the typical energy obtainable from a variety of different energy stores and sources considering

the energy that they could provide over a period of 10 years [8, 26]. Furthermore, there is a large possibility for wearable applications of WSNs harvesting energy from the human body from sources such as blood pressure, body heat, walking or breathing [26].

To maximize the benefits obtained through energy harvesting, understanding and management is required in a node's embedded software; as will be discussed in the next section.

Table 2.1: Devices with fixed amount of energy stores

Energy Source/Store	**Power / Energy Density**	**Energy Obtained over Ten Years**
Solar (Outdoors :Direct Sun)	15.0 mW/cm^2	4.73 MJ/cm^2
Solar (Outdoors: Cloudy)	0.15 mW/cm^2	47.3 kJ/cm^2
Solar (Indoors: Office Desk)	6.00 $\mu W/cm^2$	1.89 kJ/cm^2
Solar (Indoors: <60W Desk Lamp)	570 $\mu W/cm^2$	180 kJ/cm^2
Vibrations	10.0 - 250 $\mu W/cm^3$	3.15 - 78.8 kJ/cm^3
Acoustic Noise (75 - 100dB)	3.00 - 960 nW/cm^3	0.0946 - 303 J/cm^3
Air Flow (5% Efficient at 5m/s)	0.38 mW/cm^3	120 kJ/cm^3
Temperature (10C Differential)	15.0 $\mu W/cm^3$	4.73 kJ/cm^3
Human-Powered Systems (Shoe Inserts)	330 $\mu W/cm^3$	104 kJ/cm^3

Table 2.2: Devices with fixed amount of power generation (renewable energy sources)

Energy Source/Store	Energy Obtained over Ten Years
Primary Batteries (Zinc-Air)	3.78 kJ/cm^3
Primary Batteries (Lithium)	2.88 kJ/cm^3
Primary Batteries (Alkaline)	1.20 kJ/cm^3
Secondary Batteries (Li-ion)	1.08 kJ/cm^3
Secondary Batteries (Ni-MH)	960 J/cm^3
Secondary Batteries (Ni-Cad)	650 J/cm^3
Micro-Fuel Cell	3.50 kJ/cm^3
Heat Engine	3.35 kJ/cm^3
Radioactive (^{63}Ni)	1.64 kJ/cm^3

2.3.2 Energy – Aware Algorithms

Energy aware algorithms for WSNs comprise of energy harvesting management, topology control, duty cycle control and data processing, but the majority of the algorithms constitute routing and media access control which will be discussed later in this section.

In order to provide energy-aware operation, it is necessary to know that the general definition of the lifetime of a WSN; it is the time between the deployed sensor nodes start collecting data to the instance where the *monitoring quality* drops below an *acceptable threshold level* [27]. The definition of the terms monitoring quality and acceptable threshold level vary depending on the application the sensor nodes are

used for. For example, in an application that monitors the pressure of an agricultural area, regular processing of 80% of the crops might be acceptable, however in a military video surveillance application, a delay of 2s during surveillance might trigger the threshold. As it was presented in Delin et al. [28] and Cianci et al. [29], if a node's energy store depletes past a preset threshold, the node enters a sleep state to allow the energy store to be charged back to a sufficient level using energy harvesting. The result of these controls the node's sleeping behavior in the sense that, nodes that have their residual energy levels below the threshold will sleep more often. However, this will lead to data-forwarding-interruption problem.

Topology control algorithms (ASCENT [30] and Energy Conservation in WSN and connectivity and graphs [31]) extend the lifetime of WSNs by taking advantage of the redundancy of the network. If more than one node is sensing the same data, the redundant nodes are selected and put in to sleep. When the energy of the sensing nodes drops below an acceptable threshold, the sleeping nodes start sensing so that the overall consumption is spread across the sensor node.

Occasionally in a WSN, in order to extend the network lifetime, we have to trade computation processing accuracy. An example is a Finite Impulse Response (FIR) filter or Fast Fourier Transform (FFT) [21], which is a common technique of implementation that uses iterative algorithms which provide accurate results with increased operational time. Consequently, by tolerating a less accurate result, the operational time is reduced.

Up to this point, it is clear that radio transceiver in a sensor node, which is responsible for radio communication is often the major consumer of energy in a

WSN, however, reducing the number of packets communicated results in a dramatic energy reduction. Techniques and algorithms for Energy-aware information extraction will be discussed in section 2.4.

2.3.3 Discussion

In Section 2.3, we tried to provide an overview of some relevant researches to the energy management theme of this thesis. We discussed some techniques (such as, energy harvesting management, topology control, and data processing) that are use to extend the lifetime of a WSN and we discussed some energy sources (among which are blood pressure, body heat, breathing, solar and vibration harvesting). This thesis suggests that these low-power techniques and energy sources should be considered carefully in all stages of design process of a sensor node.

2.4 Information Management

So far in our discussion, we made known that the major consumer of energy in a sensor node is communication. We also observed that considering all data to be of equal usefulness by communicating all data (redundant or trivial data) will be waste of resource. That brings this thesis to the definition of information management, which is a process of distinguishing useful data from redundant data so as to reduce the rate of energy consumption in a sensor node and the sensor network at large. This section will try to provide overview of research on information management for WSNs, for the most part, information propagation will be explored.

2.4.1 Information propagation

Information propagation algorithm (or reporting technique) is defined as a process of determining how data (which is sampled by a sensor node from its sensing environment) should be made available to other nodes, sink node or the end-user.

Information propagation algorithms are in general more related to packet routing. Below are the lists of four information propagation techniques [32, 33]:

1. Continuous/Periodic Propagation (data 'pushing')
2. Query-Driven Propagation (data 'pulling')
3. Even-Driven Propagation (data 'pulling')
4. Hybrid Propagation

2.4.1.1 Continuous/Periodic Propagation

In continuous propagation, deciding on the periodic duration has a significant effect on the network performance. When a short periodic duration is chosen, packets will be often propagated; this will lead a large portion of redundant or trivial data being transmitted, hence consuming considerable amount of energy [34]. When a long periodic duration is chosen, packets will be rarely propagated; the network suffers from long delay and missing of events. While the missing of events may be avoided by locally aggregating the average-max-min sensed values, this does not avoid the issues of delay that aggregation introduces. Advantage of continuous propagation is that it is suitable for applications with random or uncharacterized signal. Its disadvantage is that does not minimize energy consumption or information throughput. Query-driven and event driven propagation approaches provide more suitable techniques, and will be discussed in the section below.

2.4.1.2 Query-Driven Propagation

In Query-driven approach to information propagation in WSNs, the user or application initializes data transfer by querying data from the network [35]; for example a query is propagated into the network requesting: "*where in the building do we have temperature about 35 degrees?*" and appropriate nodes respond with packet

similar: "*in x we have temperature above 35 degrees*". Additionally, query-driven approach pulls data from a passive network to respond to query.

In [36], the authors Y. Yao and J. Gehrke, developed a Cougar approach which uses a query-based propagation, the approach supports historic queries (for example, "what is the average snow in 2003?"). Advantage of the approach is that it provides the ability to store historic data; however it has a number of disadvantages. Firstly, in order to respond to queries that require history, each node most have a database to store the required information. Secondly, when any node is lost, it loses its entire set of historical data.

Event-driven propagation is suitable for applications where users rarely or infrequently draw information from the network (for example, users wish to know about the temperature of a node only when they wish to know).

2.4.1.3 Event-Driven Propagation

In event-driven propagation, the sensor nodes are intelligent in the sense that they decide for their selves when data should be reported to the sink node; for example a packet is transmitted containing: "*the temperature is too hot at location x*". Such propagation systems can be classified into two categories:

a) The ones that report only the digital occurrence of an event (such as motion, and smoke), and

b) The ones that report the occurrence and magnitude of an event (magnitude of vibrations over a certain threshold) [24].

A. Manjeshwar and D.P. Agrawal in [37] proposed an event-base propagation technique for WSN called TEEN. The technique is based upon the concept of two

thresholds: H_t (Hard Threshold) and S_t (Soft Threshold). When the sampled data crosses the H_t or changes in the sensed data is more than S_t, data is then sent from the sensor node. However, if neither of these two thresholds occurs, communication will never take place meaning that data will never be sent to the user or sink node.

In Merrett et. al [38], the authors improved [37] even further by introducing IDEALS (Information manageD Energy aware ALgorithm for Sensor networks). In IDEALS technique, a node senses information and based on some user defined rules, priority is given to this sensed information. Afterwards based on an energy-aware algorithm, the packet is transmitted or not.

Aside from the information propagation techniques that use information to control reporting discussed in the section above, there are other possible uses of information control; such as: sample rate adjustment, packet reliability and bandwidth management.

2.4.2 Discussion

Section 2.4 has outlined information management techniques in WSNs, focusing more on information propagation. The disadvantage of periodic propagation was discussed. Better propagation techniques (query-driven and event-driven) were also investigated. Query–driven or data pulling (data pulled from the network in response to queries sent by users or applications) technique. It has the advantage that it is suitable for applications where users infrequently draw information from the network. One of its disadvantages is that when a node containing history of event is lost, all the history set of data in the node is also lost. In Event-driven or data pushing (sensor node decides for itself when data should be reported to the sink, and pushes data to the sink when required). Its advantage is that it does not transmit packet that

are trivial or redundant, hence decrease energy consumption. These event-based detection algorithms are divided into two categories: rule-based approaches, and predictive approaches. In the rule-based approach, the user defines what is important to the application. In the predictive approach, nodes report quite a large amount of data to enable the sampled environment to be reconstructed at the sink node. Additionally, in rule-based approach, while requiring end-user input to define events of importance, often provides the best method for event detection [39].

2.5 Transmission Range Adjustments

Based on our previous discussions, we have made known that the paramount concern in WSNs is power scarcity, driven partially by energy resource (battery). In the previous sections, we have investigated the researches done on energy management and information control theme of this thesis. In this section, our aim is to give an overview of a few researches done using transmission range adjustment to minimize the energy consumption and hence, extend the network lifetime. Power saving techniques can generally be classified into the following four categories: 1) Schedule the wireless sensor node to swap between active and sleep mode. 2) Control power by adjusting transmission range of wireless sensor node. 3) Energy efficient routing and data gathering. 4) To reduce the amount of data transmitted and avoid useless activity. In this section, we consider only power control by adjusting transmission range of sensor node.

Cardei et al. in [40] presents an efficient method to lower the energy consumption by organizing the sensors into a maximal number of disjoint sets that are activated successively. Each disjoint set can monitor the entire target area and at the same time propagate information to the sink node or end-user. Only one set at a time is put into

active mode (to monitor and propagate data), while other sets are put into low power sleep mode.

Authors in [41] extend the work of [40] by considering a large number of sensors with *adjustable* sensing range that are randomly deployed to monitor a number of targets areas. Since the number of sensors is large and therefore they can redundantly cover target areas, in order to conserve energy, sensors were organized in sets and activated successively. A sensor can adjust its communication range by partaking in multiple set covers, such that its total energy spent is constraint by the initial energy resource of the sensor node.

2.5.1 Discussion

This section has outlined some works that applied transmission range adjustment and significant amount of energy was incurred. It has also mentioned the four categories of power saving techniques. Transmission range can be adjusted based on many factors such as energy resource, message importance and redundancy of node coverage. In this thesis, transmission range adjustment was based on a function or two parameters (energy resource and message importance), details will come later in subsequent sections.

2.6 Communication and Networking for WSNs

Wireless communication and networking in is a huge requirement in research, design, implementation and operation of WSNs and computer network as a whole. We will provide an overview of communication architecture and wireless networking protocols applied to WSNs. In addition, MAC protocols in WSN and routing algorithms will be discussed.

2.6.1 Communication Architecture of a WSN

A WSN generally consist of large number of nodes that are randomly and densely deployed in an environment to sense data and communicate this data according to a communication protocol. Each sensor node is capable of sensing data and forwarding this data using multi-hop routing to reach the *sink* node as shown in 2.4. The sink node may communicate with the *task manager* node through satellite or the internet [11].

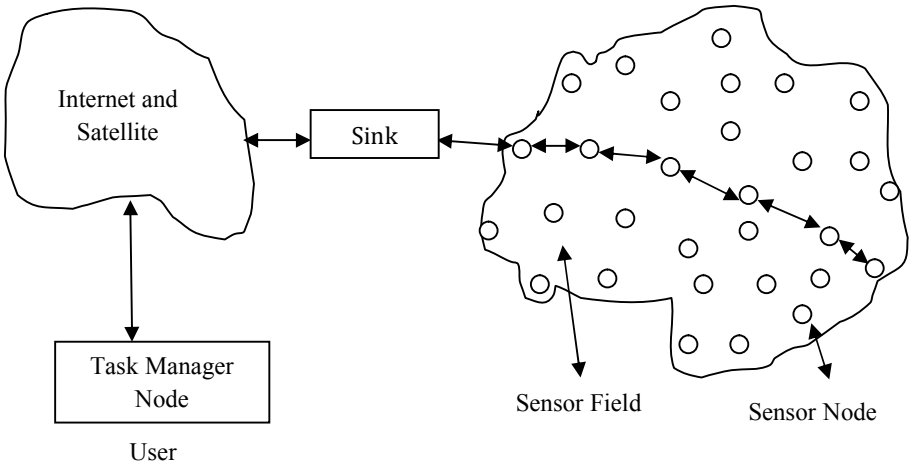
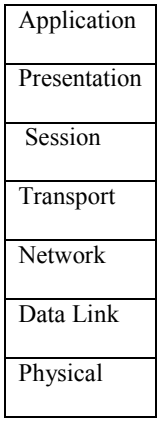


Figure 2.4: Randomly deployed sensor nodes [11]

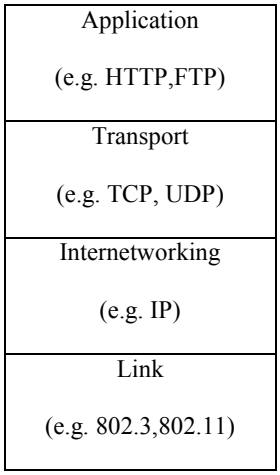
2.6.2 Introduction to Networking Protocol Stacks

Depending on the application, a WSN may consist of a few and up to thousand of sensor nodes [14]. Each of these sensor nodes in Figure 2.4 use *protocol* stack in Figure 2.5 to communicate with one another and with the sink node. Hence, the development of a reliable and energy efficient protocol stack is essential for supporting various WSNs applications. Layering can be defined as a set of communication functions that can be managed and grouped together. A Protocol is a set of rules that governs how two or more communicating entities in a layer are to

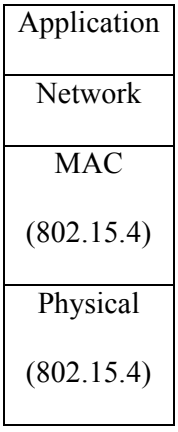
interact by providing service to the layer above. Networking architecture comprises of definition of all layers and the design of protocols for each layer as seen in Figure 2.5. The reason why layering is important is because it eases design, implementation and testing of communication component. Protocols in each layer can be design separately from those of other layers. This means that when we want to modify a layer, we can modify it easily without having to alter the whole networking architecture.



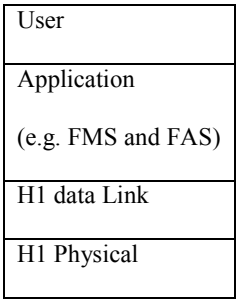
(a) OSI Basic Reference Model



(b) Internet Reference Model



(d) ZigBee



(c) Foundation FieldBus H1

Figure 2.5: (a) OSI Basic Reference Model (OSI-BRM) [42], (b) Internet Reference Model [43], (c) Foundation Fieldbus H1 Stack [44], and (d) ZigBee Stack [45].

By the mid-1970s every computer vendor had developed its own proprietary layered architecture. Problem arose when computers of different vendors try to network together for communication. For that reason, OSI (Open standard interconnection – Basic Reference Model) [42] which was an effort of ISO (International Organization for Standards) enabled multivendor communication by proposing a basic layered structure for communication shown in Figure 2.5. Many of the modern communication protocols and models (such as the Internet Reference Model [45] shown in Fig. 2.5) have modified OSI-BSM to suit their model requirements. Furthermore, most if not all protocols for WSNs are also modified OSI-BSM. We will evaluate the various energy-efficient protocols proposed for the transport layer, network layer, and data-link layer, and their crosslayer interactions.

Transport Layer: The main goal of a transport layer protocol in a WSN is to guarantee the reliability and quality of data in the sensor nodes (source and sink nodes). Transport layer protocols in WSNs ought to support multiple applications, variable reliability, packet-loss recovery, and congestion control mechanism [14]. Energy-efficient protocols proposed for transport layer are: Sensor Transmission Control Protocol (STCP), Delay Sensitive Transport (DST), Event-to-Sink Reliable Transport (ESRT), Price-Oriented Reliable Transport Protocol (PORT), Pump slowly, fetch quickly (PSFQ) and GARUDA. Some of the characteristics of these protocols are: DST, STCP, ESRT and PORT tackle the problem of congestion control and reliability guarantee from the sensors to the sink whereas PSFQ and GARUDA examine only the problem of reliability from the sink to the sensors.

Even though quite a large number of transport layer protocols have been proposed for WSNs, there is still numerous open research problems, one of them is cross-layer optimization. Crosslayer can be employed to improve the performance of transport layer protocol by for example, selecting better path for retransmission.

Network Layer: The main aim of this layer is to manage the operation of the network and route packet across the network from the source node to the sink node. Details will be explored in later sections.

DataLink Layer: Datalink layer is concern by means of data transfer among two nodes that share the same link. Given that the underlying network is wireless, there is need for medium access control (MAC) and management for effective data transfer [14]. More details on MAC protocol will we presented in the coming sections.

As was explained earlier that modern communication network architectures have modified layers from the OSI-BRM to tailor the model to their specific requirements. For example, Fieldbus H1 (which is one of the Foundation Fieldbus protocol versions) [44] was designed as a network architecture for process control applications, such as sensor networks. As can be seen from Figure 2.5, most of the higher layers of the OSI-BRM are omitted because their functionality is not required in Foundation Fieldbus H1. Additionally, Fieldbus H1 adds a user layer to the top most part of the stack. The ZigBee specification [45] defines a low-cost, low-power wireless communication standard that is mainly appropriate for WSNs. As can be seen from Figure 2.5, many of the upper part of the OSI-BRM is discarded and even the transport layer too, this is also because it is not needed in the ZigBee protocol stack. MAC and Physical layer uses the IEEE 802.15.4.

A number of variations on the basic communication stack have been proposed in the literature. One of them is the ‘three-dimensional’ stack for use with sensor networks

proposed by Akyildiz *et at*. [4]. As illustrated in Figure 2.6, besides having five tradition layer from the OSI-BRM, three 'management planes' are added. These management planes are added in order that sensor nodes can work together in a more efficient way in term of power.

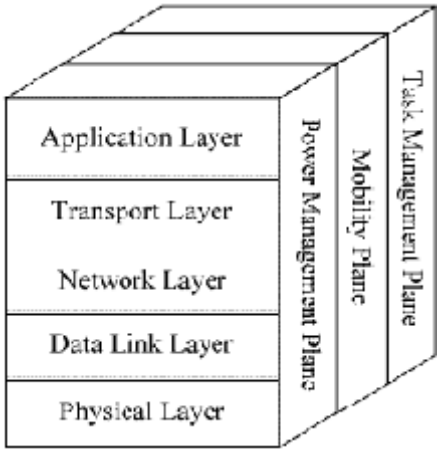


Figure 2.6: a 'Three-dimensional' stack [11].

2.6.3 Medium Access Control (MAC) Layer

MAC is traditionally a sub-layer of the data link layer, in traditional wireless networks, it manages the usage of radio interface to ensure efficient utilization of shared bandwidth and it balances throughput, delay and fairness. However in WSNs, MAC protocol manages radio activity to conserve energy and it balance energy efficiency as well. In WSNs, the primary performance metrics is usually energy efficiency, while metrics such as scalability, adaptability to changes, latency, throughput, fairness, and bandwidth utilization are of secondary importance. To design an Energy-efficient MAC protocol, the following reasons for energy wastage must be addressed [46].

Collision: When collisions occur at a node, the collided packets will be discarded and retransmitted. Retransmission incurs huge energy consumption.

Idle Listening: Radio transceivers typically have four duty cycle states: transmitting, receiving, listening (waiting to receive possible packet) and sleeping. Idle listening waste significant amount of energy as it consumes the same energy as receiving.

Overhearing: Usually in sensor networks, packets are propagated over the network using multi-hop routing (dissemination of packets from source to destination node, whereby packets pass through intermediate nodes). Overhearing is when intermediate nodes receive packet that they always have to retransmit.

Over Emitting: This involves transmitting packets to a destination that is not ready to receive packets (either destination node is sleeping or some other reason), thus causing retransmission which incurs huge energy wastage.

Below is a list of some MAC protocols used in the datalink layer of a WSNs. Details can be found in [20, 46]:

- The B-MAC (Berkeley Berkeley Media Access Control) protocol
- The S-MAC (Sensor Media Access Control) protocol
- Wise MAC protocol
- The D-MAC (Data-gathering Media Access Control) protocol
- The Z-MAC protocol

2.6.4 Network Layer

The main function of network layer is to route packets from source to destination. Routing protocols in WSNs differs from that of traditional routing protocols in numerous ways [14]. Such that in traditional routing, internet Protocol (IP) based routing is used to forward packets across the network, whereas in a WSN, sensor nodes do not use IP addresses and therefore IP based routing protocols are not used in them. Attention is given to lifetime of WSN for that reason; protocols ought to meet network resource constraints for example limited energy, communication

bandwidth, memory, and computation capabilities so as to extend the network lifetime. There are three communication topologies used for routing packet across a network: single-hop, flat multi-hop, and clustered multi-hop [47].

Single-Hop: This is a direct communication between the source node and the sink node as shown in 2.7 a.

Flat Multi-Hop: In this communication, the source node communicates with the sink node by forwarding packets through intermediate nodes, as shown in 2.7b.

Clustered Multi-hop: The entire sensor nodes are placed into groups or clusters, each cluster has a cluster head where by the source nodes communicate with their cluster heads to transmit a packet to the sink node as shown in Figure 2.7c.

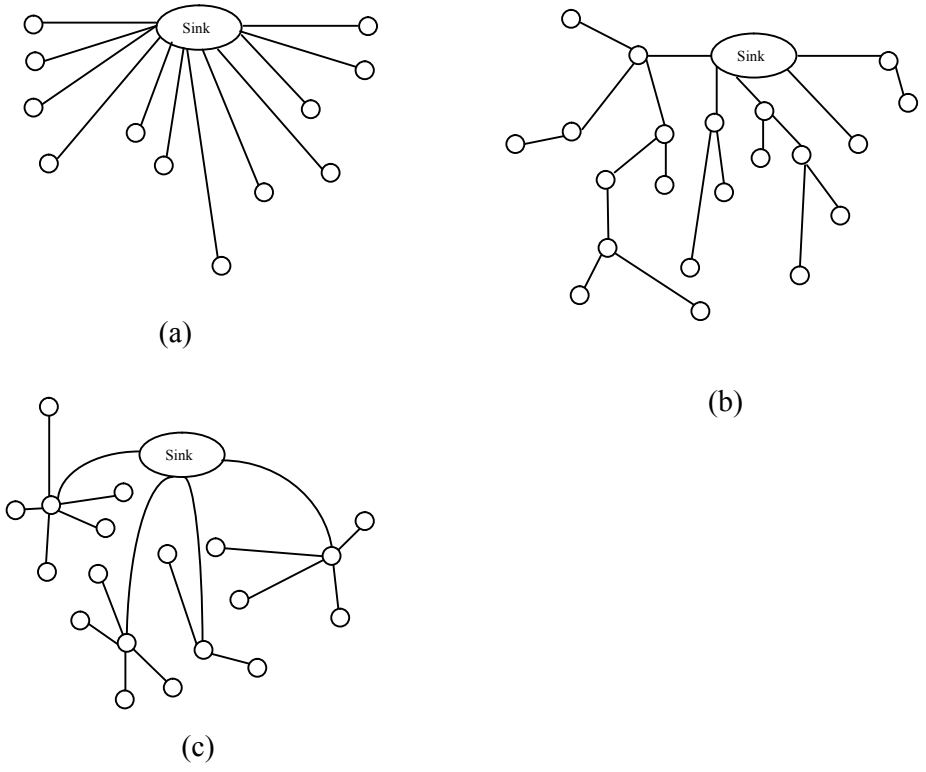


Figure 2.7: Communication topologies for routing: a) single-hop, b) flat multi-hop, and c) clustered multi-hop.

Many routing algorithms are constantly being proposed in the literature in other to extend the network lifetime. In the section below, some of the proposed routing algorithm in the literature such as flooding-based and energy-aware routing algorithms will be investigated, moreover emphasis will be put on flooding-based routing algorithm because it is assumed that the AIRT scheme in this thesis uses it to route packets to the sink.

2.6.4.1 Geographic Routing Algorithms

Geographic (or location-aware) routing algorithms are algorithms that are suitable for multi-hop routing in a dense network. Each node is assumed to know its location and the location of its neighbors. The algorithm forwards packets by choosing neighbors which are closest to the destination [14].

2.6.4.2 Energy-Aware Routing Algorithms

Authors in [38] introduced an energy-aware algorithm called IDEAL/RMR which improves the lifetime of information with high priority. This increase in network lifetime is achieved by considering the information contents of a packet and nodes level of energy resource. IDEALS/RMR was further improved by our IRT scheme in [48], whereby a sensor node adjusts its transmission range based on its level of energy reserve. We improved our IRT scheme even better by introducing a new scheme called AIRT, which improves the network lifetime of a sensor network by adjusting nodes transmission range based on both level of energy reserve and usefulness of information contents of the node.

2.6.4.3 Flooding-Based Routing algorithms

In this algorithm, nodes broadcast their packets to all of their neighboring nodes except if they already forwarded the same kind of packet or if a maximum number of hops have be reached or if the node is the packet's destination.

Advantages: Among the many advantages are: simplicity in implementation, scalability in the sense if more packets are added to the network the algorithm will still remain efficient and robustness.

Disadvantages: Some of them are: implosion (copies of the same packets sent to the neighboring nodes will be forwarded back to the sending node), and overlapping and resource blindness.

Figure 2.8 illustrates an example of 7 nodes which use flooding algorithm to route a packet from source (node1) to destination (node 7).

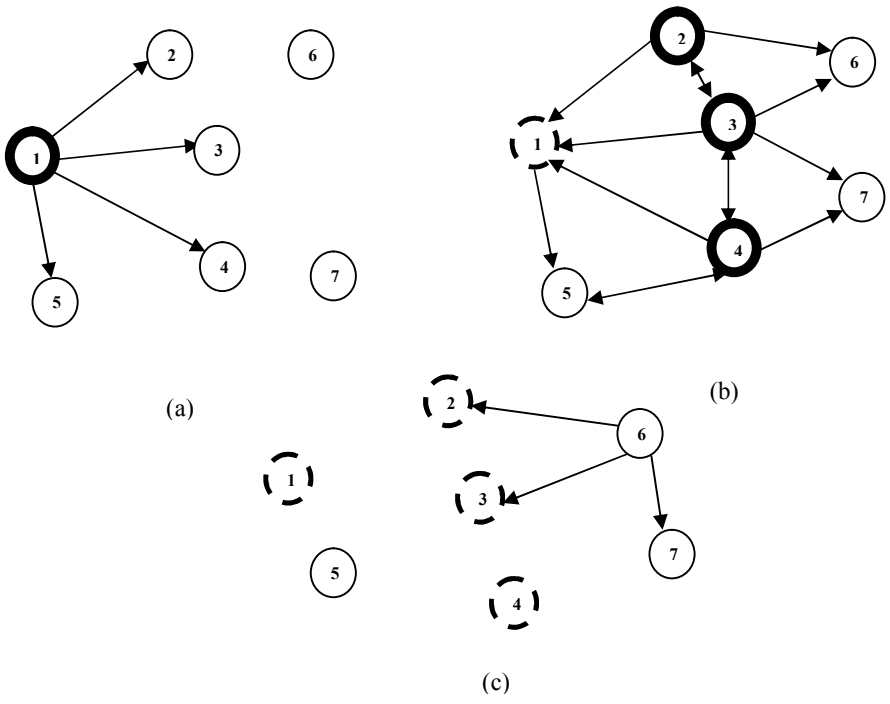


Figure 2.8: Flooding-based algorithm example

In (a), node 1 broadcast its packets to its neighbors: nodes 2, 3, 4 and 5. In b), node 2, 3, 4 broadcast to their neighbors: nodes 1, 2, 3,4,5,6 and 7 and finally in (c), node 6 broadcast to its neighbors: nodes 2, 3, and 7. Since all the nodes already received the

same packet and they don't need it, they discard the packet except the destination node 7 which process its received packet.

2.6.5 Discussion

In this section, we provided an overview of communication architecture and protocol stacks in WSN. We proceeded further by briefly discussing MAC protocols and routing algorithms though focusing on more relevant ideas to this thesis. We used a clearly illustrated Figure to describe the communication architecture of a typical in subsection 2.6.1. Designers of new and evolving applications and technologies use the OSI model as their base for designing suitable communication architectures for their applications. It was described that protocols in a layer can only communicate with protocols in the layer directly above them however, with cross layering which is a current research interest, protocols in a layer can communicate with non adjacent layers, this is providing benefits to WSNs.

A MAC protocol which is part of datalink layer is for direct communication between sensor nodes. Some factors are considered in the design of an energy efficient MAC protocol such as idle listening, overhearing, collision and over emitting.

Finally, network protocols are mainly for end-to-end communication between source and sink nodes. Many routing algorithms are proposed all the time in other to minimize the energy consumption in WSNs. Among them is the energy-aware algorithms have been considered, where a node decides on which route it should follow based on its energy resource level. Lastly, flooding algorithm which due to its simplicity it is usually adopted in WSNs, although it is highly inefficient in networks that support only unicast communication.

2.7 WSN Simulators and Energy Model

A WSN can be analyzed by either practical implementation, analytical or simulation programming. The most widely used method for analysis is simulation; this is mainly because it is simple in modeling real WSN operations and easy to modify algorithms and protocols. It can however be unrealistic because of assumptions that are made during simulation; thus the realism of simulation depends on model it is based upon.

There are numerous WSN simulators developed, some of them are developed particularly for a sensor network (such WSNsim [38]), while others are developed as a simulation tool for WSN simulations (such as ns-2 [50]). In this thesis research we analyzed a WSN and developed our AIRT algorithm by simulation using C Programming Language.

Energy models means to model the energy resource (such as battery and energy harvesting), and energy consumers (such as radio communication). There are many energy models developed in the literature. In this thesis, the energy model proposed by authors in [51] is considered; whereby the length of the packet in bits is considered as a direction function of energy incurred through transmitting a packet. The model provides equation for the energy needed by a sensor node to transmit (2.2) and receive (2.3) a single packet in bits, where E_{elec} in Joules is the energy need for the circuitry to transmit or receive a single bit, E_{amp} in Joules is the energy needed for the transmit amplifier to transmit a single bit a distance of one meter.

$$E_{tx}(l,d) = E_{elec}l + E_{amp}ld^2 . \quad (2.1)$$

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}. \quad (2.2)$$

2.8 Summery

This section had investigated some of the background information in WSNs. Energy-aware, information-aware, and transmission range adaptation themes of this thesis were also explored. The chapter was then concluded by briefly discussing networking protocols, simulators and energy models.

Many of the research in WSN is about how to lower the energy consumption, so as to improve the network lifetime, this is mainly because WSNs are used in many attractive applications and their batteries are difficult to replace. Therefore energy-aware algorithms developed should carefully consider the nodes life time in all operations.

Communication of sensed data across the network and to the sink node or end-user is of paramount importance; therefore limiting the number of communicating information can considerably increase the network lifetime. Most of researchers consider information to be of equal importance in a WSN, thus they transmit this information irrespective of whether it is important or not. However in this thesis, by prioritizing nodes information a considerable increase in the network lifetime was achieved. A number of information-aware algorithms were discussed and rule-base which is the most efficient is used in this thesis.

Adjusting transmission range so as not to transmit information with the same single transmission range is considered. Based on researches, it is observed that a great deal of increase in network lifetime is achieved. It will be a good idea to consider it in minimizing network consumption.

Network and datalink layer were also considered, where the focus was MAC protocols for WSNs. The two categories of network simulators for evaluating WSNs where discussed and examples of them were given. The energy model used in this thesis was also mentioned in this chapter.

Chapter 3

AIRT: ADAPTIVE INFORMATION MANAGED ENERGY-AWARE ALGORITHM FOR SENSOR NETWORKS WITH RULE MANAGED REPORTING AND TRANSMISSION RANGE ADJUSTMENTS

In chapter 2, some background information on wireless sensor networks focusing on energy awareness was explored and most importantly, significance of power saving techniques such as energy-aware, information-aware, and transmission range adjustment were presented. This chapter presents AIRT (**A**daptive **I**nformation managed energy-aware algorithm for sensor networks with **R**ule managed reporting and **T**ransmission range adjustments) which extends the network lifetime based on combination of energy-aware, information-aware, and transmission range operations. Section 3.1 presents an overview of the whole AIRT scheme; sections 3.2, 3.3, 3.4 present RMR, IDEALS, TRA operation units respectively. Figure 3.1 shows an overview of the entire AIRT system. The overview of the system is shown so as to give the reader an insight of the overall system which will be shown in details later in the coming sections.

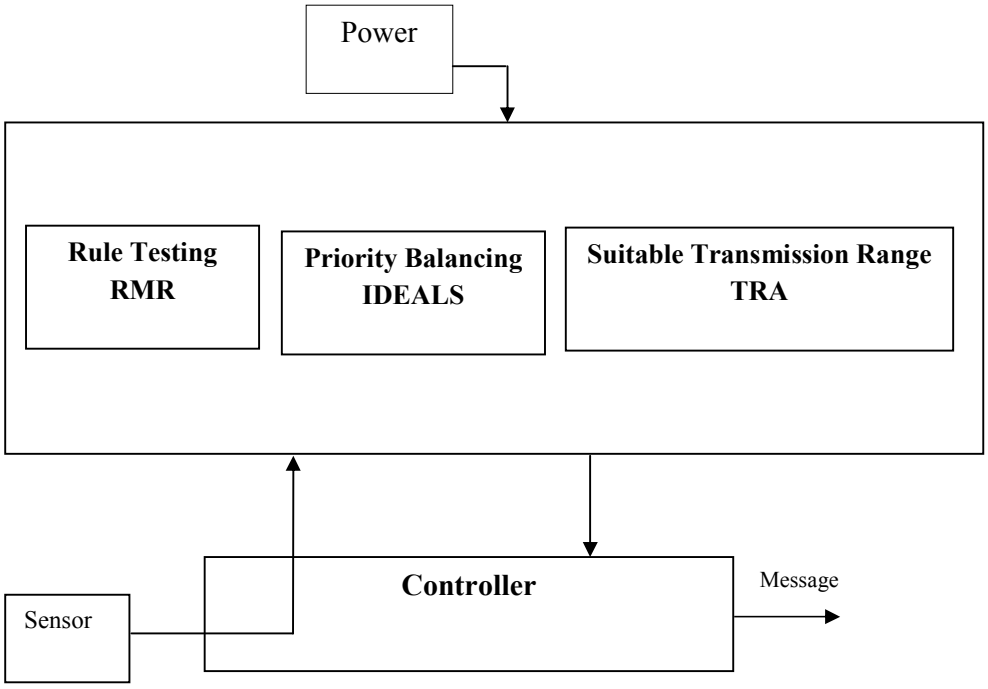


Figure 3.1 Overview of AIRT System Diagram

3.1 Overview of AIRT

AIRT is a scheme that offers significant energy savings and extends the network lifetime. AIRT algorithm runs in each and every node in the WSN. The scheme extends the network lifetime by ignoring low importance information and further extends the network lifetime by adjustment of nodes transmission ranges. These extensions are achieved based on the combination of the following power saving techniques:

Information-aware: This is an operation in which a sensor node differentiates between important and non important messages based on messages information contents. In this thesis work, this process is done by the RMR (Rule Managed Reporting) unit. Its purpose is to determine if the sensed data is to be processed and how useful is the sensed data (details are provided in section 3.2).

Energy-aware: This is the process of differentiating between messages that will or will not be transmitted to the sink node, based on the nodes energy resource level. In

this work, the operation is performed by the IDEALS (Information manageD Energy Aware Algorithm for Sensor networks) unit (details are provided in section 3.3).

Transmission range adjustment: This is the process of adjusting of node's transmission range based on its energy resource level and importance of sensed data. The TRA (Transmission Range Adjustment) unit is responsible for the operation (details are provided in section 3.4).

The result of the union of information-aware, energy-aware and transmission range adjustment mainly depends on the importance of sensed data and level of node's energy resource which we believe have never been considered by other researchers. The key concept of the AIRT scheme is that a node which has high battery life benefits the whole network by generating and forwarding messages and the node does that with different node transmission ranges (based on importance of message and energy resource level). However, a node with low battery life forwards only messages which have high information contents and it does that with different transmission ranges (based on message importance and energy resource level). By performing these operations, AIRT extend the lifetime of important messages via transmission range adjustment and the possible loss of messages of less important.

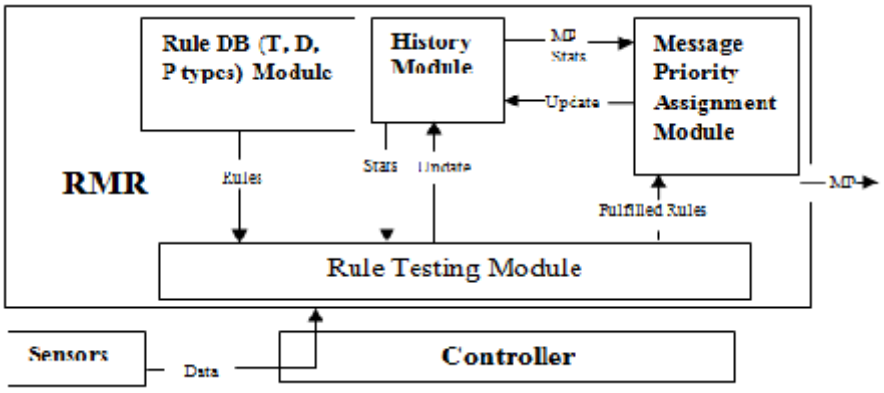


Figure 3.2 RMR Operation

3.2 RMR

The operation of RMR unit depends on the set of rules defined by the designer to decide on which data could be sensed and the level of importance of this sensed data (some examples of user possible user defined rules are mentioned below). The system diagram of RMR is given in Figure 3.2. Firstly, when the sensor node senses data, the node passes the data to the controller, the controller then sends a value (e.g. temperature) to the RMR (Rule Management Reporting) unit. The data is then received by the *Rule Testing Module,* whose responsibility is to determine if the event should be reported or not. It does that by checking the sensed data against the rules in the *Rule Database Module (*getting *history* information about the previously sensed values*),* simultaneously updates the history by adding the current information of data and the sensed data to it. Rules may be triggered or not. Those rules which are triggered are forwarded to the *Message Priority Assignment module* to determine how important the content of the message is. It does that by assigning message priorities (MP) to the triggered rules. This research uses five different MPs which are (MP1-MP5). MP1 relates to the most important message which might represent drastic change in the sensed data value. Conversely, MP4 - MP5 relates to the least important packets which might represents slight or no change in the sensed value. MP2 - MP3 relates to intermediate priorities packets which might represent moderate change in the sensed value. The designer can enter any number of user defined rules; these rules express different kind of events that the user is willing to detect in the sensed region.

Examples of possible rules:

- Threshold rule [31]: This rule is applied when the current and last sensed values (data such as pressure) are in opposite sides of the threshold value. For example, *"if the pressure rises above or falls below 70 Pascal"*.
- Differential Rule [31]: This rule is applied when the dissimilarity among the current and last sampled values is greater than some certain amount. For example, "*If the pressure of the current and last sensed value changes more than 7 Pascal*".
- Periodic Rule [31]: This rule is applied when a specific defined rule has been idle for a certain time duration, may be, "*every 240 seconds*".

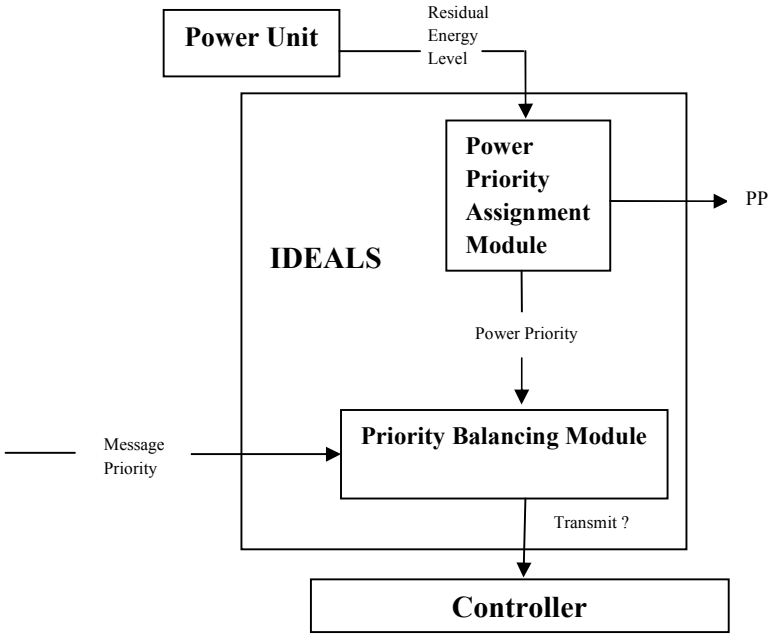


Figure 3.3 IDEALS Operation

3.3 IDEALS

The IDEALS system diagram is given in Figure 3.3. Data received from Message Priority Assignment Module of RMR is passed to the IDEALS unit. Its responsibility is to decide if the node should transmit a message or not, and this is done by the *Priority Balancing Module*. The node's energy resource is characterized by the *Power Priority Assignment Module,* which allocates a power priority (PP) depending on the state of the battery. The highest power priority is PP5, and it is

allocated to the node which has the highest battery life, whereas the lowest power priority is PP1 and it is allocated to the node which has the lowest battery life. When priority balancing module receives MP and PP, it compares them and if PP ≥ MP, a message will be transmitted. The clear description of priority balancing is given in Figure 3.4.

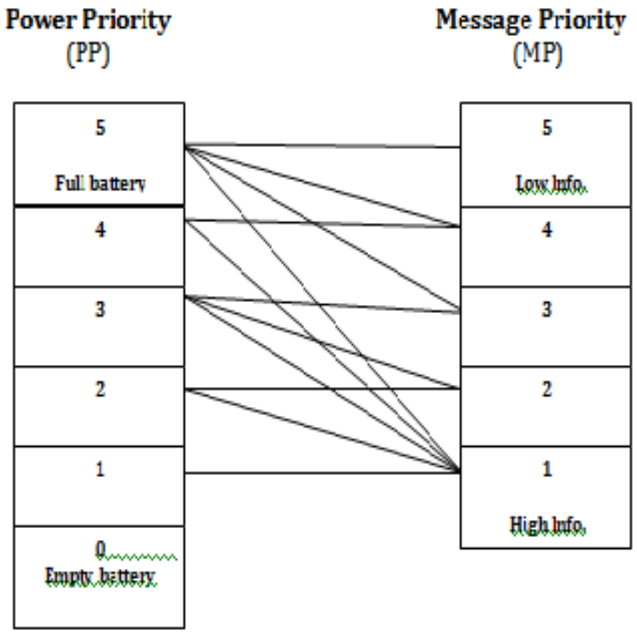


Figure 3.4 Priority Allocation and Balancing Process

3.4 TRA

TRA is also a part of the AIRT scheme given in Figure 3.6 just as RMR and IDEALS are. TRA's system diagram is illustrated in Figure 3.5. When a node reaches a conclusion to transmit a message because PP>=MP as illustrated in priority allocation, and balancing process of Figure 3.4, PP and MP are passed to *transmission range adjustment* (TRA) unit. Its purpose is to decide with what range a sensor node will transmit a message, which is calculated by the *Suitable Transmission Range Module.* Suitable transmission range module gets PP from the power priority assignment module, MP from message priority assignment module and coordinates from the *reachable sensors module.* The module's reachable sensors are the entire sensors in the maximum transmission range of the sending node. Now,

depending on PP and MP values, a suitable transmission range is determined and passed to the controller to successfully transmit the message with the new range, Table 3.1 shows the suitable transmission ranges with respect to PP and MP values. In this work, five different TRs are used (TR1-TR5), where TR1 is the minimum transmission range and TR5 is the maximum transmission range. For example, when a node has a full battery PP5, it will transmit messages with MP1 with TR5, MP2 with TR4, MP3 with TR3, MP4 with TR2 and MP5 with TR1. However, if a nodes' battery power decreases to its minimum PP1, it will have the chance to transmit only packets with the highest message priority MP1 and with the lowest transmission range TR1.

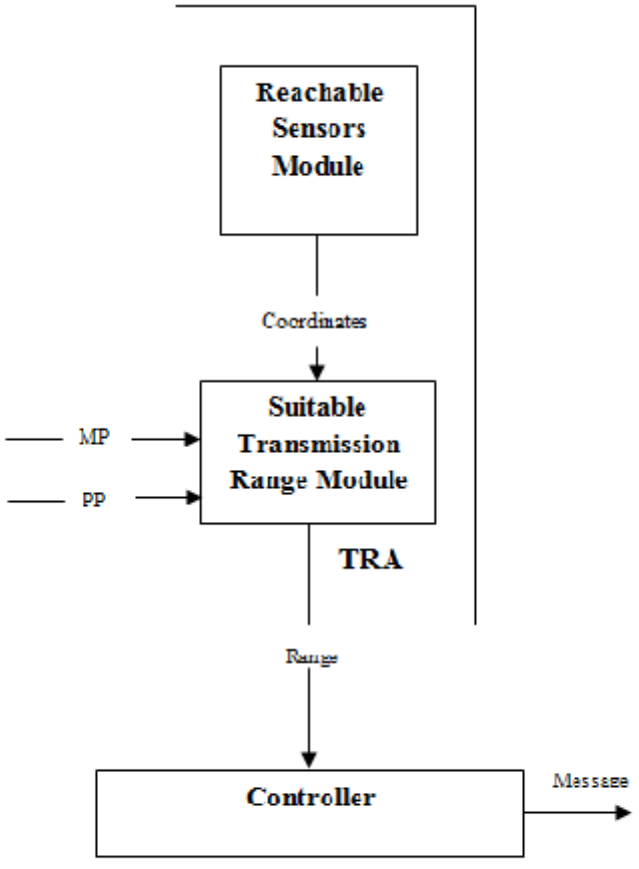


Figure 3.5 Transmission Range Adjustment (TRA) Operation

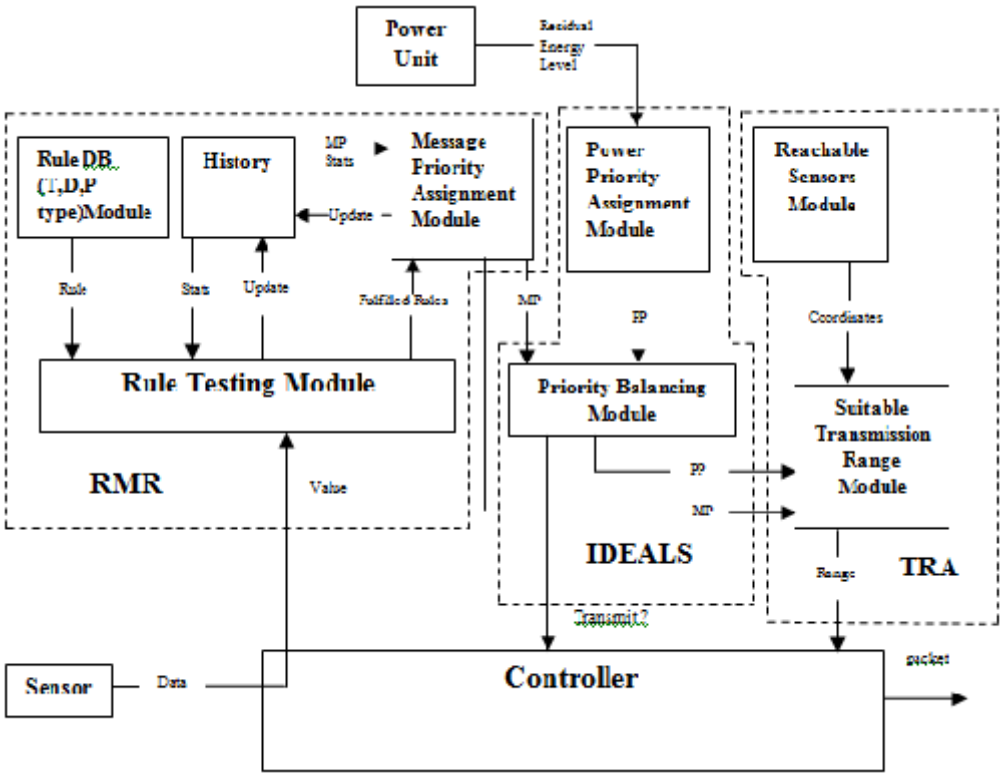


Figure 3.6 Proposed AIRT System Diagram

In the hardware implementation of the transmission range, a power control mechanism is embedded in the sensor node so that the node can adjust its transmission range.

The transmission ranges of Table 3.1 below were derived from the given algorithm:

It is assumed that the number of levels used for MP, PP and TR is MP=PP=TR=L

Let's assume Table 3.1 represents a matrix A and MP and PP represent I and J respectively.

A [I, J] = 0, if I < J

A [I, J] = 2, if I = J and I ≠ L

A [I, J] = I, if I > J, I ≠ 5

A [I, J] = (L + 1) – J, I = L

Table 3.1 Intuitionally determined transmission ranges

MP \ PP	5 (Highest)	4	3	2	1 (Lowest)
5 (Lowest)	1(Min. TR)	0	0	0	0
4	2	2	0	0	0
3	3	4	2	0	0
2	4	4	3	2	0
1 (Highest)	5(Max. TR)	4	3	2	2

It should be noted that in AIRT scheme, a message may be dropped because of any of the following scenarios: no message generation (that is a change in the sensed data does not activate a rule), local priority unbalancing (meaning that if PP<MP, a message will not be transmitted after it has been generated by a node), and routing failure (that is to say there is no route for the packet to be propagated through the network where PP≥MP due to loops, the packet will not be able to reach its destination and therefore will be dropped).

So far in this section, we discussed the overall AIRT system diagram operation and the operations of information-aware, energy-aware and transmission range-aware sub-systems. Figure 3.7 below illustrates the flow chart of the AIRT algorithm developed in the thesis research.

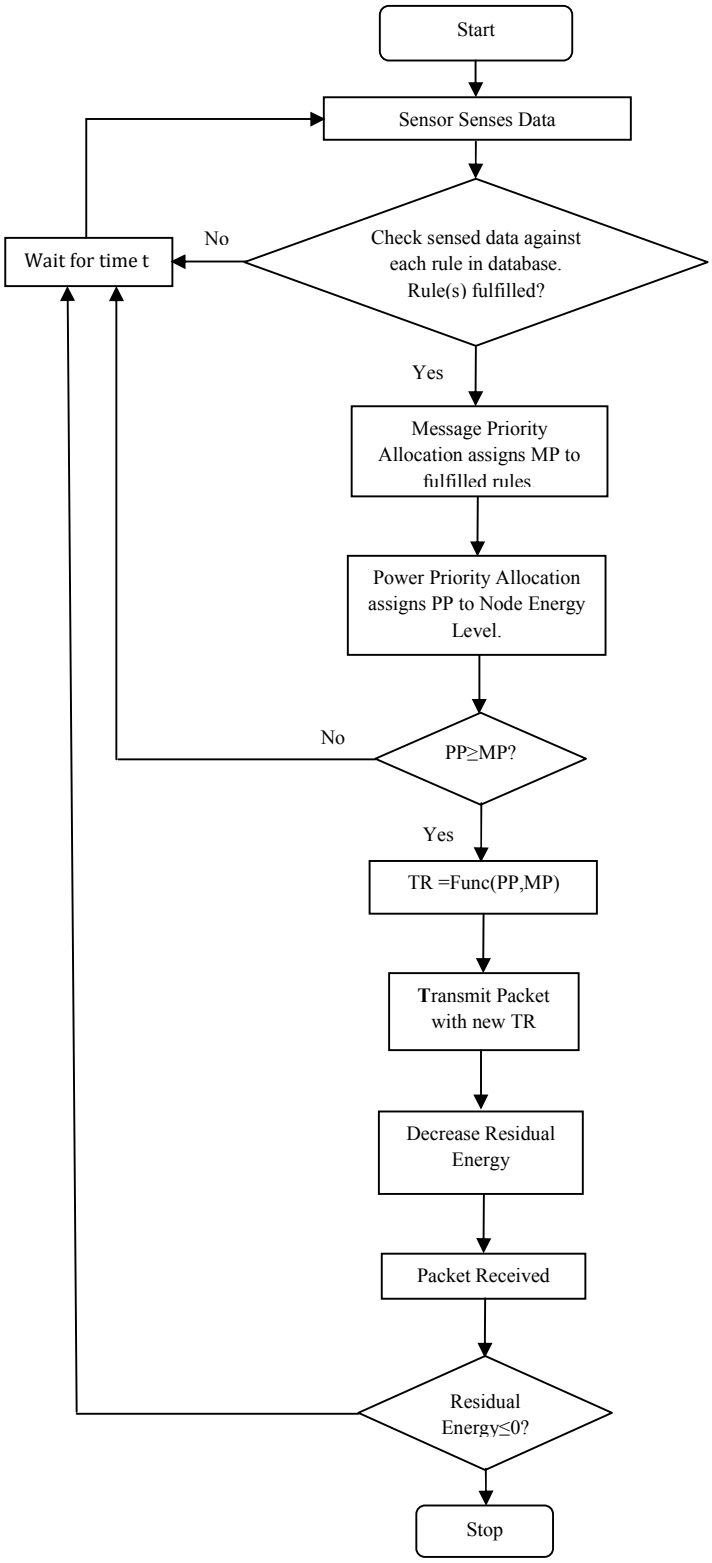


Figure 3.7 Proposed AIRT Flowchart

3.5 Discussion and Summery

This chapter has managed to describe the energy-aware, information-aware and transmission range-aware theme of this thesis research via the introduction of AIRT technique. AIRT technique is broken in to three parts (RMR, IDEALS, and TRA) that perform separate operations, each of them could be modified or used as a whole for further research on this topic. AIRT is a technique that extends the lifetime of a WSN by ignoring low important packets and adjusting of nodes communication range, which it is believed that based on this thesis research has never been considered before. This is achieved through the union on information control (by RMR), energy management (by IDEALS) and transmission range control (by TRA). Considering the fact that no realistic scenario can be 100% efficient, the AIRT scheme proposed in the thesis has quite a number of packet loss (sensed data not matching any of the defined rules may be dropped, battery life less than packet priority and during the propagation of packet in the network). Since a WSN is application dependant, the AIRT technique proposed in this thesis research is suitable for applications wherein events must be of different importance (it is not suitable for applications that all events are of equal importance). So it is suggested that AIRT or the operations (RMR, IDEALS and TRA) inside it should be modified to suit a given application.

AIRT has the advantage of low complexity and low cost because complex mathematical operations are not performed; it performs only comparisons and increment operations which are known to be of low cost. Chapter 4 presents the evaluation of AIRT through simulation.

Chapter 4

PERFORMANCE STUDY

Chapter 3 presented a discussion of the AIRT scheme, which is an energy-aware, information-aware and transmission range algorithm for WSNs. This chapter presents the evaluation of the AIRT scheme by simulation using the C Programming Language to show its advantages. The AIRT technique is evaluated based on two performance measures (network lifetime and connectivity) and it is compared with other related energy saving techniques. The simulation results show a considerable advantage of AIRT over other related energy saving schemes.

4.1 Simulation Setup

The simulation was performed using 20 sensor nodes in a network size of 70*70 meters. Each of the sensor nodes has the same maximum communication range of 20 meters. A predefined node placement topology has been considered in this implementation. A snap shot of the network under simulation is shown in Figure 4.1. The round dark dots correspond to sensor nodes and the links amongst them correspond to the distance of communication (less than equal to 20meters) [31]. At the beginning of the simulation, all sensor nodes have identical initial energy of 100 Joules [31], the equation for energy required to transmit a packet is shown in (1). The simulation parameters are given in Table 4.1.

$$E_{tx}(l,d) = E_{elec}l + E_{amp}ld^2 \text{ [31].} \quad (1)$$

where E_{elec}[J] is the energy required for the circuitry to transmit or receive a single bit, E_{amp}[J] is the energy required for the transmit amplifier to transmit a single bit a distance of one meter, d is the separation distance in meters and l is the length of the packet.

When the simulation program is executed, it is assumed that all nodes perform the AIRT algorithm, sensed information in their environment is propagated into the network using multi-hop routing. Packet flooding is an algorithm whereby a sensor node broadcasts sensed information to all its neighboring sensor nodes until the information gets to the receiver node. The Flooding algorithm is often used in WSNs due to its simplicity in implementation and suitability for different network sizes.

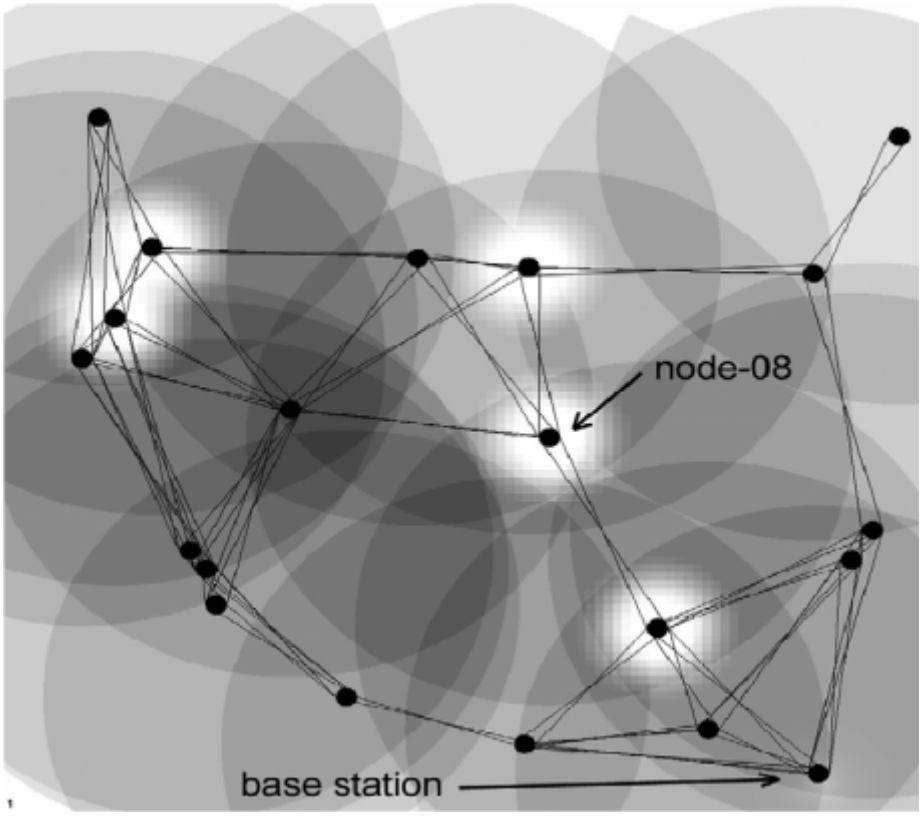


Figure 4.1 A snap shot of a predefined node placement used in the simulation.

Table 4.1 Simulation parameters.

Simulation area	70×70 meters
Number of nodes	20 nodes
Packet length	1000 bits
Initial node energy	100 Joules
Simulated Node Id	Node - 08
Minimum transmission range	13.04 meters
Maximum transmission range	20 meters
Simulated node Coordinates	(x = 38 , y = 37)
Waiting time 't'	5 minutes

WSN are usually placed randomly for many applications; however there are some applications where the placement can be predefined. Our proposed AIRT scheme is suitable for such predefined applications.

4.2 Simulation of AIRT algorithm

The simulation program works as follows:

First, the user has to create a file, and provide the coordinates of sensors in it; the program then outputs (sending node id, its coordinates, the node ids within its maximum transmission range and their distance to the sending node), for all sensor coordinates provided. The distances to each and every one of the sensor nodes which are found within the maximum communication range of a sending sensor node is determined using the distance formula (2).

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad [32]. \tag{2}$$

Only one sensor node is now chosen for the simulation as the remaining sensor nodes are assumed to operate the same way. The chosen sensor node's id and the distance to its closest sensor node are given as inputs. The sensor node senses data and our

AIRT algorithm is performed as illustrated in Figure 4.2. Since the maximum transmission range (TR5) is fixed for every sensor node, five different transmission ranges are easily calculated by taking into consideration the minimum transmission range (TR1) as the distance to the nearest sensor node in the sending node's maximum transmission range. So the ranges between TR1 to TR5 are calculated successively by adding $\Delta TR = (TR5-TR1)/4$. That is, $TR(i) = TR(i-1) + \Delta TR$, for $i=2, 3, 4$. For example, adding ΔTR to TR1 gives TR2, and so on. The reason we took TR1 as the distance to the closest sensor node in the sending node's maximum transmission range is because it covers at least one sensor node, so that in the worst case (PP1), we still have network connectivity (packets can be delivered to the sink node).

Every single node except the sink node (final destination of packets), performs multi-hop routing of packets by using the flooding algorithm. Our program is dynamic in the sense that different, coordinates from the ones used in our simulation can be entered and any node can be chosen for the simulation. Figure 4.1 shows a snap shot of predefined node placement used in the simulation. Circles represent the maximum transmission range of sensors and lines represent probable communication link [31]. We chose node-8 as it's located in the middle. We assumed messages are transmitted every 5 minutes due to application independence of sensor nodes.

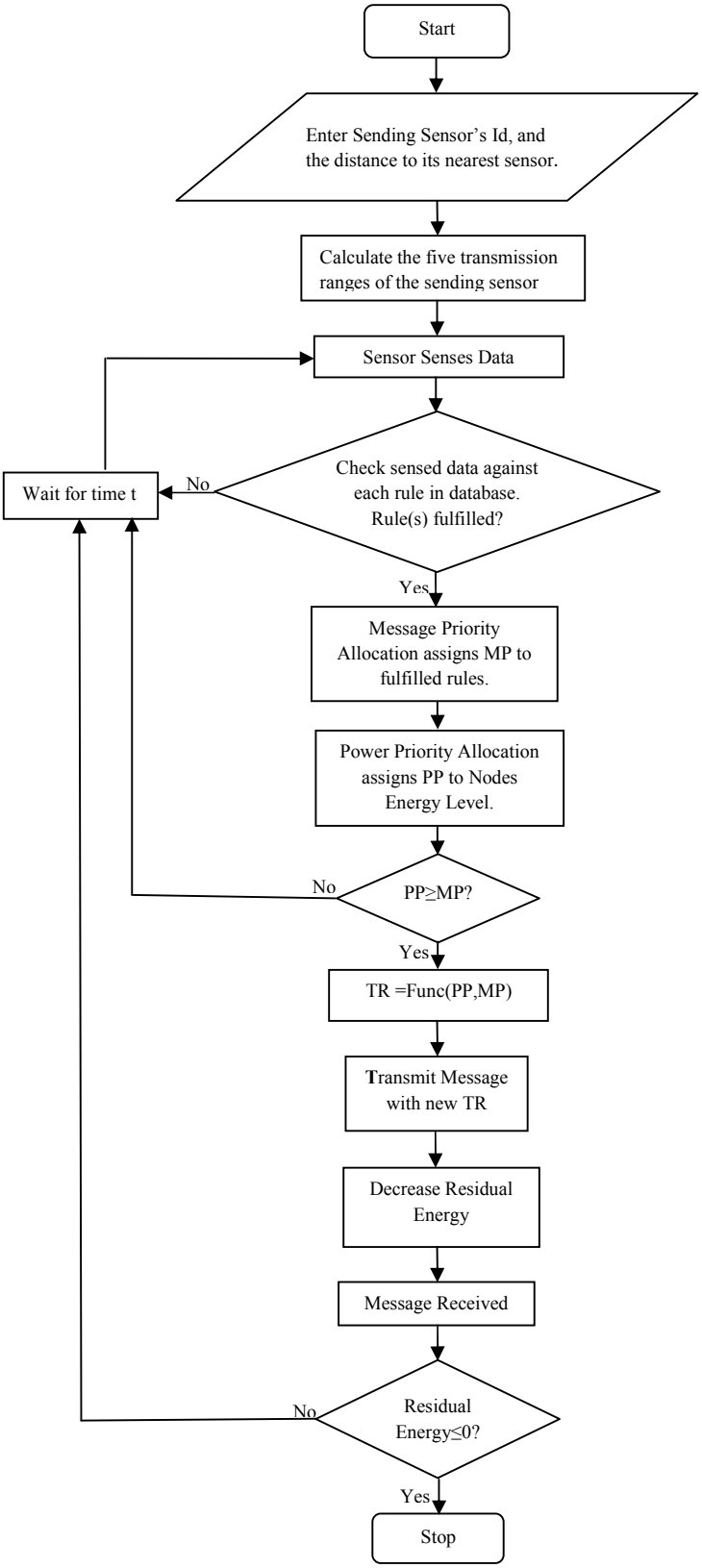


Figure 4.2: Flowchart of AIRT simulation

4.3 Simulation results

The simulation results show the magnitude of the extension of network life time that is made possible through the use of our proposed AIRT system. Four different simulations were conducted and for each simulation, two performance metrics (nodes energy depletion times and network connectivity) are recorded and compared to show the advantage of AIRT over other schemes which are:

(a) Traditional [31]

(b) IDEALS/RMR [31]

(c) IRT [41]

(d) AIRT

(1) *Node Energy Depletion Times*: Figure 4.3 shows graphs of node-8 energy depletion times for all the four simulations. Appendix A.1 contains the numerical simulation results. In the figure, '100' corresponds to a sensor node with full node battery life, while '0' corresponds to a sensor node with completely exhausted battery life. . For the traditional scheme, node-8 depleted its energy reserve after around 9h, this is because it is transmitting messages regularly every 5 minutes, and it does not take into account the its energy reserve level and message importance. For the IDEALS|RMR scheme, it can be seen that the nodes energy level drops suddenly, this is because the node has high energy reserve and it is transmitting every message that comes to it. The energy level then remains constant for a while because of less importance messages which are not transmitted. For the IRT scheme, the energy level drops and then remains constant because the IDEALS|RMR scheme is embedded inside IRT. However, the network lifetime increased almost twice that of the IDEALS|RMR due to the adjustment of

transmission ranges based on the nodes energy reserve level. Finally, for the AIRT scheme, the same process of sudden dropping of energy level and then remaining constant occurs. However, the network lifetime is significantly enhanced compared to all other three schemes. The achieved improvements of the AIRT scheme over traditional, IDEALS|RMR, and IRT schemes are 720%, 135%, and 33% respectively. This is due to the fact that nodes are adapting their transmission ranges based on their energy reserve level and message importance.

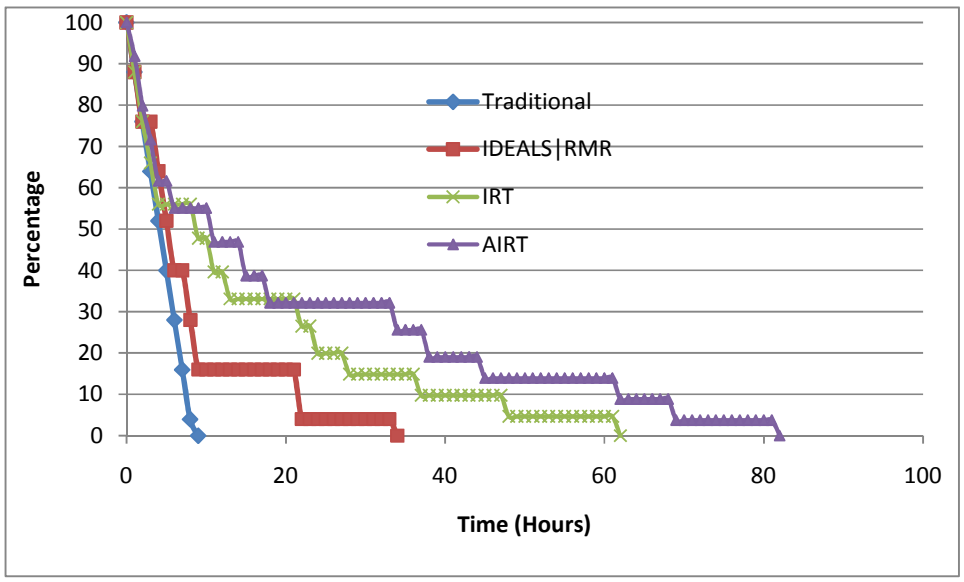


Figure 4.3 Node energy depletion times.

Additionally, it can be seen from Figure 4.3 that the number of steps for each scheme differs. For example, in the traditional scheme, no algorithm is applied to it therefore it contains no steps. In the IDEALS/RMR scheme, it can be observed that there are 5 steps in total. This is because the node transmits messages with fixed transmission range. In the IRT scheme, the number of steps increases and it contains 9 steps in total. This is because the node transmit messages with different transmission ranges based its energy level. In the AIRT scheme, the number of steps increases even further therefore containing 10 steps in total. This is because the node adapts a

suitable transmission range based on both the importance of the message and its energy reserve level. We can say for a fact that the number of steps increased with increase in the lifetime of the sensor nodes.

(2) *Network connectivity*: Network connectivity is defined as the measure of the capability of any sensor node in the network to transmit message to the sink node successfully. When all sensor nodes successfully transmit message to the sink node, then the network is 100% connected. However if the network is 50% connected, then only half of the nodes can successfully transmit a message to the sink node [31]. Figure 4.4 shows that the connectivity of the Traditional scheme is completely lost after around 9 hrs. Figure 4.5 shows the connectivity of the IDEALS|RMR scheme. It is clear from the figure that this scheme extends the network lifetime and hence improves the network connectivity. The network lifetime for the most trivial message (MP5) is lost after around 4hrs (therefore no message of MP5 importance can reach the sink node after 4hrs) while it is connected for about 76%. However the network is still around 80% connected for the most important message (MP1) for 34 hrs. This is because the messages are not transmitted every 5 minutes as in the traditional scheme. Figure 4.6 shows the performance of the IRT scheme. As it can be seen from the figure, IRT manages to extend the network lifetime almost twice that of the IDEALS/RMR scheme. This is because of the adjustment of transmission range based on nodes energy level. Additionally, network lifetime for the most trivial message is lost after around 13hrs while it is connected for about 76%. However the network is 79.6% connected for the most important message for 63hrs. Finally, Figure 4.7 shows the connectivity of the proposed AIRT scheme. It is obvious that AIRT scheme outperforms all other schemes as it has the longest network lifetime and maximum connectivity. It is interesting to note that AIRT extends the network

lifetime twice longer that of IDEALS/RMR scheme and a little longer than the IRT scheme for MP5. Despite its lifetime finishes in 83hours, the network is 84.7% connected for most important message MP1. Appendix A.2, A.3, A.4, A.5 shows the tabulated numerical results of the network connectivity of all the four simulations. Table 4.2 shows the percentage improvement of our proposed AIRT scheme over traditional, IDEALS/RMR and IRT schemes in terms of network connectivity for the different types of message priorities. It is important to note that for the most important message (MP1). The AIRT scheme achieved 811%, 141%, and 32% improvement over Traditional, IDEALS/RMR and IRT respectively. Whereas for the least important message (MP5). The scheme achieved 811%, 450%, and 104% improvement over Traditional, IDEALS/RMR and IRT respectively.

Table 4.2 Percentage improvement of AIRT Scheme over all other Schemes in terms of Network Connectivity.

	MP1	MP2	MP3	MP4	MP5
Traditional	811	811	811	811	811
IDEALS/RMR	141	209	375	381	450
IRT	32	45	97	69	104

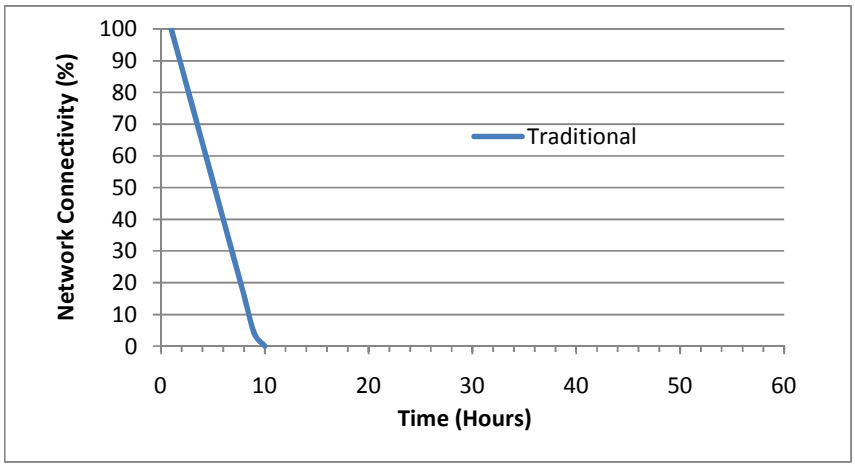


Figure 4.4 Traditional

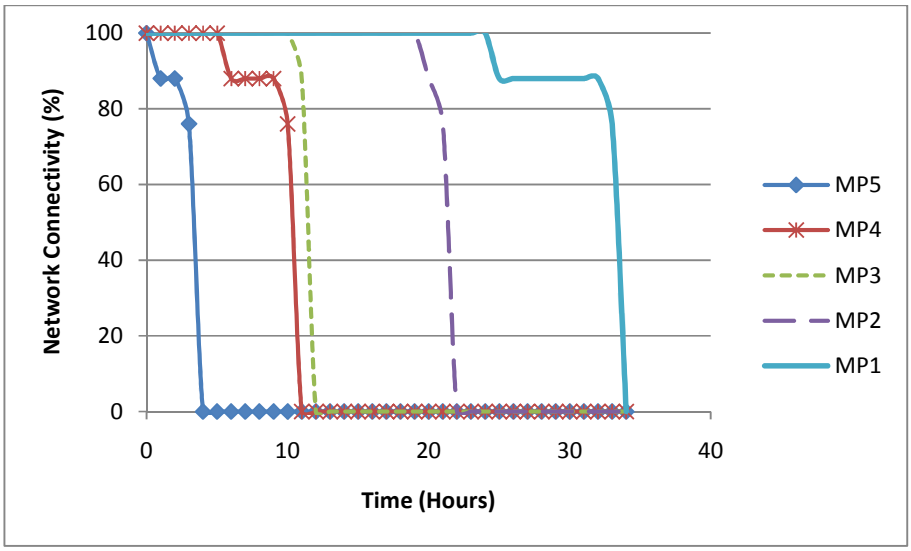


Figure 4.5 IDEALS|RMR

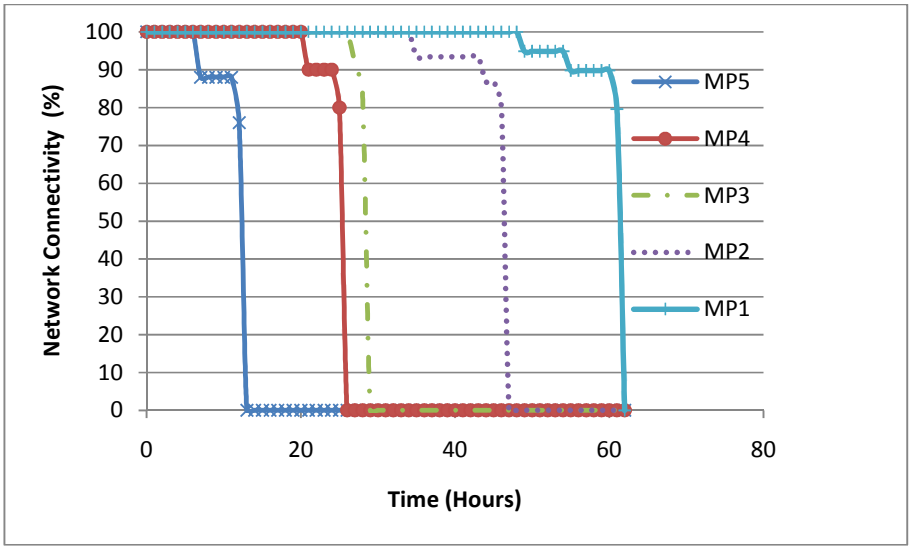


Figure 4.6 IRT

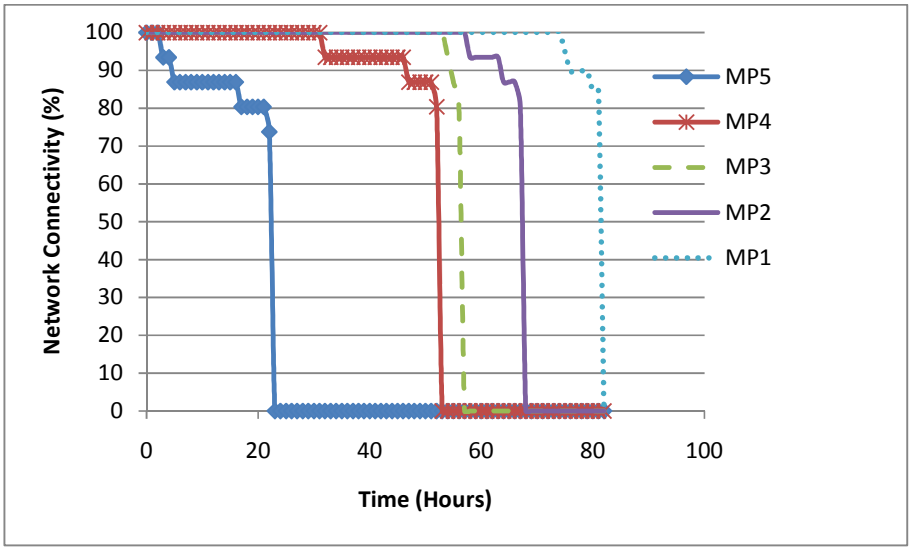


Figure 4.7 AIRT

It is a known fact that there is no scheme, technique, development or invention which is 100% efficient. That is to say that every scheme contains some drawbacks. In our proposed AIRT scheme some drawbacks exists such as propagation time and processing time. Propagation time is the time it takes for a sensor node forward the message to the sink node. Since nodes adapt their transmission ranges based on message importance and energy level, the transmission ranges are constantly changing, which may increase the number of hops needed by the message to reach its destination. However in the other schemes such as Traditional and IDEALS/RMR, their transmission range is always the maximum, therefore allowing nodes to arrive in fewer hops than AIRT scheme. Processing time is the time spent by a message in a particular node. In our AIRT scheme, more processing is needed because a node needs to check its energy reserve and the message importance to decide whether to transmit a message. After it decides to transmit, it adapts a suitable transmission range based on its energy level and message importance. However in the other schemes, they do less processing because they do not take into account message

importance and energy level to decide whether to transmit a message and the range to transmit the message with.

4.4 Discussion

This chapter has presented the simulation algorithm for the AIRT scheme proposed in this thesis. It provides the simulation results of a WSN environment using the AIRT scheme and compares these results to other similar energy saving schemes. It is seen that traditional case which did not use any power saving method, had the shortest lifetime. When the IDEALS/RMR scheme was simulated, it showed a considerable extension in network lifetime by extending the lifetime of high priority messages and ignoring low priority messages. Similarly, IRT and AIRT which show a considerable increase in network lifetime compared to IDEALDS/RMR extend their lifetime by dropping low priority messages and extending lifetime of high priority messages. The difference between IRT and AIRT is that the former adjusts it transmission range based on nodes energy resource only, while the later extends it based on energy resource and message importance. For that reason, AIRT is seen as the best power saving technique compared to other three techniques as was illustrated in the simulation results. The complete source codes of all the four energy management schemes were provided in appendix B.

Chapter 5

CONCLUSIONS

In the introductory chapters of this thesis, the background information of a WSN was discussed whereby a WSN was defined as a network which comprise of large number of tiny sensor nodes which are deployed in close proximity to each other so as to sense information in an environment and communicate this sensed information wirelessly using multi-hop routing to the sink node. WSNs are suited for wide range of applications and therefore receiving great research interest in academic, industrial and the commercial. One of the greatest challenges in WSN is how to improve the network lifetime. For that reason, this thesis research among many ongoing researches developed a technique to increase the lifetime of a WSN. The increase in network lifetime was possible through the combination of energy-aware, information-aware and transmission range adjustment operations. The energy saving technique proposed in this thesis was simulated with other related energy saving techniques from other researchers using C Programming, and the proposed energy saving technique for this thesis showed a considerable increase in network lifetime compared to that of other researchers.

Chapter 3 investigated the energy-aware, information-aware and transmission range adjustment operations theme of this thesis via the proposal of AIRT technique. AIRT is a technique that offers significant energy savings and extends the network lifetime by adjustment of node transmission ranges and ignoring information of low

importance. The extension in network life was possible through the combination of RMR (for controlling information sensing), IDEAL (for controlling information propagation) and TRA (adjusting of communication range).

Chapter 4 presents the simulation results obtained using C Programming Language to evaluate the proposed AIRT algorithm of this thesis. The results show a considerable increase in network lifetime of high importance messages compared to similar researches of other researchers. Besides extending the network lifetime which was the primary goal of this thesis, network connectivity was also enhanced compared to that of other researchers.

This thesis has highlighted the benefit of combining various power saving techniques (such as information control, energy control and transmission range control) to improve network lifetime.

The most important finding in this thesis is the development of the AIRT scheme. It is important to note that for the node energy depletion time performance metric. The achieved improvements of the AIRT scheme over traditional, IDEALS|RMR, and IRT schemes are 720%, 135%, and 33% respectively. Additionally, for the network connectivity performance metric. The AIRT scheme achieved 811%, 141%, and 32% improvement over Traditional, IDEALS/RMR, and IRT schemes respectively for the most important message (MP1). Whereas the scheme achieved 811%, 450%, and 104% improvement over Traditional, IDEALS/RMR and IRT respectively for the least important message (MP5). This advantage of the AIRT scheme over other related energy saving schemes is due to the fact that nodes are adapting their transmission ranges based on their energy reserve level and message importance.

Despite the achieved improvements of our proposed AIRT scheme, the scheme does not escape from some drawbacks such as propagation time, and processing time.
The drawbacks mentioned do not have much effect on our scheme. This is because our scheme is intended for networks with few number of sensor nodes, as wireless sensor networks are application dependant.

Using the AIRT scheme proposed and simulated in this thesis a considerable increase in network lifetime and connectivity is achieved. For that reason, the research aims mentioned in section 1.1 were successfully fulfilled.

Future works

As WSNs are continuously been popular, the need for further research is to extend the network lifetime is required. Example of possible further research could be:

- To use RMR, IDEALS and TRA operations separately in other researches in other to improve the network lifetime.
- The AIRT could be employed to use the forth power saving technique which is the duty cycle operation (alternating between sleep and active mode) to extend the network lifetime.
- Fuzzy logic may be added to the RMR operation of AIRT in deciding the importance of a message.
- Weights can be given to message types and
- Studying of more than five levels may be considered.

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APPENDIX

Appendix A: Simulation Raw Data

Table A.1 Energy depletion times of Traditional, IDEALS/RMR, IRT and AIRT simulations

Time (Hours)	Traditional (Joules)	IDEALS/RMR (Joules)	IRT (Joules)	AIRT (Joules)
0	100	100	100	100
1	88	87.999702	87.999702	91.813179
2	76	75.999405	75.999405	79.812881
3	64	75.999405	65.996712	71.62606
4	52	63.999104	55.994019	61.623367
5	39.99	51.998802	55.994019	61.623367
6	27.99	39.998501	55.994019	55.070675
7	15.99	39.998501	55.994019	55.070675
8	3.99	27.998201	55.994019	55.070675
9	0	15.997901	47.807198	55.070374
10		15.997901	47.807198	55.070374
11		15.997901	39.620377	46.883553
12		15.997901	39.620377	46.883251
13		15.997901	33.067684	46.88295
14		15.997901	33.067684	46.882648
15		15.997901	33.067684	38.695827
16		15.997901	33.067684	38.695827
17		15.997901	33.067684	38.695827
18		15.997901	33.067684	32.143135
19		15.997901	33.067684	32.143135
20		15.997901	33.067684	32.143135
21		15.997901	33.067684	32.143135
22		3.997601	26.514994	32.143135
23		3.997601	26.514994	32.143135
24		3.997601	19.962303	32.143135
25		3.997601	19.962303	32.143135
26		3.997601	19.962303	32.143135
27		3.997601	19.962303	32.143135
28		3.997601	14.862002	32.143135
29		3.997601	14.862002	32.143135
30		3.997601	14.862002	32.143135
31		3.997601	14.862002	32.143135
32		3.997601	14.862002	32.143135
33		3.997601	14.862002	32.143135

Table A.1 (continued) Energy depletion times of Traditional, IDEALS/RMR, IRT and AIRT simulations

34		0	14.862002	25.590445
35			14.862002	25.590445
36			14.862002	25.590445
37			9.761702	25.590445
38			9.761702	19.037754
39			9.761702	19.037754
40			9.761702	19.037754
41			9.761702	19.037754
42			9.761702	19.037754
43			9.761702	19.037754
44			9.761702	19.037754
45			9.761702	13.937453
46			9.761702	13.937453
47			9.761702	13.937453
48			4.661401	13.937453
49			4.661401	13.937453
50			4.661401	13.937453
51			4.661401	13.937453
52			4.661401	13.937453
53			4.661401	13.937453
54			4.661401	13.937453
55			4.661401	13.937453
56			4.661401	13.937453
57			4.661401	13.937453
58			4.661401	13.937453
59			4.661401	13.937453
60			4.661401	13.937453
61			4.661401	13.937453
62			0	8.837152
63				8.837152
64				8.837152
65				8.837152
66				8.837152
67				8.837152
68				8.837152

Table A.1 (continued) Energy depletion times of Traditional, IDEALS/RMR, IRT and AIRT simulations

69				3.736852
70				3.736852
71				3.736852
72				3.736852
73				3.736852
74				3.736852
75				3.736852
76				3.736852
77				3.736852
78				3.736852
79				3.736852
80				3.736852
81				3.736852
82				0

Table A.2 Network connectivity for Traditional simulation

Time (Hours)	**Traditional (Joules)**
0	100
1	88
2	76
3	64
4	52
5	39.99
6	27.99
7	15.99
8	3.99
9	0

Table A.3 Network connectivity for IDEALS/RMR simulation

Time (Hour)	MP5	MP4	MP3	MP2	MP1
0	100	100	100	100	100
1	87.999702	100	100	100	100
2	87.999702	100	100	100	100
3	75.999405	100	100	100	100
4	0	100	100	100	100
5	0	100	100	100	100
6	0	87.999702	100	100	100
7	0	87.999702	100	100	100
8	0	87.999702	100	100	100
9	0	87.999702	100	100	100
10	0	75.999405	100	100	100
11	0	0	87.999702	100	100
12	0	0	0	100	100
13	0	0	0	100	100
14	0	0	0	100	100
15	0	0	0	100	100
16	0	0	0	100	100
17	0	0	0	100	100
18	0	0	0	100	100
19	0	0	0	100	100
20	0	0	0	87.999702	100
21	0	0	0	75.999405	100
22	0	0	0	0	100
23	0	0	0	0	100
24	0	0	0	0	100
25	0	0	0	0	87.999702
26	0	0	0	0	87.999702
27	0	0	0	0	87.999702
28	0	0	0	0	87.999702
29	0	0	0	0	87.999702
30	0	0	0	0	87.999702
31	0	0	0	0	87.999702
32	0	0	0	0	87.999702
33	0	0	0	0	75.999405
34	0	0	0	0	0

Table A.4 Network connectivity for IRT simulation

Time (Hour)	MP5	MP4	MP3	MP2	MP1
0	100	100	100	100	100
1	100	100	100	100	100
2	100	100	100	100	100
3	100	100	100	100	100
4	100	100	100	100	100
5	100	100	100	100	100
6	100	100	100	100	100
7	87.999702	100	100	100	100
8	87.999702	100	100	100	100
9	87.999702	100	100	100	100
10	87.999702	100	100	100	100
11	87.999702	100	100	100	100
12	75.999405	100	100	100	100
13	0	100	100	100	100
14	0	100	100	100	100
15	0	100	100	100	100
16	0	100	100	100	100
17	0	100	100	100	100
18	0	100	100	100	100
19	0	100	100	100	100
20	0	100	100	100	100
21	0	89.997307	100	100	100
22	0	89.997307	100	100	100
23	0	89.997307	100	100	100
24	0	89.997307	100	100	100
25	0	79.994614	100	100	100
26	0	0	100	100	100
27	0	0	91.813179	100	100
28	0	0	83.626358	100	100
29	0	0	0	100	100
30	0	0	0	100	100
31	0	0	0	100	100
32	0	0	0	100	100
33	0	0	0	100	100
34	0	0	0	100	100
35	0	0	0	93.447311	100

Table A.4 (continue) Network connectivity for IRT simulation

36	0	0	0	93.447311	100
37	0	0	0	93.447311	100
38	0	0	0	93.447311	100
39	0	0	0	93.447311	100
40	0	0	0	93.447311	100
41	0	0	0	93.447311	100
42	0	0	0	93.447311	100
43	0	0	0	93.447311	100
44	0	0	0	86.894623	100
45	0	0	0	86.894623	100
46	0	0	0	80.341934	100
47	0	0	0	0	100
48	0	0	0	0	100
49	0	0	0	0	94.899696
50	0	0	0	0	94.899696
51	0	0	0	0	94.899696
52	0	0	0	0	94.899696
53	0	0	0	0	94.899696
54	0	0	0	0	94.899696
55	0	0	0	0	89.799393
56	0	0	0	0	89.799393
57	0	0	0	0	89.799393
58	0	0	0	0	89.799393
59	0	0	0	0	89.799393
60	0	0	0	0	89.799393
61	0	0	0	0	79.598785
62	0	0	0	0	0

Table A.5 Network connectivity for AIRT simulation

Time (Hour)	**MP5**	**MP4**	**MP3**	**MP2**	**MP1**
0	100	100	100	100	100
1	100	100	100	100	100
2	100	100	100	100	100
3	93.447372	100	100	100	100
4	93.447372	100	100	100	100
5	86.894745	100	100	100	100
6	86.894745	100	100	100	100
7	86.894745	100	100	100	100

Table A.5 (continue) Network connectivity for AIRT simulation

8	86.894745	100	100	100	100
9	86.894745	100	100	100	100
10	86.894745	100	100	100	100
11	86.894745	100	100	100	100
12	86.894745	100	100	100	100
13	86.894745	100	100	100	100
14	86.894745	100	100	100	100
15	86.894745	100	100	100	100
16	86.894745	100	100	100	100
17	80.342117	100	100	100	100
18	80.342117	100	100	100	100
19	80.342117	100	100	100	100
20	80.342117	100	100	100	100
21	80.342117	100	100	100	100
22	73.78949	100	100	100	100
23	0	100	100	100	100
24	0	100	100	100	100
25	0	100	100	100	100
26	0	100	100	100	100
27	0	100	100	100	100
28	0	100	100	100	100
29	0	100	100	100	100
30	0	100	100	100	100
31	0	100	100	100	100
32	0	93.447372	100	100	100
33	0	93.447372	100	100	100
34	0	93.447372	100	100	100
35	0	93.447372	100	100	100
36	0	93.447372	100	100	100
37	0	93.447372	100	100	100
38	0	93.447372	100	100	100
39	0	93.447372	100	100	100
40	0	93.447372	100	100	100
41	0	93.447372	100	100	100
42	0	93.447372	100	100	100
43	0	93.447372	100	100	100
44	0	93.447372	100	100	100
45	0	93.447372	100	100	100
46	0	93.447372	100	100	100
47	0	86.894745	100	100	100

Table A.5 (continue) Network connectivity for AIRT simulation

48	0	86.894745	100	100	100
49	0	86.894745	100	100	100
50	0	86.894745	100	100	100
51	0	86.894745	100	100	100
52	0	80.342117	100	100	100
53	0	0	100	100	100
54	0	0	93.447372	100	100
55	0	0	86.894745	100	100
56	0	0	80.342117	100	100
57	0	0	0	100	100
58	0	0	0	93.447372	100
59	0	0	0	93.447372	100
60	0	0	0	93.447372	100
61	0	0	0	93.447372	100
62	0	0	0	93.447372	100
63	0	0	0	93.447372	100
64	0	0	0	86.894745	100
65	0	0	0	86.894745	100
66	0	0	0	86.894745	100
67	0	0	0	80.342117	100
68	0	0	0	0	100
69	0	0	0	0	100
70	0	0	0	0	100
71	0	0	0	0	100
72	0	0	0	0	100
73	0	0	0	0	100
74	0	0	0	0	100
75	0	0	0	0	94.89978
76	0	0	0	0	89.799561
77	0	0	0	0	89.799561
78	0	0	0	0	89.799561
79	0	0	0	0	89.799561
80	0	0	0	0	84.699341
81	0	0	0	0	84.699341
82	0	0	0	0	0

Appendix B: Source Codes which are used in the performance measurement

Source Code for Energy Depletion Times simulation of Traditional algorithm

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```
/* The coordinates of all the sensor nodes must be saved in a file*/
#include<stdio.h>
#include<stdlib.h>
#include<time.h>

#define SENS 20 /* the number of nodes */
#define RADIUS 20 /* radius of each node */
#define GEN 9 /* number of generations */

struct Sensor{

        int id;             /* identity of this sensor */
        double battery;  /* the energy of this sensor, i.e. 100 J*/
        int x_coord,y_coord;    /* x and y coordinates of this sensor */
        int reachable_sensors[SENS - 1];    /* the maximum number of nodes that are
                                               in radius of this sensor */
        int data;       /* information that is sensed by this sensor */
        int sent;       /* whether information was sent by this sensor */
        double transmission_range[SENS - 1];
};
#include "init.h" /* containing functions for initializing the sensors nodes with */
                  /* coordinates and finding sensor nodes in the 20meters radius */
#include "send_data.h" /* contains a function for sending sensed data */
```

```
int main(void)
{
        struct Sensor sensors[SENS];
        int i,j, count,l;

        FILE *fp1;
        FILE *fp2;
        double save[SENS][GEN]; /* 20 here is the value in while loop, can be less*/
                                        /*or more and so on...*/
for(i = 0; i < SENS; i++)
{
        sensors[i].id = i+1;
        sensors[i].sent = 0;
        sensors[i].battery = 100;
        for(j = 0; j < SENS-1; j++)
                sensors[i].reachable_sensors[j] = 0;
}
for(i = 0; i < SENS; i++)
        for(j = 0; j < GEN; j++)
                save[i][j]=101;
/*initialize the coordinates of sensors(nodes) and then*/
/*find out the sensors that are in radius to send*/
initialize_coord(sensors);
/*print to see*/
/*printf("Sensors in each sensors transmission range\n",)*/
for(i = 0; i < SENS; i++)
{
        printf("%d %d %d :   ",sensors[i].id, sensors[i].x_coord,sensors[i].y_coord);
        //getch();
        for(j = 0; j < SENS-1; j++)
```

```
                if(sensors[i].reachable_sensors[j] != 0)
                        {
            printf("\t%d",sensors[i].reachable_sensors[j]);
            printf(" = %f,",sensors[i].transmission_range[j]);
            /*getch();*/
            }
                else
                {
                        printf("\n\n");
                        break;
                }
}
getch();
fp2 = fopen("sensors_with_distances.txt","w");
            if(fp2 == NULL)
            {
                printf("Error in opening file...\n");
                exit(1);
            }
            for(i = 0; i < SENS; i++)
            {
            fprintf(fp2,"%d%d%d: ",sensors[i].id,sensors[i].x_coord,sensors[i].y_coord);
             getch();
            for(j = 0; j < SENS-1; j++)
                if(sensors[i].reachable_sensors[j] != 0)
                        {
             fprintf(fp2,"  %d",sensors[i].reachable_sensors[j]);
             fprintf(fp2," = %f,",sensors[i].transmission_range[j]);
                         getch();
```

```
        }
                else
                {
                        fprintf(fp2,"\n\n");
                        break;
                }
}
fclose(fp2);
/*generate random data*/
fp1 = fopen("TRADITIONAL-CASE-RESULTS.txt","w");
        if(fp1 == NULL)
        {
                printf("Error in opening file...\n");
                exit(1);
        }
count = 0;
srand(time(NULL));
while (count<GEN)
{
for(i=0;i<SENS;i++)
{
        if(sensors[i].battery>0)
        {
                sensors[i].data = 25+rand()%50;
        send_data(sensors,sensors[i].id,sensors[i].data);
        }
for(l=0;l<SENS;l++)
sensors[l].sent = 0;
        for(l=0;l<SENS;l++)
```

```
        save[l][count] = sensors[l].battery;
}
count++;
}
for(i=0;i<SENS;i++)
{
        if(save[i][0] != 101.0)
        {
                fprintf(fp1,"100\t");
                for(j=0;j<GEN;j++)
                fprintf(fp1,"%.2lf\t",save[i][j]);
                fprintf(fp1,"\n");
        }
}
        fclose(fp1);
for(i=0;i<SENS;i++)
{
        {
                printf("100\t");
                for(j=0;j<GEN;j++)
                printf("%.2lf\t",save[i][j]);
                printf("\n");
        }
}
getch();
return 0;
}
```

/**********Init.h header file**********/

```
#include<math.h>
void find_in_radius(struct Sensor ss[SENS]);
void initialize_coord(struct Sensor s[SENS]) /*creating a structure of 20 sensors*/
{
        char c,c1;
        int i;
        FILE *fp;
        fp = fopen("coordinates.txt","r");
        if(fp == NULL)
        {
                printf("Error in opening file...\n");
                exit(1);
        }
        for(i=0;i<SENS;i++)
        {
        fscanf(fp,"%d%c%d%c",&s[i].x_coord,&c,&s[i].y_coord,&c1                    );
        /*intializing each of the sensors with the values in*/
        }
        fclose(fp);
        find_in_radius(s);
}
void find_in_radius(struct Sensor ss[SENS])
{       int i,j,k,p;
        int x1,y1,x2,y2,d;
        double distance;
        for(i = 0; i < SENS; i++)
        {
                k = 0;
                p = 0;
                x1 = ss[i].x_coord;
```

```
                y1 = ss[i].y_coord;
                for(j = 0; j < SENS; j++)
                {
                        if(j==i) continue;
                        x2 = ss[j].x_coord;
                        y2 = ss[j].y_coord;
                        d = (x2-x1)*(x2-x1) + (y2-y1)*(y2-y1);
                        distance = sqrt(d);
                        if( distance <= RADIUS )
                        {
                                ss[i].reachable_sensors[k++] = ss[j].id;
                                ss[i].transmission_range[p++] = distance;
        }
            }
    }
}
```

/********send_data.h header file**********/**

```
#include<math.h>
int Received = 0;
void send_data(struct Sensor s[SENS],int id, int data)
{
        static int value = 0;
        int j;
if(s[id-1].battery>0)
{
        s[id-1].battery -= 0.0000003*1000 + 0.00003*1000*pow(RADIUS,2);
        s[id-1].sent = 1;
        for(j=0;j<SENS-1;j++)
        {
                if(s[id-1].reachable_sensors[j]!=0)
                {
                s[s[id-1].reachable_sensors[j]-1].battery -= 0.0000003*1000;
                s[s[id-1].reachable_sensors[j]-1].data = data;
                if(s[s[id-1].reachable_sensors[j]-1].id == 20)//if sink node received
                                                              //the data...
                {
                Received = 1;
                break;
                }
                }
                }
}
if(Received == 0)
for(j=0;j<SENS-1;j++)
{
if(s[id-1].reachable_sensors[j]!=0 && s[id-1].sent != 1)
send_data(s, s[id-1].reachable_sensors[j], s[s[id-1].reachable_sensors[j]-1].data);
```

```
}
else
Received = 0;
}
```

//Source Codes for IREALS/RMR algorithm

```
//By, Abdullahi Ibrahim Abdu
/*****Energy depletion time source code for IDEALS/RMR algorithm******/
#include<stdio.h>
#include<stdlib.h>
#include<conio.h>
#include<time.h>
#include<math.h>
#define SENS 1
#define RADIUS 20
#define MAX 5
#define GEN 288
int main(void)
{
   int node_id,PP,MP,TR;
   int cnt = 0,i=0;
   float min_dist,range_interval,tr[MAX];
   float battery = 100.0;
   float battery_buffer[GEN];
   int mp5_sent=0,mp4_sent=0,mp3_sent=0,mp2_sent=0,mp1_sent=0;
   int mp5_lost=0,mp4_lost=0,mp3_lost=0,mp2_lost=0,mp1_lost=0;

   FILE *fp;
   printf("ENTER SENSOR NODE ID: ");
   scanf("%d",&node_id);
   printf("\n");

            for(int w=0;w<GEN;w++)
                  battery_buffer[w]=0;
             srand(time(NULL));
```

```
while(battery>=0.0)
{
  MP = 1+rand()%5;
  if((battery<=100.0)&&(battery>=80.0))
  {
   PP=5;
   if(MP==5) mp5_sent++;
   if(MP==4) mp4_sent++;
   if(MP==3) mp3_sent++;
   if(MP==2) mp2_sent++;
   if(MP==1) mp1_sent++;
   if(PP>=MP)
   {
     battery-= 0.0000003*1000 + 0.00003*1000*pow(RADIUS,2);
      battery_buffer[i] = battery;
       cnt++;
        i++;
        continue;
   }
   }
   if((battery<=80.0)&&(battery>=60.0))
   {
   PP=4;
   if(MP==5) mp5_lost++;
   if(MP==4) mp4_sent++;
   if(MP==3) mp3_sent++;
   if(MP==2) mp2_sent++;
   if(MP==1) mp1_sent++;
   if(PP>=MP)
```

```
{
  battery-= 0.0000003*1000 + 0.00003*1000*pow(RADIUS,2);
    battery_buffer[i] = battery;
     cnt++;
     i++;
     continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=60.0)&&(battery>=40.0))
{
PP=3;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_sent++;
if(MP==2) mp2_sent++;
if(MP==1) mp1_sent++;
if(PP>=MP)
{
  battery-= 0.0000003*1000 + 0.00003*1000*pow(RADIUS,2);
  battery_buffer[i] = battery;
   cnt++;
   i++;
   continue;
}
battery_buffer[i] = battery;
```

```
cnt++;
i++;
continue;
}
if((battery<=40.0)&&(battery>=20.0))
{
PP=2;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_lost++;
if(MP==2) mp2_sent++;
if(MP==1) mp1_sent++;
if(PP>=MP)
{
  battery-= 0.0000003*1000 + 0.00003*1000*pow(RADIUS,2);
   battery_buffer[i] = battery;
   cnt++;
    i++;
    continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=20.0)&&(battery>=1.0))
{
PP=1;
if(MP==5) mp5_lost++;
```

```
                if(MP==4) mp4_lost++;
                if(MP==3) mp3_lost++;
                if(MP==2) mp2_lost++;
                if(MP==1) mp1_sent++;
                if(PP>=MP)
                {
                 battery-= 0.0000003*1000 + 0.00003*1000*pow(RADIUS,2);
                 battery_buffer[i] = battery;
                 cnt++;
                  i++;
                  continue;
                 }
                 battery_buffer[i] = battery;
                 cnt++;
                 i++;
                continue;
                }
                }
                printf("\n\n");
                for(int p=0;p<cnt;p++)
                printf("battery_buffer %d : %f\n",p+1,battery_buffer[p]);
printf("%d%d%d%d%d\n",mp5_sent,mp4_sent,mp3_sent,mp2_sent,mp1_sent);
printf("%d%d%d%d %d\n",mp5_lost,mp4_lost,mp3_lost,mp2_lost,mp1_lost);
printf("\n");
getch();
 fp = fopen("IDEAL-RMR-lifetime.txt","w");
 if(fp == NULL)
 {
  printf("Error in opening file...\n");
```

```
        exit(1);
        }
        for(int p=0;p<cnt;p++)
        fprintf(fp,"battery_buffer %d : %f\n",p+1,battery_buffer[p]);
  fprintf(fp,"%d%d%d%d%d\n",mp5_sent,mp4_sent,mp3_sent,mp2_sent,mp1_sent);
  fprintf(fp,"%d %d %d %d %d\n",mp5_lost,mp4_lost,mp3_lost,mp2_lost,mp1_lost);
  fprintf(fp,"\n");
  getch();
  return 0;
}
```

/*****Network connectivity source code for IDEALS/RMR algorithm******/**

```
#include<stdio.h>
#include<stdlib.h>
#include<conio.h>
#include<time.h>
#include<math.h>
#define SENS 1
#define RADIUS 20
#define MAX 5
#define GEN 288
int main(void)
{
   int node_id,PP,MP;
   int cnt = 0,i=0;
   float min_dist,range_interval,tr[MAX];
   float;
battery=100.0,MP_conn=100.0,MP_conn1=100.0,MP_conn2=100.0,MP_conn3=100
.0;
   float TR=0.0;
   float
MP5_conn[GEN],MP4_conn[GEN],MP3_conn[GEN],MP2_conn[GEN],MP1_conn[
GEN];
   FILE *fp;
   printf("ENTER SENSOR ID: ");
   scanf("%d",&node_id);
   printf("\n");
   printf("ENTER THE DISTANCE TO THE CLOSEST REACHABLE SENSOR:
");
   scanf("%f",&min_dist);
   printf("\n");
   range_interval=(RADIUS-min_dist)/4.0;
   printf("Range interval = %f\n",range_interval);
```

```
tr[0]=min_dist;
for(int i=0; i < MAX-1; i++)
        tr[i+1]=tr[i]+range_interval;
        for(int j=0;j<MAX;j++)
                printf("\t%f",tr[j]);
                getch();
                srand(time(NULL));
                while(battery>=0.0)
                {
                 MP = 1+rand()%5;
                 if((battery<=100.0)&&(battery>=80.0))
                 {
                  PP=5;
                  TR=tr[4];
                  if((PP>=MP)&&(MP==5))
                  {
                    battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
                       MP5_conn[i]=battery;
                       MP4_conn[i]=100.0;
                       MP3_conn[i]=100.0;
                       MP2_conn[i]=100.0;
                       MP1_conn[i]=100.0;
                       cnt++;
                       i++;
                       continue;
                  }
                  MP5_conn[i]=battery;
                  MP4_conn[i]=100.0;
                  MP3_conn[i]=100.0;
```

```
MP2_conn[i]=100.0;
MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
if((battery<=80.0)&&(battery>=60.0))
{
PP=4;
TR=tr[3];
if((PP>=MP)&&(MP==4))
{
  battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=MP_conn;
    MP3_conn[i]=100.0;
    MP2_conn[i]=100.0;
    MP1_conn[i]=100.0;
    cnt++;
    i++;
    continue;
}
MP5_conn[i]=0.0;
MP4_conn[i]=MP_conn;
MP3_conn[i]=100.0;
MP2_conn[i]=100.0;
MP1_conn[i]=100.0;
cnt++;
```

```
i++;
continue;
}

if((battery<=60.0)&&(battery>=40.0))
{
PP=3;
TR=tr[2];
if((PP>=MP)&&(MP=3))
{
        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn1 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=0.0;
    MP3_conn[i]=MP_conn1;
    MP2_conn[i]=100.0;
    MP1_conn[i]=100.0;
    cnt++;
    i++;
    continue;
}
 MP5_conn[i]=0.0;
 MP4_conn[i]=0.0;
 MP3_conn[i]=MP_conn1;
 MP2_conn[i]=100.0;
 MP1_conn[i]=100.0;
cnt++;
i++;
continue;
```

```
}

if((battery<=40.0)&&(battery>=20.0))
{
PP=2;
TR=tr[1];
if((PP>=MP)&&(MP==2))
{
        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
  MP_conn2 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
  MP5_conn[i]=0.0;
  MP4_conn[i]=0.0;
  MP3_conn[i]=0.0;
  MP2_conn[i]=MP_conn2;
  MP1_conn[i]=100.0;
  cnt++;
  i++;
  continue;
 }
 MP5_conn[i]=0.0;
 MP4_conn[i]=0.0;
 MP3_conn[i]=0.0;
 MP2_conn[i]=MP_conn2;
 MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
```

```
if((battery<=20.0)&&(battery>=1.0))
{
PP=1;
TR=tr[0];
if((PP>=MP)&&(MP==1))
{
        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn3 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=0.0;
    MP3_conn[i]=0.0;
    MP2_conn[i]=0.0;
    MP1_conn[i]=MP_conn3;
    cnt++;
    i++;
    continue;
}
MP5_conn[i]=0.0;
MP4_conn[i]=0.0;
MP3_conn[i]=0.0;
MP2_conn[i]=0.0;
MP1_conn[i]=MP_conn3;
cnt++;
i++;
continue;
}
break;
}
MP1_conn[i]=0.0;
```

```
    printf("\n\n");
    printf("     MP5          MP4          MP3          MP2          MP1\n");
    for(int p=0;p<cnt;p++)
printf("%d:%f\t%f\t%f\t%f\t%f\t\n",p+1,MP5_conn[p],MP4_conn[p],MP3_conn[p],
MP2_conn[p],MP1_conn[p]);
    printf("\n");
    getch();
                fp = fopen("IRT-connectivity.txt","w");
                    if(fp == NULL)
                    {
                        printf("Error in opening file...\n");
                        exit(1);
                }

   fprintf(fp," MP5          MP4          MP3          MP2          MP1\n");
   for(int p=0;p<cnt;p++)
fprintf(fp,"%d:%f\t%f\t%f\t%f\t%f\t\n",p+1,MP5_conn[p],MP4_conn[p],MP3_conn[
p],MP2_conn[p],MP1_conn[p]);
   fprintf(fp,"\n");
   getch();
   return 0;
}
```

//**Source Codes for IRT algorithm**

```
//By, Abdullahi Ibrahim Abdu
/*****Energy depletion time source code for IRT algorithm******/
#include<stdio.h>
#include<stdlib.h>
#include<conio.h>
#include<time.h>
#include<math.h>
#define SENS 1
#define RADIUS 20
#define MAX 5
#define GEN 288
int main(void)
{
   int node_id,PP,MP;
   int cnt = 0,i=0;
   float min_dist=0.0,range_interval,tr[MAX];
   float battery = 100.0,TR=0.0;
   float battery_buffer[GEN];
   int mp5_sent=0,mp4_sent=0,mp3_sent=0,mp2_sent=0,mp1_sent=0;
   int mp5_lost=0,mp4_lost=0,mp3_lost=0,mp2_lost=0,mp1_lost=0;
   FILE *fp;
   printf("ENTER SENSOR ID: ");
   scanf("%d",&node_id);
   printf("\n");
   printf("ENTER THE DISTANCE TO THE CLOSEST REACHABLE SENSOR:
         ");
   scanf("%f",&min_dist);
   printf("\n");
   range_interval=(RADIUS-min_dist)/4.0;
   printf("Range interval = %f\n",range_interval);
```

```
tr[0]=min_dist;
for(int i=0; i < MAX-1; i++)
        tr[i+1]=tr[i]+range_interval;
        for(int j=0;j<MAX;j++)
                printf("\t%f",tr[j]);
                getch();
              for(int w=0;w<GEN;w++)
                        battery_buffer[w]=0;
                srand(time(NULL));
                while(battery>=0.0)
                {
                 MP = 1+rand()%5;
                 if((battery<=100.0)&&(battery>=80.0))
                 {
                  PP=5;
                  if(MP==5) mp5_sent++;
                  if(MP==4) mp4_sent++;
                  if(MP==3) mp3_sent++;
                  if(MP==2) mp2_sent++;
                  if(MP==1) mp1_sent++;
                  TR=tr[4];
                  if(PP>=MP)
                  {
                      battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
                      battery_buffer[i] = battery;
                      cnt++;
                      i++;
                      continue;
                  }
```

```
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=80.0)&&(battery>=60.0))
{
PP=4;
if(MP==5) mp5_lost++;
if(MP==4) mp4_sent++;
if(MP==3) mp3_sent++;
if(MP==2) mp2_sent++;
if(MP==1) mp1_sent++;
TR=tr[3];
if(PP>=MP)
{
    battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=60.0)&&(battery>=40.0))
{
```

```
PP=3;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_sent++;
if(MP==2) mp2_sent++;
if(MP==1) mp1_sent++;
TR=tr[2];
if(PP>=MP)
{
    battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=40.0)&&(battery>=20.0))
{
PP=2;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_lost++;
if(MP==2) mp2_sent++;
if(MP==1) mp1_sent++;
TR=tr[1];
```

```
if(PP>=MP)
{
    battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=20.0)&&(battery>=1.0))
{
PP=1;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_lost++;
if(MP==2) mp2_lost++;
if(MP==1) mp1_sent++;
TR=tr[0];
if(PP>=MP)
{
    battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
```

```
                }
                battery_buffer[i] = battery;
                cnt++;
                i++;
                continue;
                }
                break;
                }
                for(int p=0;p<cnt;p++)
                printf("battery_buffer %d : %f\n",p+1,battery_buffer[p]);
                printf("%d %d %d %d %d\n",mp5_sent,mp4_sent,mp3_sent,mp2_sent,mp1_sent);
                printf("%d %d %d %d %d\n",mp5_lost,mp4_lost,mp3_lost,mp2_lost,mp1_lost);
                printf("\n");
                getch();
               fp = fopen("IRT-lifetime.txt","w");
                     if(fp == NULL)
                     {
                          printf("Error in opening file...\n");
                          exit(1);
                }
               for(int p=0;p<cnt;p++)
                fprintf(fp,"battery_buffer %d : %f\n",p+1,battery_buffer[p]);
                fprintf(fp,"%d %d %d %d %d\n",mp5_sent,mp4_sent,mp3_sent,mp2_sent,mp1_sent);
                fprintf(fp,"%d %d %d %d %d\n",mp5_lost,mp4_lost,mp3_lost,mp2_lost,mp1_lost);
                fprintf(fp,"\n");
   return 0; }
```

/********Network Connectivity source code for IRT algorithm**********/**

```
#include<stdio.h>
#include<stdlib.h>
#include<conio.h>
#include<time.h>
#include<math.h>
#define SENS 1
#define RADIUS 20
#define MAX 5
#define GEN 288
int main(void)
{
   int node_id,PP,MP;
   int cnt = 0,i=0;
   float min_dist,range_interval,tr[MAX];
   float
battery=100.0,MP_conn=100.0,MP_conn1=100.0,MP_conn2=100.0,MP_conn3=100
.0;
   float TR=0.0;
   float
MP5_conn[GEN],MP4_conn[GEN],MP3_conn[GEN],MP2_conn[GEN],MP1_conn[
GEN];
   FILE *fp;
   printf("ENTER SENSOR ID: ");
   scanf("%d",&node_id);
   printf("\n");
   printf("ENTER THE DISTANCE TO THE CLOSEST REACHABLE SENSOR:
");
   scanf("%f",&min_dist);
   printf("\n");
   range_interval=(RADIUS-min_dist)/4.0;
   printf("Range interval = %f\n",range_interval);
```

```
tr[0]=min_dist;
for(int i=0; i < MAX-1; i++)
        tr[i+1]=tr[i]+range_interval;
        for(int j=0;j<MAX;j++)
                printf("\t%f",tr[j]);
                getch();
                srand(time(NULL));
                while(battery>=0.0)
                {
                 MP = 1+rand()%5;
                 if((battery<=100.0)&&(battery>=80.0))
                 {
                  PP=5;
                  TR=tr[4];
                  if((PP>=MP)&&(MP==5))
                  {
                          battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
                      MP5_conn[i]=battery;
                      MP4_conn[i]=100.0;
                      MP3_conn[i]=100.0;
                      MP2_conn[i]=100.0;
                      MP1_conn[i]=100.0;
                      cnt++;
                      i++;
                      continue;
                  }
                  MP5_conn[i]=battery;
                  MP4_conn[i]=100.0;
                  MP3_conn[i]=100.0;
```

```
MP2_conn[i]=100.0;
MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
if((battery<=80.0)&&(battery>=60.0))
{
PP=4;
TR=tr[3];
if((PP>=MP)&&(MP==4))
{
    battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=MP_conn;
    MP3_conn[i]=100.0;
    MP2_conn[i]=100.0;
    MP1_conn[i]=100.0;
    cnt++;
    i++;
    continue;
}
MP5_conn[i]=0.0;
MP4_conn[i]=MP_conn;
MP3_conn[i]=100.0;
MP2_conn[i]=100.0;
MP1_conn[i]=100.0;
cnt++;
```

```
i++;
continue;
}
if((battery<=60.0)&&(battery>=40.0))
{
PP=3;
TR=tr[2];
if((PP>=MP)&&(MP=3))
{
        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn1 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=0.0;
    MP3_conn[i]=MP_conn1;
    MP2_conn[i]=100.0;
    MP1_conn[i]=100.0;
    cnt++;
    i++;
    continue;
}
 MP5_conn[i]=0.0;
 MP4_conn[i]=0.0;
 MP3_conn[i]=MP_conn1;
 MP2_conn[i]=100.0;
 MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
```

```
if((battery<=40.0)&&(battery>=20.0))
{
PP=2;
TR=tr[1];
if((PP>=MP)&&(MP==2))
{
        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
  MP_conn2 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
  MP5_conn[i]=0.0;
  MP4_conn[i]=0.0;
  MP3_conn[i]=0.0;
  MP2_conn[i]=MP_conn2;
  MP1_conn[i]=100.0;
  cnt++;
  i++;
  continue;
 }
 MP5_conn[i]=0.0;
 MP4_conn[i]=0.0;
 MP3_conn[i]=0.0;
 MP2_conn[i]=MP_conn2;
 MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
if((battery<=20.0)&&(battery>=1.0))
{
```

```
                PP=1;
                TR=tr[0];
                if((PP>=MP)&&(MP==1))
                {
                        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
                    MP_conn3 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
                    MP5_conn[i]=0.0;
                    MP4_conn[i]=0.0;
                    MP3_conn[i]=0.0;
                    MP2_conn[i]=0.0;
                    MP1_conn[i]=MP_conn3;
                    cnt++;
                    i++;
                    continue;
                }
                MP5_conn[i]=0.0;
                MP4_conn[i]=0.0;
                MP3_conn[i]=0.0;
                MP2_conn[i]=0.0;
                MP1_conn[i]=MP_conn3;
                cnt++;
                i++;
                continue;
                }
                break;
                }
               MP1_conn[i]=0.0;
printf("\n\n");
printf("    MP5          MP4          MP3          MP2          MP1\n");
```

```
   for(int p=0;p<cnt;p++)
printf("%d:%f\t%f\t%f\t%f\t%f\t\n",p+1,MP5_conn[p],MP4_conn[p],MP3_conn[p],
MP2_conn[p],MP1_conn[p]);
   printf("\n");
   getch();
                fp = fopen("IRT-connectivity.txt","w");
                     if(fp == NULL)
                     {
                          printf("Error in opening file...\n");
                          exit(1);
                }

  fprintf(fp,"     MP5          MP4          MP3          MP2          MP1\n");
  for(int p=0;p<cnt;p++)
fprintf(fp,"%d%f\t%f\t%f\t%f\t%f\t\n",p+1,MP5_conn[p],MP4_conn[p],MP3_conn
p],MP2_conn[p],MP1_conn[p]);
  fprintf(fp,"\n");
  getch();
  return 0;
}
```

//**Source Codes for AIRT algorithm proposed in this Thesis**

```
//By, Abdullahi Ibrahim Abdu
/*****Energy depletion time source code for AIRT algorithm******/
#include<stdio.h>
#include<stdlib.h>
#include<conio.h>
#include<time.h>
#include<math.h>

#define SENS 1
#define RADIUS 20
#define MAX 5
#define GEN 300
#define MIN_DIST 13.038405

int main(void)
{
   int node_id,PP,MP;
   int cnt = 0,i=0,k=0;
   float battery = 100.0,sum_gen=0.0,sum_gen1=0.0,sum_gen2=0.0;
   float battery_buffer[GEN],range_interval;
   int mp5_sent=0,mp4_sent=0,mp3_sent=0,mp2_sent=0,mp1_sent=0;
   int mp5_lost=0,mp4_lost=0,mp3_lost=0,mp2_lost=0,mp1_lost=0;
   double sum_lost=0.0,sum_lostt=0.0,sum_losttt=0.0,a=0.0,b=0.0,c=0.0;
   float sum_MP5_MP4=0.0,sum_MP3=0.0,sum_MP2_MP1=0.0;
   float tr[MAX],TR=0.0;
   FILE *fp;
   srand(time(NULL));
   range_interval=(RADIUS-MIN_DIST)/4.0;
   tr[0]=MIN_DIST;
```

```
for(int i=0; i < MAX-1; i++)
        tr[i+1]=tr[i]+range_interval;
              fp = fopen("AIRT-lifetime.txt","w");
                    if(fp == NULL)
                    {
                          printf("Error in opening file...\n");
                          exit(1);
                    }
              for(int w=0;w<GEN;w++)
                        battery_buffer[w]=0.0;
              for(int x=0;x<40;x++)
              {
               fprintf(fp,"RUN %d\n",x+1);
                 while(battery>=0.0)
                 {
                   MP = 1+rand()%5;
                   if((battery<=100.0)&&(battery>=80.0))
                   {
                    PP=5;
                    if(MP==5) mp5_sent++;
                    if(MP==4) mp4_sent++;
                    if(MP==3) mp3_sent++;
                    if(MP==2) mp2_sent++;
                    if(MP==1) mp1_sent++;
                    if(PP>=MP)
                    {
                          if(MP==5)TR=tr[0];
                          else
                          if(MP==4)TR=tr[1];
```

```
            else
            if(MP==3)TR=tr[2];
            else
            if(MP==2)TR=tr[3];
            else
            if(MP==1)TR=tr[4];
            else
            break;
              battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
        battery_buffer[i] = battery;
        cnt++;
        i++;
        continue;
    }
    cnt++;
    i++;
    battery_buffer[i] = battery;
    continue;
    }
    if((battery<=80.0)&&(battery>=60.0))
    {
    PP=4;
    if(MP==5) mp5_lost++;
    if(MP==4) mp4_sent++;
    if(MP==3) mp3_sent++;
    if(MP==2) mp2_sent++;
    if(MP==1) mp1_sent++;
    if(PP>=MP)
    {
```

```
        if(MP==4)TR=tr[1];
        else
        if(MP==3)TR=tr[2];
        else
        if(MP==2)TR=tr[3];
        else
        if(MP==1)TR=tr[3];
        else
        break;
          battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=60.0)&&(battery>=40.0))
{
PP=3;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_sent++;
if(MP==2) mp2_sent++;
if(MP==1) mp1_sent++;
if(PP>=MP)
```

```
{
        if(MP==3)TR=tr[1];
        else
        if(MP==2)TR=tr[2];
        else
        if(MP==1)TR=tr[2];
        else
        break;
          battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=40.0)&&(battery>=20.0))
{
PP=2;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_lost++;
if(MP==2) mp2_sent++;
if(MP==1) mp1_sent++;
TR=tr[1];
if(PP>=MP)
```

```
{
    battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
}
battery_buffer[i] = battery;
cnt++;
i++;
continue;
}
if((battery<=20.0)&&(battery>=1.0))
{
PP=1;
if(MP==5) mp5_lost++;
if(MP==4) mp4_lost++;
if(MP==3) mp3_lost++;
if(MP==2) mp2_lost++;
if(MP==1) mp1_sent++;
TR=tr[0];
if(PP>=MP)
{
  battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    battery_buffer[i] = battery;
    cnt++;
    i++;
    continue;
}
```

```
battery_buffer[i] = battery;

cnt++;

i++;

continue;

}

break;

}

for(int p=0;p<cnt;p++)

fprintf(fp,"battery_buffer %d : %f\n",p+1,battery_buffer[p]);

fprintf(fp,"RECEIVED PACKETS %d %d %d %d %d\n",mp5_sent,mp4_sent,mp3_sent,mp2_sent,mp1_sent);

fprintf(fp,"LOST PACKETS %d %d %d %d %d\n",mp5_lost,mp4_lost,mp3_lost,mp2_lost,mp1_lost);

sum_gen=mp5_lost+mp4_lost+mp5_sent+mp4_sent;

sum_lost=mp5_lost+mp4_lost;

a=(sum_lost/sum_gen)*100;

fprintf(fp,"MP5 + MP4 PACKETS LOST(%): %f\n",a);

fprintf(fp,"AVERAGING MP5 + MP4 PACKETS LOST PERCENTAGE: %f\n",sum_MP5_MP4+=a);

sum_gen1=mp3_lost+mp3_sent;

b=(mp3_lost/sum_gen1)*100;

fprintf(fp,"MP3 PACKETS LOST(%): %f\n",b);

fprintf(fp,"AVERAGING MP3 PACKETS LOST PERCENTAGE: %f\n", sum_MP3+=b);

sum_gen2=mp2_lost+mp1_lost+mp2_sent+mp1_sent;

sum_lostt+=mp2_lost+mp1_lost;

c=(sum_lostt/sum_gen2)*100;

fprintf(fp,"MP2 + MP1 PACKETS LOST(%): %f\n",c);

fprintf(fp,"AVERAGING MP2 + MP1 PACKETS LOST PERCENTAGE: %f\n",sum_MP2_MP1+=c);

fprintf(fp,"\n");
```

```
                range_interval=(RADIUS-MIN_DIST)/4.0;
                tr[0]=MIN_DIST;
                for(int g=0; g < MAX-1; g++)
                tr[g+1]=tr[g]+range_interval;
                TR=0.0;
                cnt=0,i=0,MP=0,PP=0;
                battery=100.0;
                mp5_sent=0,mp4_sent=0,mp3_sent=0,mp2_sent=0,mp1_sent=0;
                mp5_lost=0,mp4_lost=0,mp3_lost=0,mp2_lost=0,mp1_lost=0;
                sum_lost=0,sum_lostt=0,sum_losttt=0,a=0.0,b=0.0,c=0.0;
                for(int f=0;f<GEN;f++)
                battery_buffer[f]=0;
                }
   return 0;
}
```

/********Network Connectivity source code for AIRT algorithm**********/**

```
#include<stdio.h>
#include<stdlib.h>
#include<conio.h>
#include<time.h>
#include<math.h>

#define SENS 1
#define RADIUS 20
#define MAX 5
#define GEN 288
int main(void)
{
   int node_id,PP,MP;
   int cnt = 0,i=0;
   float min_dist=0.0,range_interval,tr[MAX];
   float battery = 100.0,TR=0.0;
   float MP_conn=100.0,MP_conn1=100.0,MP_conn2=100.0,MP_conn3=100.0;
   float
MP5_conn[GEN],MP4_conn[GEN],MP3_conn[GEN],MP2_conn[GEN],MP1_conn[
GEN];
   FILE *fp;
   printf("ENTER SENSOR ID: ");
   scanf("%d",&node_id);
   printf("\n");
   printf("ENTER THE DISTANCE TO THE CLOSEST REACHABLE SENSOR:
");
   scanf("%f",&min_dist);
   printf("\n");
   range_interval=(RADIUS-min_dist)/4.0;
   printf("Range interval = %f\n",range_interval);
   tr[0]=min_dist;
```

```
for(int i=0; i < MAX-1; i++)
        tr[i+1]=tr[i]+range_interval;
        for(int j=0;j<MAX;j++)
                printf("\t%f",tr[j]);
                getch();
                srand(time(NULL));
                while(battery>=0.0)
                {
                 MP = 1+rand()%5;
                 if((battery<=100.0)&&(battery>=80.0))
                 {
                  PP=5;
                  if((PP>=MP)&&(MP==5))
                  {
                      TR=tr[1];
                            battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
                      MP5_conn[i]=battery;
                      MP4_conn[i]=100.0;
                      MP3_conn[i]=100.0;
                      MP2_conn[i]=100.0;
                      MP1_conn[i]=100.0;
                      cnt++;
                      i++;
                      continue;
                  }
                  MP5_conn[i]=battery;
                  MP4_conn[i]=100.0;
                  MP3_conn[i]=100.0;
                  MP2_conn[i]=100.0;
```

```
MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
if((battery<=80.0)&&(battery>=60.0))
{
PP=4;
if((PP>=MP)&&(MP==4))
{
    TR=tr[1];
        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=MP_conn;
    MP3_conn[i]=100.0;
    MP2_conn[i]=100.0;
    MP1_conn[i]=100.0;
    cnt++;
    i++;
    continue;
}
MP5_conn[i]=0.0;
MP4_conn[i]=MP_conn;
MP3_conn[i]=100.0;
MP2_conn[i]=100.0;
MP1_conn[i]=100.0;
cnt++;
i++;
```

```
continue;
}
if((battery<=60.0)&&(battery>=40.0))
{
PP=3;
if((PP>=MP)&&(MP=3))
{
    TR=tr[1];
       battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn1 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=0.0;
    MP3_conn[i]=MP_conn1;
    MP2_conn[i]=100.0;
    MP1_conn[i]=100.0;
    cnt++;
    i++;
    continue;
}
 MP5_conn[i]=0.0;
 MP4_conn[i]=0.0;
 MP3_conn[i]=MP_conn1;
 MP2_conn[i]=100.0;
 MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
if((battery<=40.0)&&(battery>=20.0))
```

```
{
 PP=2;
 TR=tr[1];
 if((PP>=MP)&&(MP==2))
 {
          battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP_conn2 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
  MP5_conn[i]=0.0;
  MP4_conn[i]=0.0;
  MP3_conn[i]=0.0;
  MP2_conn[i]=MP_conn2;
  MP1_conn[i]=100.0;
  cnt++;
  i++;
  continue;
 }
 MP5_conn[i]=0.0;
 MP4_conn[i]=0.0;
 MP3_conn[i]=0.0;
 MP2_conn[i]=MP_conn2;
 MP1_conn[i]=100.0;
cnt++;
i++;
continue;
}
if((battery<=20.0)&&(battery>=1.0))
{
PP=1;
TR=tr[0];
```

```
if((PP>=MP)&&(MP==1))
{
        battery -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
   MP_conn3 -= 0.0000003*1000 + 0.00003*1000*pow(TR,2);
    MP5_conn[i]=0.0;
    MP4_conn[i]=0.0;
    MP3_conn[i]=0.0;
    MP2_conn[i]=0.0;
    MP1_conn[i]=MP_conn3;
    cnt++;
    i++;
    continue;
}
MP5_conn[i]=0.0;
MP4_conn[i]=0.0;
MP3_conn[i]=0.0;
MP2_conn[i]=0.0;
MP1_conn[i]=MP_conn3;
cnt++;
i++;
continue;
}
break;
}
MP1_conn[i]=0.0;
printf("\n\n");
printf("    MP5          MP4          MP3          MP2          MP1\n");
  for(int p=0;p<cnt;p++)
printf("%d:%f\t%f\t%f\t%f\t%f\t\n",p+1,MP5_conn[p],MP4_conn[p],MP3_conn[p],
MP2_conn[p],MP1_conn[p]);
```

```
    printf("\n");
    getch();
                fp = fopen("NEW-IRT-connectivity.txt","w");
                    if(fp == NULL)
                    {
                        printf("Error in opening file...\n");
                        exit(1);
                }
                fprintf(fp,"      MP5          MP4          MP3          MP2
MP1\n");
   for(int p=0;p<cnt;p++)
fprintf(fp,"%d:%f\t%f\t%f\t%f\t%f\t\n",p+1,MP5_conn[p],MP4_conn[p],MP3_conn[
p],MP2_conn[p],MP1_conn[p]);
   fprintf(fp,"\n");
   getch();
   return 0;
}
```