REDUCE ENERGY CONSUMPTION IN THE WIRELESS SENSOR NETWORK BY USING EEL-MAC PROTOCOL

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2015

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Abstrak

Nod Rangkaian Pengesan Tanpa Wayar (WSN) digunakan secara meluas dalam pelbagai sektor. Selama ini, WSN telah muncul sebagai penggerak untuk mengumpul dan memproses data dari lokasi yang jauh atau kawasan bencana. WSNs bergantung kepada kesederhaan perkakasan untuk membuat lapangan pengesan bersifat mampu milik dan tahan lama tanpa sokongan penyelenggaraan. Walau bagaimanapun, nod WSN mengalami banyak masalah seperti lampau dengar, perlanggaran, terminal tersembunyi, dengaran terbiar dan kependaman tinggi, yang mengakibatkan penggunaan tenaga yang tinggi, dengan itu menghadkan hayat nod. Selain itu, nod WSN amat bergantung kepada kuasa bateri yang terhad, tetapi sukar untuk menambah semula kuasa. Oleh itu, kajian ini mengkaji protokol Kawalan Capaian Medium (MAC) cekap tenaga yang direka untuk melanjutkan hayat kedua-duanya dengan pengurusan tenaga yang berkesan melalui penurunan masa terbiar dan peningkatan masa tidur untuk nod menjimatkan tenaga. Kajian ini juga bertujuan untuk mengurangkan kependaman antara nod dan nod tenggelam. Protokol hidbrid EEL-MAC bermula dengan fasa penyegerakan menggunakan TDMA untuk menyegerakkan semua nod dalam lapangan pengesan. Dalam fasa kedua, skim ini menggunakan mekanisme CSMA untuk komunikasi antara nod dan nod tenggelam. Kajian ini memberi dua sumbangan besar kepada rangkaian pengesan tanpa wayar. Pertama, protokol EEL-MAC menawarkan penjimatan tenaga penting dan memanjangkan jangka hayat rangkaian. Sumbangan kedua adalah pengenalan sambutan tinggi, dengan mereka bentuk komunikasi satu-hop untuk mengurangkan kedua-dua kelewatan dan kependaman hujung ke hujung.

Kata kunci: Penggunaan tenaga, Kependaman, Protokol, Memanjangkan hayat rangkaian.

Abstract

Wireless Sensor Network (WSN) nodes are broadly used in various sectors. Over the years, WSN has emerged as an enabler to collect and process data from remote locations or disaster areas. WSNs rely on hardware simplicity to make sensor field deployments both affordable and long-lasting without maintenance support. However, the WSN nodes experience a lot of problems such as, overhearing, collision, hidden terminal, idle listening and high latency, which resulted in high energy consumption, thus limiting the lifetime of the node. Moreover, WSN nodes are strongly dependent on their limited battery power, and replenishing them again is difficult. Therefore, this research investigates the energy-efficient Medium Access Control (MAC) protocols designed to extend both the lifetime by effective energy management through a reduction in idle time and increased sleep time for nodes to save energy. This study also aims to reduce the latency between nodes and sink node. The EEL-MAC hybrid MAC protocol starts by a synchronization phase using TDMA to synchronize all nodes in the sensor field. In the second phase the scheme uses the CSMA mechanism for communication between nodes and the sink node. In this study makes two significant contributions to wireless sensor networks. First, the EEL-MAC protocol offers significant energy savings and prolongs network lifetime. The second contribution is the introduction of high response, by designing a one-hop communication to reduce both end-to-end delay and latency.

Keywords: Energy consumption, Latency, Protocol, Prolongs the network lifetime.

Acknowledgement

In the Name of ALLAH, the Most Gracious and the Most Merciful. Peace is upon to Muhammad S.A.W., the messenger sent to guide people in a truthful way.
First, all praises and thanks goes to almighty ALLAH for giving me the patience, health and guidance to complete this thesis successfully, as well as giving me the chance to work in an environment such as Malaysia, and UUM in particular.

Furthermore, I would like to express my gratitude and special appreciation to my supervisors, Mr. Suwannit Chareen Chit and Dr. Mohd. Hasbullah Omar, who have been tremendous mentors for me. I would like to thank you both for your encouragement and advice in both pieces of research, as well as my career. It has been priceless.

I am grateful to my country, which gave me this opportunity despite the difficult conditions experienced by it and the people of Iraq. Words cannot express my thanks to my family, who have given me their support and prayers, love and encouragement to see their son succeed to get the master's degree in spite the wishes of health issues for to my dear father and darling mother. Moreover, I especially wish to express my love to my wife, who supported me and give me the conditions necessary and appropriate to study in alienation country, in spite of hardship, disease and study. Also, to my dear daughter for always putting a smile on my face.

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List of Abbreviations

AAS	: Automatic Active and Sleep
AM-MAC	: Adaptive Mobility-Supporting MAC
BN-MAC	: Boarder Node MAC
CFP	: Contention-Free Period
CSMA	: Carrier Sensing Multiple Access
CSMA/CA	: Carrier Sensing Multiple Access/Collision Avoided
CTS	: Clear To Send
DBNSP	: Dynamic Boarder Node Selection Process
DM-MAC	: Distribute Moving-MAC
EEL-MAC	: Enhance Energy and Latency MAC protocol
IDM	: Intelligent Decision-Making
LDSNS	: Least Distance Smart Neighboring Search
LLC	: Logical Link Control
LPL	: Lower Power Listening

LPRT-MAC	: Low Power Real Time-MAC
MAC	: Medium Access Control
MH-MAC	: A Mobility Adaptive Hybrid MAC
MS-MAC	: Mobile Sensor-MAC
NS2	: Network Simulator 2
ODFF	: Optimized Data Frame Format
OS	: Operating System
OTCL	: Object Oriented Tool Command Language
QoS	: Quality of Service
RF	: Radio Frequency
RTS	: Request To Send
S-MAC	: Sensor-MAC
TDMA	: Time division multiple access
WSN	: Wireless Sensor Network
Z-MAC	: Zebra-MAC

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Wireless Sensor Network (WSN) has attracted tremendous attention from researchers in the recent years (Meng, Xie, & Xiao, 2013). Consisting of sensor nodes and a sink node, WSN is used to sense parameters such as temperature, pressure and radiation from the surroundings. The data is then relayed to the sink node, and a server (Suriyachai, Roedig, & Scott, 2012).

A sensor node consists of several modules, namely the sensing, processing and communication module. These modules are highly dependent on the scarce battery supply. Therefore, a major challenge in a WSN is its short network lifetime. Power replenishment is a challenging task as these nodes are scattered randomly (Cano, Bellalta, Sfairopoulou, & Oliver, 2011). Although there has been enormous development in WSN technology. However, the progress of battery technology has been slow, and researchers are seeking new ways to prolong the lifetime of the network (Corke et al., 2010).

A wireless sensor network is composed of a number of sensor devices and sink(s). Sensor nodes communicate with their neighbors through shared channels. As these nodes compete for channel access, a mechanism is needed to ensure that the sensor nodes are able to effectively send data to the sink node. Figure 1.1 illustrates the general architecture of a WSN deployment (Kabara & Calle, 2012).

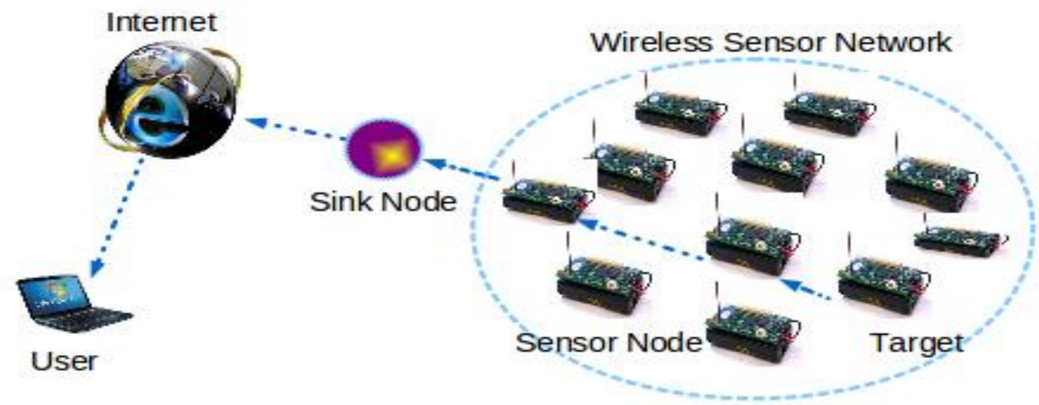


Figure 1.1 Wireless Sensor Network (Dovlatabadi & Mohammadpoor, 2015)

Previous conducted research has shown that most power is consumed during the active state of a node (Liu & Ni, 2007). Therefore, researchers have attempted to design Media Access Control (MAC) protocols to have the ability to prolong the lifetime of the network by reducing energy consumption. The design of a MAC protocol also presents several challenges such as the avoidance of collision, latency and, most importantly energy consumption. These protocols can be classified into three, namely schedule-based, contention-based and hybrid MAC protocols (Zhao, Miao, Ma, Zhang, & Leung, 2012).

Nodes compete to access the air interface in contention-based MAC protocols. The node that intends to transmit a packet should sense the channel before sending it. The sensor-MAC (S-MAC) protocol is the most common MAC protocol and has been enhanced and evolved into other MAC protocols, such as the Mobile Sensor-MAC (MS-MAC) and others (Jadidoleslamy, 2014). MS-MAC uses Carrier Sensing Multiple Access/Collision Avoided (CSMA/CA) to avoid collision. However, a problem associated with it is the hidden terminal problem. It happens when two or more nodes try to send a message in the same channel at exactly the time which leads to drop the packet and data loss (Tripathi & Kapoor, 2013). Carrier Sensing Multiple Access (CSMA) is suitable for scalability and mobility because it does not have a schedule. If a node senses that the channel is unclear, it then waits for a random time before attempting to transmit. This involves latency and delay to the channel (Bachir, Dohler, Watteyne, & Leung, 2010). The waiting time causes some problems as latency and throughput reduction.

Schedule-based MAC, such as Time Division Multiple Access (TDMA), can overcome the collision problem as nodes are only allowed to transmit during a specified period. However, schedule-based MAC has another problem. Clocks in WSN may be skewed, thus resulting in schedule drifts. When schedule drifts happen, nodes may transmit at times when other nodes are transmitting. This results in collisions and requires retransmissions. Retransmissions of packets then lead to energy wastage. Additionally, schedule-based schemes are unable to deal with changes in network topology and scalability (Rhee, Warrier, Aia, Min, & Sichitiu, 2008). Schedule-based is useful in eliminating collision, high data delivery and is predictable for sending packets. Despite, there are still having some problems like its table lost in tight schedule and the inability to support scalability in the network (Suriyachai et al., 2012).

The hybrid MAC protocol has been developed to overcome some of the previous problems. It is based on the useful properties from contention-based and schedule-based MAC. It combines the strong points of both TDMA and CSMA techniques to form a modern class hybrid. The hybrid MAC protocol has high-quality performance, which usually to achieve high throughput with efficient power consumption and scalability support through the elimination of latency (Zhao et al., 2012).

In this study attempts to enhance the MS-MAC protocol. While the Z-MAC protocol is adaptable to the level of contention in the network under low contention, it behaves like CSMA, and under high contention, like TDMA. Therefore, Z-MAC is considered within a hybrid class because it is a mixture of CSMA and TDMA (Rhee et al., 2008). Furthermore, the MS-MAC is based on S-MAC, as mentioned above. It uses CSMA techniques and enhances the preamble message by the addition of data. Therefore, it supports mobility while maintain energy consumption (Pham & Jha, 2005).

In this study, an enhanced MAC protocol is proposed to reduce energy consumption. The enhancement is made on the hybrid MAC mechanism. The proposed enhanced MAC protocol can be simulated and its results verified.

1.2 Statement of Problem

One of the key problems in WSNs is the conservation of energy in the sensors to prolong the lifetime of the network (Cano et al., 2011). Most WSN nodes are powered by battery and have limited power supply, which dries up after a period of time (Zhao, Sun, Wei, & Li, 2011). Research has been conducted in WSNs to reduce energy consumption but the issue of high-energy consumption has still not been resolved (Razaque & Elleithy, 2014a). When the power source (batteries) is exhausted, it is usually difficult to be replace. When the battery runs dry, nodes are inoperable which makes the WSN useless.

There are three modules in a sensor node: sensing, processing and communication. The largest consumer of power is the node communication module (Suriyachai et al., 2012). The communication module transmits and receives data during the active state, and continuously scans the air interface for incoming messages during idle state. The communication module commonly uses the CSMA technique, which can lead to serious conflicts, thus causing latency and heavy package loss as well as consuming a certain amount of energy to retransmit these packets (Fang, Yu, Xiaobin, & Kai, 2014).

On the other hand, high duty cycle (switching state from active to idle and vice-versa) consumes a significant amount of energy. During its idle state, a node listens to the air interface for incoming messages (SYNC messages) and wakes up periodically to transmit data (Ahmad, Dutkiewicz, & Huang, 2009) . A sudden switch of state boosts energy usage, thus draining the battery (Ruzzelli, Hare, Tynan, Cotan, & Havinga, 2006). Numerous researchers have attempted to control the duty cycle so that it is a low duty cycle with high-up throughput to reduce energy consumption and ensures high performance (Razaque & Elleithy, 2014b).

Boarder Node MAC (BN-MAC) (Abdul Razaque, 2015) protocol is very complex and requires a specific network content. The special nodes have the ability to implement more than ten models and techniques. The special node is cost a lot, hence the complexities of design and high cost are considered negative features for the BN-MAC protocol.

In this study solves some problems of the MS-MAC protocol. Such as high duty cycle which leads to an increase in energy consumption (Dong & Dargie, 2013). On the one hand, this protocol depends on active zone to support the mobility node. All nodes in this region are going to be effective with high frequency or full duty cycle, which results in a rise in energy consumption (Pham & Jha, 2005). It cannot make the nodes return to the normal frequency. However, the nodes keep the increased frequency forever, again with no need for a high duty cycle (Dong et al., 2013).

On the other hand, MS-MAC has the active zone which supports two hop communication. Furthermore, it has a high duty cycle and is based on contention-based CSMA. This means it is unable to overcome the overhead and it is difficult to access a medium, thus generating the latency problems (Razaque & Elleithy, 2014b)

1.3 Research Question

i. How to reduce energy consumption in WSN?

ii. How to reduce latency in WSN?

1.4 Objectives

The main objective of this research is to enhance the existing MS-MAC protocol by making it more efficient in the energy consumption protocol by using a low duty cycle mechanism. Finally, to obtain a MAC protocol that can widely support a lot of Wireless Sensor Network (WSN) applications. The research mentions the following specific objectives that have been defined.

i. To enhance MS-MAC protocol through using a hybrid MAC design so that the proposed protocol can reduce energy consumption.

ii. To reduce latency by using one hop communication to obtain high-performance.

iii. To simulate and evaluate the performance of the proposed protocol in order to compare it with the current protocols.

1.5 Significance of Research

The main significance of this study is prolonging the WSN lifetime by extending battery-life by saving energy. By enhancing the MS-MAC protocol from a simply designed hybrid MAC protocol energy consumption and latency will be reduced.

The proposed MAC protocol uses TDMA and CSMA mechanisms, as well as the one hop communication technique to reduce energy consumption and latency in WSN.

1.6 Contributions

The outcome of this research into the hybrid MAC protocol is that it reduces energy consumption for WSN after enhancements are made to the original MS-MAC protocol. Furthermore, it supports the MAC protocol with enhancements in MS-MAC to work in WSN application to reduce energy consumption and latency and to prolong network lifetime. Because the major challenge in a WSN is its energy consumption the researcher has to find how network lifetime can be prolonged (Cano et al., 2011).

1.7 Scope of The Study

The scope of this dissertation shall be the consideration of designing a hybrid Medium Access Control (MAC) protocol, called the Enhance Energy and Latency MAC (EEL-MAC) protocol. This proposed protocol addresses the energy and latency issues that are related to Wireless Sensor Network (WSN) nodes. The conservation of both energy and reduced latency in the WSN are the main points of the research. It is proposed that the EEL-MAC combines a hybrid design between two TDMA and CSMA mechanism to save energy with the one hop communication technique to reduce latency. The proposed EEL-MAC protocol focuses on stationary nodes which deploy randomly in the sensing field and all homogeneous nodes have the same capabilities, uniform sensing and communication range. It is also assumed that the flat sensor networks without obstacles propagate in the Line Of Sight (LOS). The proposed protocol is then tested with simulation known as Network Simulator 2 (NS2).

1.8 Organization of The Thesis

This thesis is organized in six chapters as follows:

Chapter 1 presents a brief background and introduction to WSN. This chapter also highlighted the related problem statement, research objectives, research questions, research scope, and the research significance.

Chapter 2 is a literature review that includes a background material on WSN and Challenges of WSN. Then, explain MAC and types of MAC with MS-MAC and group of hybrid MAC protocol.

Chapter 3 presents the methodology followed in order to carry out this thesis and illustrate Briefly about enhanced on MS-MAC protocol by proposed the new design MAC protocol.

Chapter 4 presents the development of enhance MS-MAC protocol by proposed EEL-MAC protocol and phases design EEL-MAC protocol. Furthermore, how calculate Performance Metrics the energy consumption and latency.

Chapter 5 presents a detailed of validate the energy consumption and latency and throughput by compare original MS-MAC protocol and significant hybrid MAC protocols with propose the protocol EEL-MAC protocol and discussed the results.

Chapter 6 presents the conclusions of the research work presented in this thesis and provide some suggestions for future work.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

WSN has attracted huge attention in recent years. These nodes are used in a wide range of applications in various fields such as the medical domain, transportation systems, monitoring and surveillance applications for environmental, industrial and military purposes (Meng et al., 2013).

A typical sensor node device has three functions, namely communication, processing and sensing capabilities. A node is also equipped with memory modules to save information needed by the node. The Radio Frequency (RF) system assures communication with other nodes. A small battery represents the main (and most often the only) source of power due to the limited capacity of batteries and the difficulty of frequent battery recharging or replacement in many situations (Ye, Heidemann, & Estrin, 2002).

Designing and developing new effective protocols to overcome the different obstacles presented in the protocol has been the focus of researchers for the past few years (Razaque & Elleithy, 2014a). This dissertation addresses the important issue of limited energy in WSNs by using techniques and mechanisms to conserve energy and increase network lifetime.

The topics covered in this chapter are organized as follows. Section 2.2 introduces the background about WSN and the components, as well as some of the examples implemented in WSN. Section 2.3 illustrates the obstacles and challenges in WSN like energy consumption, latency, high duty cycle and collisions. Section 2.4 shows medium access control and the types with some MAC protocol. Section 2.5 discusses related works. Section 2.6 summarize the chapter.

2.2 Wireless Sensor Network (WSN)

A WSN is composed of a number of sensor devices and sink(s). There are three modules in a sensor node: sensing, processing and communication as illustrated in Figure 2.1. Furthermore, there is the power unit. The sensing module collects data from the sensor field, It can sense different types of data like temperature, movement, radiation, vibration and so on.

The processing module processes the data which is sensed in the sensing module, as well as the data which comes from the communication module. Finally, the communication module can receive instructions from the sink node and transfer this information to the processing module. In addition, it can send all data to the sink node through a radio frequency in communication module (Healy, Newe, & Lewis, 2008).

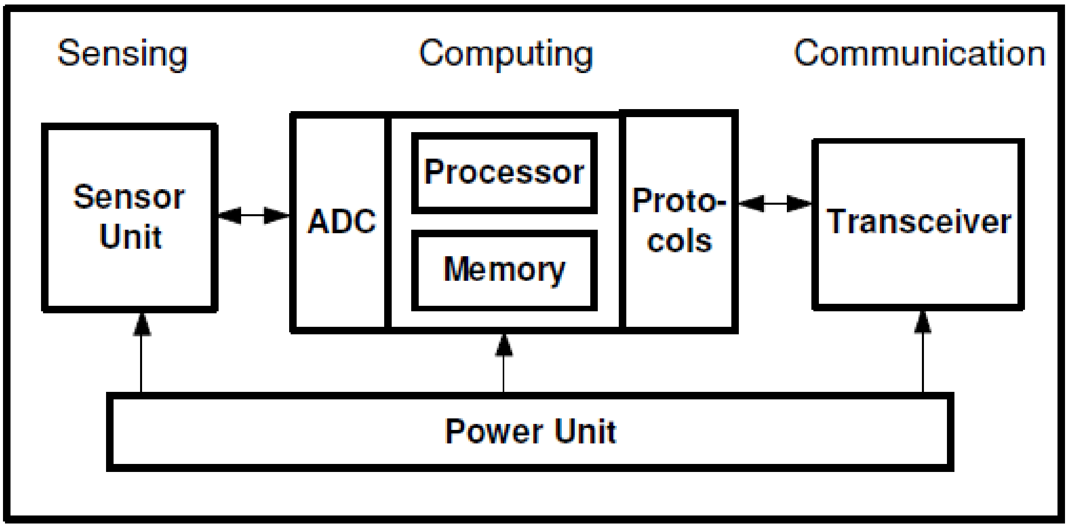


Figure 2.1 Sensor Node Modules (Kazienko, Ribeiro, Moraes, & Albuquerque, 2011)

They are most often used in places that are difficult to access such as natural disaster areas volcanoes and war zones. WSNs are widely used in a broad range of applications including field surveillance, industrial control systems, and monitoring applications in healthcare systems (Huang, Xiao, Soltani, Mutka, & Xi, 2013). Because sensor devices generally have low processing power, limited battery power, small memory size and suffer from collisions and interference in wireless transmissions, optimizing the operation of a WSN is challenging (Yadav, Varma, & Malaviya, 2009).

Since wireless sensor devices are powered by battery, energy consumption is a major issue to be addressed when designing the communication protocols between the sensor devices and the sink or coordinator. Sensor devices consume a significant amount of energy while transmitting and receiving data (Cheng, Tse, & Lau, 2010). Sensor devices do not transmit at high power to achieve longer life time of the battery. Therefore, short-range communication protocols are suitable for wireless sensor networks.

Figure 2.2 shows an example of a complete solution that integrates WSNs with other current technologies, like cellular networks, the Internet, and other wireless ad hoc technologies (Labrador & Wightman, 2009).

Furthermore, the sink nodes allow information from outside into the WSN, like commands, updates or queries. In some cases, the sink nodes also play the role of organizers of the network, keeping track of the state of the nodes and addressing assignation, or by being the initiators of the maintenance procedures. However, at the present time, of all the constraints considered in most available wireless sensor devices, energy consumption is the most important.

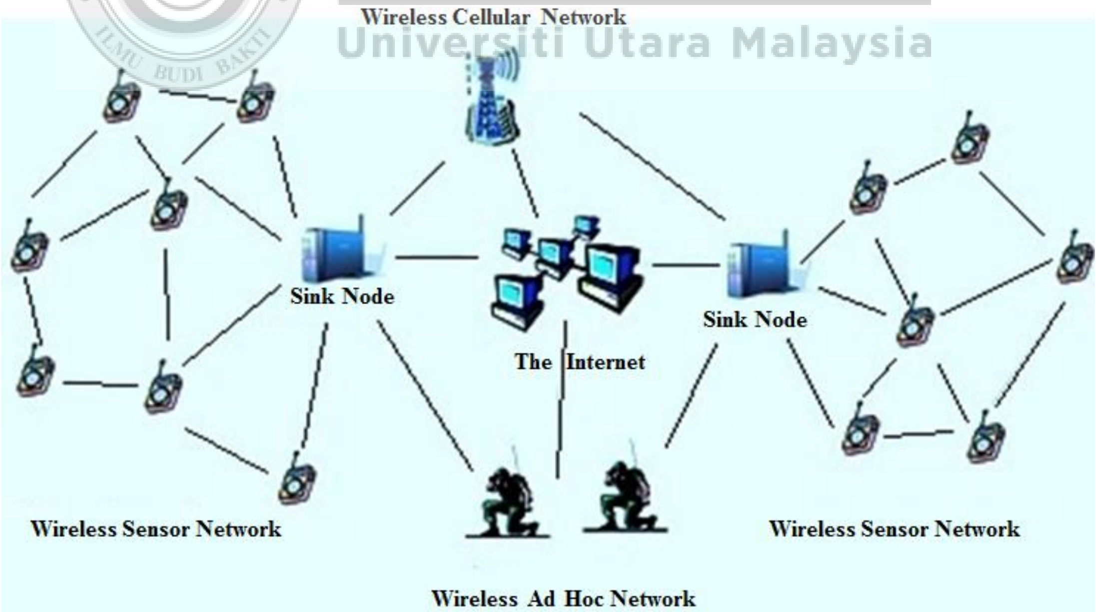


Figure 2.2 Deployment and Communication WSN (Labrador & Wightman, 2009)

2.3 Challenges of Wireless Sensor Network

While WSN is used in a very wide range of application there are issues and challenges in its deployment. Limited energy in the WSN and consumption are big issues. Energy is stored in a typically non-rechargeable battery on each node. The sensor node must operate in a low energy-consumption status to be able to maintain its function for a long period of time. Therefore, saving energy and the lifetime network are the most important factors in WSN (Razaque & Elleithy, 2014a).

There are other obstacles the protocols which must be taken into account, such as efficiency, in order to save resources and particular energy. Many technical issues are still to be fully addressed and solved. For example, the reduction of latency, the reduction of collisions and high duty cycling (Razaque & Elleithy, 2014b).

2.3.1 Energy Consumption

Energy limitation is always a major constraint when observing WSN resources. These networks consist of numerous hardware components, which lack the ability to recharge and are often too expensive to be replaced. Moreover, most cases are about the inability to access the position of sensors. For these reasons, we must take into consideration at all times the node lifetime and its effects on the network lifetime (Yadav et al., 2009).

Adding intensive processor functionality has an impact on a sensor lifetime by using more power, requiring more transmission overhead due to the fact that this extra burden on the energy system is not negligible. Finally, these things should be taken into consideration when designing the EEL-MAC protocol. The research design helps to reduce energy consumption and prolongs the lifetime of the sensor. As a result, the network lifetime depending on these sensors.

2.3.2 Collision

Collisions in WSNs protocols often occur. This may result in two neighboring nodes transmitting a data packet simultaneously, which in turn leads to a collision and failure midway between the nodes. As a result, both nodes are unable to complete their task of sending or receiving the packet. This case is called hidden terminals (Cano et al., 2011).

This is another source of energy wasting which occurs as a result of packet collisions. Collision of a packet not only results in time and energy wasting on failing to deliver that packet, it also causes the MAC protocol to retransmit the packet, which in turn increases network latency and energy consumption. In duty cycling networks, failure to get a packet delivered usually means the node has to wait until the next cycle to make another attempt (Razaque & Elleithy, 2014c). This problem must also be taken into consideration when looking at designing an EEL-MAC protocol.

Zebra–MAC (Z-MAC) uses TDMA mechanism because in design this greatly helps to prevent collisions in data packets and generates good energy efficiency (Rhee et al., 2008). Therefore, the research uses the TDMA mechanism for synchronization to reduce collision in the initialization phase and reduces energy consumption.

2.3.3 Latency

Latency in networking is one of the biggest challenges from a practical viewpoint. It is very hard to minimize it other than in a theoretical manner. Latency is the measure of the delay time between when a packet is sent to when it is received. Multi-hop communication makes it especially difficult to achieve synchronicity among network nodes and depends on contention-based CSMA in some protocols, which has an impact on the latency of a WSN (Razaque & Elleithy, 2014b).

Furthermore, there are many reasons for latency, but the researcher focus on multi-hop communication for reasons mentioned above. Minimizing latency is essential in minimizing the overall schedule time and reducing energy. This is the main objective of most protocols in the WSN data collection. The one hop communication technique is a very efficient way to reduce latency (Afonso, Rocha, Silva, & Correia, 2006).

2.3.4 Duty Cycle

Duty cycling has been introduced into wireless sensor networks to help the nodes save energy. With duty cycling, a node turns its radio on and off periodically. When the radio is on, the node can send or receive packets from other nodes. However the node sleeps to save energy when the radio is off (Bachir et al., 2010).

Duty cycling in wireless sensor networks can be classified into two categories: synchronous and asynchronous. In asynchronous duty cycling networks, nodes may wake up and go to sleep at different times with different schedules. Examples of asynchronous duty cycling MAC protocols include WiseMAC (El-Hoiydi & Decotignie, 2004) and EM-MAC (Tang, Sun, Gurewitz, & Johnson, 2011) .

A node may turn off its radio after finishing a packet transmission and does not have to follow other nodes' schedules, i.e., go to sleep with others at the same time. Furthermore, whereas nodes running a synchronous duty cycling MAC protocol must wake up at the beginning of the data period and typically remain awake for all or most of the data period, nodes running an asynchronous duty cycling protocol are often able to go to sleep right after transmitting a packet. However, it is also possible that a receiving node wakes up earlier than the intended sender and consumes energy when waiting. In order to minimize this kind of energy wasting, an asynchronous duty cycling MAC protocol needs to develop energy efficient node scheduling methods (Razaque & Elleithy, 2014b).

In synchronous duty cycling MAC protocols, all the nodes start a cycle at the same time with the same duty cycle setting. Examples of synchronous duty cycling MAC protocols include S-MAC (Ye, Heidemann, & Estrin, 2004) and Z-MAC (Rhee et al., 2008).

The advantage of synchronous duty cycling is that a node can easily meet other nodes schedules and communicate with them, which simplifies the design of the MAC protocol as all nodes are awake at the same time (Jadidoleslamy, 2014).

The synchronous design also reduces idle listening in nodes when waiting for another node to wake up, thus helping to increase energy efficiency (Maróti, Kusy, Simon, & Lédeczi, 2004). Nevertheless, timing synchronization across the network creates a design challenge (Ahmad et al., 2009).

Finally, high duty cycle consumes a significant amount of energy. Due to, the fact that switching between active and sleep mode consumes energy it knows the switching energy Figure 2.3 shows every duty cycle and the node states in a one duty cycle. Thus, to reduce energy consumption for switching energy it is necessary to ensure that the duty cycle its low (Ruzzelli et al., 2006).

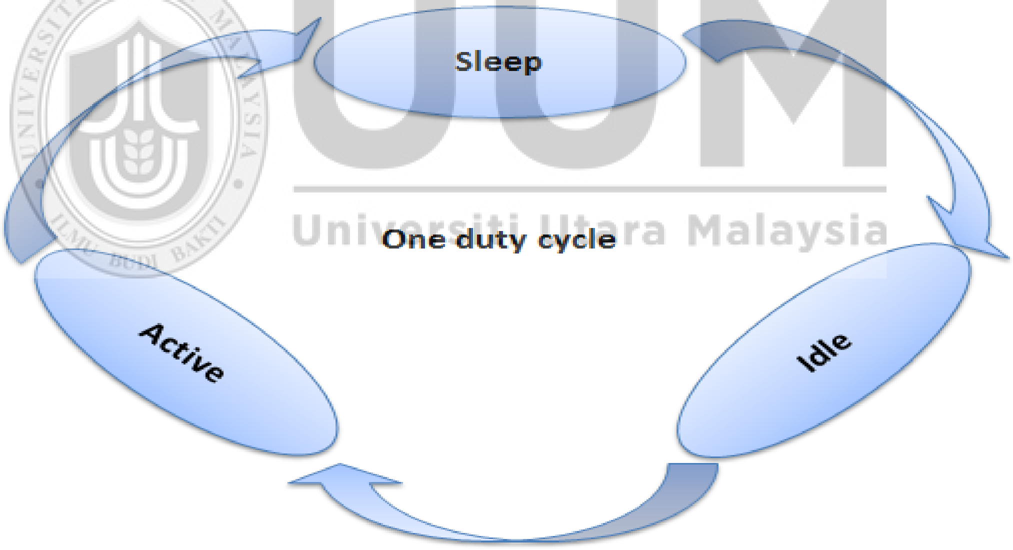


Figure 2.3 One Duty Cycle

2.4 Medium Access Control (MAC)

In WSNs, sensor nodes communicate with their neighbors through shared wireless channels. If multiple nodes in a neighbor send data through the shared channel at the same time, collision occurs and data may be garbled. Therefore, some kind of coordination mechanisms are needed for such one-hop communications (Kabara & Calle, 2012).

The MAC is a sub-layer of the Logical Link Control (LLC) layer in the OSI model, (Labrador & Wightman, 2009). Medium Access Control (MAC) layer protocols provide such mechanisms by deciding which node(s) should be transmitted first.

The bursty traffic is one of the unique features of WSNs. Radios on sensor nodes stay in an idle-listening state for most of the time since heavy traffic loads are only present when events occur. It is a known fact that most radio devices consume a lot of energy (Jadidoleslamy, 2014).

Significant amount of energy are wasted if radios are left in an idle-listening state. Many energy-efficient MACs protocols have been proposed for WSNs. They attempt to lower node idle-listening power consumption by lowering the duty cycles of radios through sleep scheduling. In other words, radios are put into sleep state if they are not involved in any data communication (Yadav et al., 2009).

There are several classifications for the MAC Protocols. It is dependent on division based on how to access channel: the contention-based, schedule-based and the hybrid MAC protocol (Zhao et al., 2012).

2.4.1 Schedule-Based

In this type of Medium Access Control the schedule-based its appear to reduce the collision and is successful in eliminating collision, high data delivery and is predictable for packet sending. The best way to utilize the bandwidth channel is by using the Time Division Multiple Access (TDMA) mechanism. In TDMA, a channel is divided into slots, and these slots are grouped into frames. The payload transmitted in one physical block is referred to as a packet (Havinga & Smit, 2000). In TDMA, an efficient time schedule in a scalable fashion is not unimportant. It often requires a centralized node to find a collision-free schedule. Furthermore, developing an efficient schedule with a high degree of concurrency eliminating collision (Rhee et al., 2008). TDMA is used to enable several nodes to transmit on the same frequency channel. It splits the signal into different time frames. Each time frame is divided into several time slots, where each node is assigned to a time slot to transmit (Almalag, Olariu, & Weigle, 2012). The length of the time slot may vary, based upon the needs of the node assigned to it. For example, if a node needs to be transmitted on the channel, it uses its own time slot to transmit. The nodes are transmitted in rapid succession, each using its own time slot as shown in Figure 2.4.

The main advantage of TDMA is a reduction in interference between nodes and the ability to solve collision course, as well as the hidden terminal problem. This is due to the fact that it can schedule communication times of neighboring nodes to occur at different times. Moreover, it adds slot allocation like the Z-MAC protocol, as shown in section 2.4.3.1. However, during low contention, TDMA gives much lower channel utilization and higher delays than CSMA because in TDMA a node can transmit only during its scheduled time slots, thus consuming more of energy (Rhee et al., 2008).

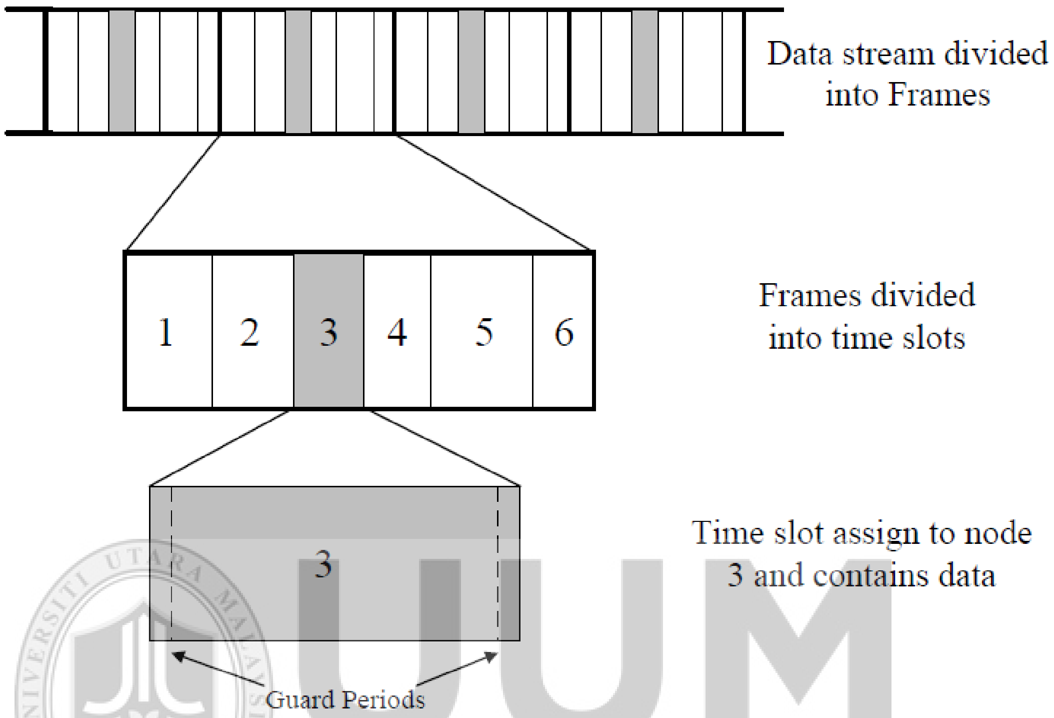


Figure 2.4 TDMA Divided to Frames and It Divided Into Slots Then Slot Assign to The Node (Almalag, 2013)

2.4.2 Contention-Based

The contention-based mechanism requires nodes that wish to be transmitted to see the channel before transmission. The Sensor-MAC (S-MAC) protocol is the most common MAC protocol, and S-MAC has contributed to the emergence of other MAC protocols (Jadidoleslamy, 2014). MS-MAC, an extension of S-MAC is based on Carrier Sensing Multiple Access/Collision Avoided (CSMA/CA). A competition state could lead to a collision among packets it is called the hidden terminal problem. It happens when the two nodes are sent in the same channel at exactly the same time. This leads to drop in the packet and data loss (Tripathi & Kapoor, 2013).

Carrier Sensing Multiple Access (CSMA) is suitable for scalability and mobility because it does not have a schedule. However, the node senses if the channel is clear, before any packets are transmitted. If the channel is busy it waits until it is clear (Bachir et al., 2010). Waiting time may cause some problems like latency and reduced throughput. Thus, using the CSMA technique leads to serious conflicts. This in turn causes latency and heavy package loss and a certain amount of energy is consumed to retransmit these packets in heavy traffic networks (Fang et al., 2014).

2.4.2.1 MS-MAC Protocol

The mobility-aware (MS-MAC) protocol is extended to the S-MAC protocol. There are a lot of MACs protocols which depend on the S-MAC protocol design. The MS-MAC protocol appears to be a solution to some S-MAC problems like scalability and energy consumption.

The duty cycle of MS-MAC introduces coordinated sleep/listen and periodically synchronizes messages every 5 minutes for 30 seconds. Furthermore, if a node receives a new schedule, it adopts with both schedules and becomes different from the existing one. However, in some cases, the node cannot communicate with a neighboring node through the old schedule because the topology has changed. Therefore, in this case, the new synchronized message should wait. This may take about five minutes (equal to one duty cycle). After that, the node updates the schedule and can then communicate with its neighbors (Pham & Jha, 2005). This compared advantages and disadvantages of MS-MAC protocol illustrate in Table 2.1.

Table 2.1 Advantage and Disadvantage for MS-MAC Protocol

Advantages	Disadvantages
1) It can transmit using the old neighbors at the same time creates connection with new nodes.	1) It consumes higher energy to reduce latency.
2) The synchronized frequency can change with speed of a moving node neighbors (Dong & Dargie, 2013).	2) The neighbors node is for moving node, consume high level of energy, even if it is stationary (Dong & Dargie, 2013).

2.4.3 Hybrid-Based

The Hybrid MAC protocol is designed to overcome problems such as energy consumption, throughput, latency in CSMA (Javaid et al., 2013) scalability and mobility in TDMA. It is based on useful properties from the contention-based and schedule-based mechanisms. This is achieved by combining the advantage of TDMA and CSMA techniques to get a hybrid (Park, 2011).

The hybrid MAC protocol offers high-quality performance and tends to achieve high throughput with efficient power consumption and support scalability through latency elimination (Zhao et al., 2012).

There are a lot of MACs protocols based on the hybrid approach due to the quickly and easily adapt to traffic conditions, which can lead to reduction in the amount of energy consumed (Yahya & Ben-Othman, 2008) like Zebra-MAC protocol (Rhee et al., 2008).

2.4.3.1 Z-MAC Protocol

Zebra-MAC (Z-MAC) (Rhee et al., 2008) used a hybrid TDMA and CSMA protocol. It was designed to use the advantages of both TDMA and CSMA based schemes and to avoid their weaknesses.

Under low contention conditions, Z-MAC operates like a CSMA based protocol and, thus, achieve high throughput and low latency communication among the nodes. In contrast, it functions as a TDMA based protocol under high contention situations, and, as a result, it achieves high channel utilization and nearly eliminates collisions among two-hop neighbors (Arshad, Al-Sadi, & Barnawi, 2013).

Z-MAC succeeded in solving the problems of synchronization, network topology variations and time varying channel conditions. There are several solutions Z-MAC protocol which depend on confronting the problem like using hybrid-based to reduce energy consumption, as mentioned (Rhee et al., 2008). Furthermore, it uses the owner slots technique to reduce collisions when the high contention case to obtain the channel. Finally, in the worst case, it can go back to CSMA for re-sync when it fails. From this, good features can enhance the MS-MAC protocol design. This compared advantages and disadvantages of Z-MAC protocol illustrate in Table 2.2.

Table 2.2 Advantage and Disadvantage for Z-MAC Protocol

Advantage	Disadvantage
1) It can dynamically adjust the behavior of protocol technique between CSMA and TDMA depending on the contention level in the network (Rhee et al., 2008).	1) Z-MAC lacks which way node's not own slot can be informed in advance in when slot they be the receiver. Accordingly, nodes have to continue sensing and listening in all time slots. Therefore, it be wasting a large amount of energy (Liu & Ni, 2007).
2) Used owner slots technique to reduce the collision occur when the high contention case to get the channel (Yigitel, Incel, & Ersoy, 2011).	2) Two-hop transmitting is the impact of getting High Contention Level. Furthermore, the number of hidden terminals increases and proves the overhead (Yigitel et al., 2011).
3) High performances are two-issues the energy and Throughput if it use one-hop (Ramchand & Lobiyal, 2011).	3) Under high overhead the delivery packet rate decreased to the two third of the information (one from three is lost). Furthermore, spend the amount of energy for retransmission these packets (Arshad et al., 2013).

2.4.3.2 LPRT-MAC Protocol

Low Power Real Time (LPRT) MAC protocol (Afonso et al., 2006), is hybrid-based, and uses a superframe structure illustrated in the Figure 2.5 (Silva, Afonso, Macedo, & Rocha, 2011). All the superframes are divided into mini slots which use beacon (B) base station through the contention access period (CAP). This uses CSMA/CA (Carrier Sensings Multiple Access/Collisions Avoided) to carry traffic (Algaet, Noh, Shibghatullah, Milad, & Mustapha, 2014). The Contention Free Period (CFP) is used schedule by the station and composed by Retransmission Period (RP).

It is composed by mini slots reserved by the station for the retransmission of the packet in the superframe if it is not reserved in the normal transmission period (NTP) of the last superframe. The LPRT MAC protocol in the medical field uses large-size beacons and supports the one hop (Gama, Carvalho, Mendes, & Afonso, 2009).

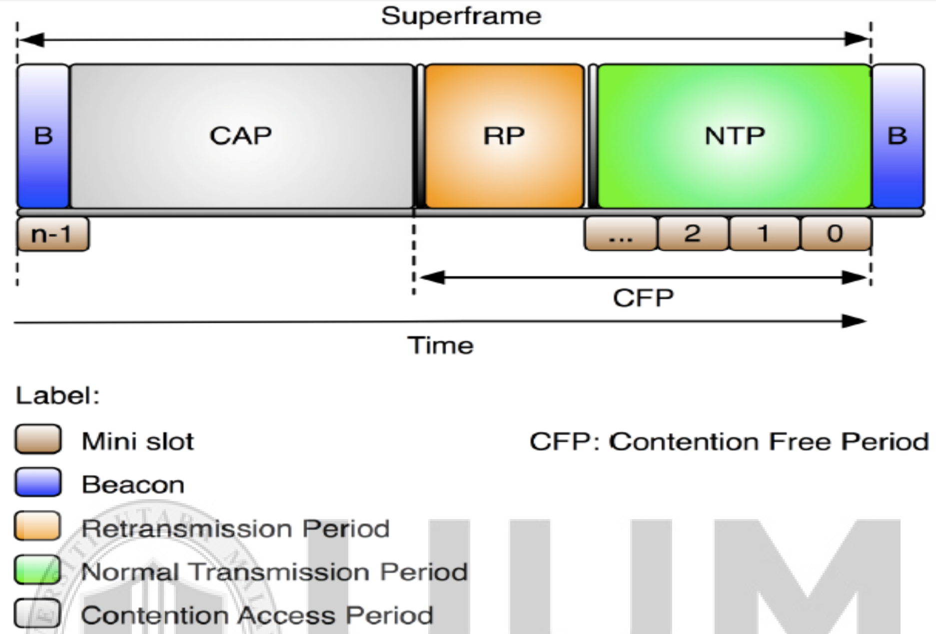


Figure 2.5 Superframe of LPRT MAC Protocol (Silva et al., 2011)

The single hop communication is the important feature for enhancing design of MS-MAC protocol because it reduces latency and enhances performance of protocol (Razaque & Elleithy, 2014b). This compared advantages and disadvantages of LPRT-MAC protocol illustrate in Table 2.3.

Table 2.3 Advantage and Disadvantage for LPRT MAC Protocol

Advantage	Disadvantage
1) LPRT-MAC protocol gives low latency due to the scheduled communications are contention-free and do not have to multiple-hops (Afonso et al., 2006). 2) It provides reliability by the acknowledgement of all information packets (Afonso et al., 2006). 3) It performs efficiency, high throughput (Afonso et al., 2006).	1) Its performance is significantly the impact by bit errors. Due to the length (size) it is required for the beacon (Algaet et al., 2014). 2) The delivery ratio decreases slightly as the number of sensor nodes and the size of the beacon increase (Silva et al., 2011). 3) LPRT MAC is unsuitable and limited for multi-hop communication. Thus, the topological change causes the additional energy consumption, and reduces the throughput (Razaque & Elleithy, 2014b).

2.4.3.3 Speck-MAC Protocol

The Speck MAC (Wong & Arvind, 2006) protocol is a type of continuous preamble sampling and asynchronous random-access MAC protocol. It is a protocol with the conceptions of redundant communication of short packets and an inserted destination address. Firstly, the concept aims to minimize the communication energy.

Speck MAC-B (Speck MAC-Back off) is useful in unicast information transmission, while the other concept Speck MAC-D (Speck MAC-Data) is energy efficient in broadcast transmission. It provides a measure to reduce the significant overhearing problem in heavy traffic conditions. Figure 2.6 shows the fundamental operation of the Speck MAC protocol (Ahmad et al., 2009). Finally, Speck-MAC uses short packet to reduce energy consumption in the SYNC packet in the enhanced MS-MAC proposed protocol and reduces packet size by putting only scheduled data to reduce energy consumption.

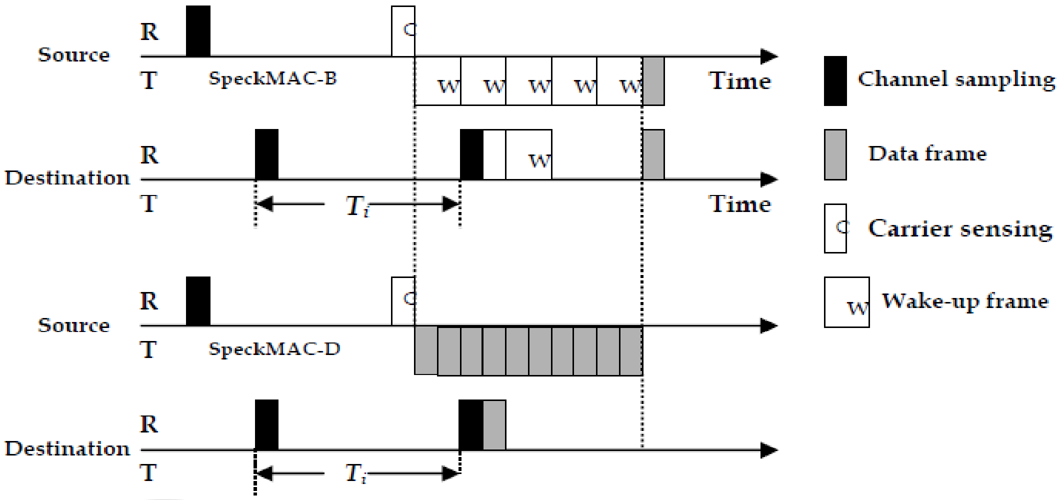


Figure 2.6 Fundamental Asynchronous Speck MAC (Ahmad et al., 2009)

This compared advantages and disadvantages of Speck-MAC protocol illustrate in Table 2.4.

Table 2.4 Advantage and Disadvantage for Speck-MAC Protocol

Advantage	Disadvantage
1) It uses acknowledgements and a low-power listening (Meier, Motani, Siquan, & Künzli, 2008).	1) It suffers from latency problem (Ahmad et al., 2009) .
2) Achieve energy efficiency can be reduced energy significantly (Ahmad et al., 2009).	2) Suffer from lost in transmission energy due to redundant data packets (Lanjewar & Adane, 2014).
3) Reduces energy consumption especially at receiver (Lanjewar & Adane, 2014).	3) The sender wastes excess energy by sending extra frames even though the receiver has already received the frames. The additional frames consume channel bandwidth and thus reduce the packet delivery rate (Razaque & Elleithy, 2014a).

2.5 Related Work

As the MS-MAC suffers from energy consumption, there are some researchers who have tried to find solutions to this problem like An Adaptive Mobility-Supporting MAC (AM-MAC) protocol (Choi, Lee, & Kim, 2008). The AM-MAC protocol enhances energy consumption in the MS-MAC protocol by using the energy efficient secondary listening period mechanism by making the border node depend on just a secondary schedule of the new virtual cluster not on two schedules of both primary (old virtual cluster) and secondary. Additionally, the AM-MAC protocol uses the smart scheduling adaptation mechanism for sink node which adopt the schedule by moving toward the inside virtual cluster secondary schedule. The AM-MAC from these mechanisms tries to reduce idle time for sink node and border node thus reduce energy consumption.

A major drawback for the AM-MAC protocol is that the node has to wake up according to both the schedule but cannot transmit or receive data packets during the wake up schedule other than the current cluster. This contributes to significant latency and loss of energy due to idle wake up (Khan & Ali, 2011).

A Mobility Adaptive Hybrid MAC (MH-MAC) Protocol design hybrid MAC protocol has the energy efficiency problem as its main objective (Raja & Su, 2008). The MH-MAC design hybrid MAC uses a contention-based approach to deal with mobile nodes and is scheduled based for static nodes. The MH-MAC protocol dynamically adapts the ratio between static and mobile nodes depending on some of the mechanisms.

The MH-MAC protocol has the mobility information from the beginning of each frame to exchange mobility information. Each node is assumed to have mobility information on all sensor nodes in the network which can be an invalid assumption in the large WSNs (Awwad, Ng, & Noordin, 2010).

Finally, the Boarder Node MAC (BN-MAC) protocol is a new design which uses several models to reduce energy consumption idle listening time. Firstly, the Automatic Active and Sleep (AAS) model is used to reduce idle time to automatically go to the sleep state to avoid the idle listening state. Additionally, the Intelligent Decision-Making (IDM) model helps to make the node use the active or passive mode. Finally, the Least Distance Smart Neighboring Search (LDSNS) model is used to determine the shortest efficient path, As well as the Intra Synchronized Communication model to SYNC the nodes inside one region. On the other hand, the BN-MAC protocol which is needed to reduce latency uses, one hop communication and a semi-synchronous feature is used to reduce energy consumption, latency and maximize throughput (Razaque & Elleithy, 2014a).

The BN-MAC protocol uses four models to conserve energy and uses another three models to enhance Quality of Service (QoS). Furthermore, there are two models and some of the techniques for more services. All these models and techniques make the design of the protocol very complex and it is necessary to have special nodes to implement these requirements. For more detail go to Section 5.3.1 in chapter five .

2.6 Conclusion

This chapter has shown sequentially the field to the research. It started with the wireless sensor network, then the challenges of the protocols designed such as energy consumption, latency, collision and duty cycle. Moreover, the medium access control and some of the types such as schedule-based, contention-based and hybrid based were presented. Finally, the group of protocols as an example of a hybrid MAC protocol with related works were discussed.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

Research methodology defines the research steps and procedures to be performed in this research. This section introduces the general research methodology in network simulation. Generally, this study is conducted in four phases; namely, problem definition, designing the proposed MAC protocol, implementing the protocol using a simulation tool as illustrated in Figure 3.1 and, finally, evaluating the proposed MAC protocol. These phases are described in detail in the following sections.

The organization of this chapter is as follows. Section 3.2 gives an overview of the problem and analysis. Section 3.3 illustrates basic design of proposed protocol EEL-MAC where all the details of the design will be given and initial implementation will be given in Chapter Four. Section 3.4 discusses the simulation parameters and performance metrics used for the EEL-MAC protocol. Finally, Section 3.5 provides of summary this chapter.

3.2 Definition The Problem and Analysis

The MS-MAC protocol suffers from energy wastage due to high duty cycle or sometimes reached to maximum duty cycle which results in an increase in energy consumption (Pham & Jha, 2005) and (Razaque & Elleithy, 2014b). The nodes cannot be made to return to the normal frequency. As, they keep the increased frequency forever (Dong et al., 2013). Finally, high duty cycle leads to an increase in energy consumption (Dong & Dargie, 2013).

As a result, the research adopts a group of hybrid MAC protocol Z-MAC, speck-MAC and LPRT-MAC to help solving the problems of MS-MAC due to the same challenges and problems these protocols faced in MS-MAC. From the Z-MAC protocol, the design combines both the TDMA and CSMA mechanisms by depending on the positive characteristics of both mechanisms. Furthermore, there is reduced energy consumption through a reduction in contention and collisions when happened it's increased consumption energy because protocol tries to retransmit the packets lost (Rhee et al., 2008).

Otherwise, LPRT- MAC protocol uses the one hop communication technique to reduce latency and faces the problem of delay in the protocol (Afonso et al., 2006). This technique helpful in solving the latency problems in the MS-MAC protocol.

Finally, Speck-MAC uses short packet to reduce energy consumption in SYNC packet (Wong & Arvind, 2006) and MS-MAC protocol had in SYNC packet data of schedule and RSSI (Dong & Dargie, 2013) but in the enhanced proposed protocol reduce packet size by putting only schedule data to reduce energy consumption.

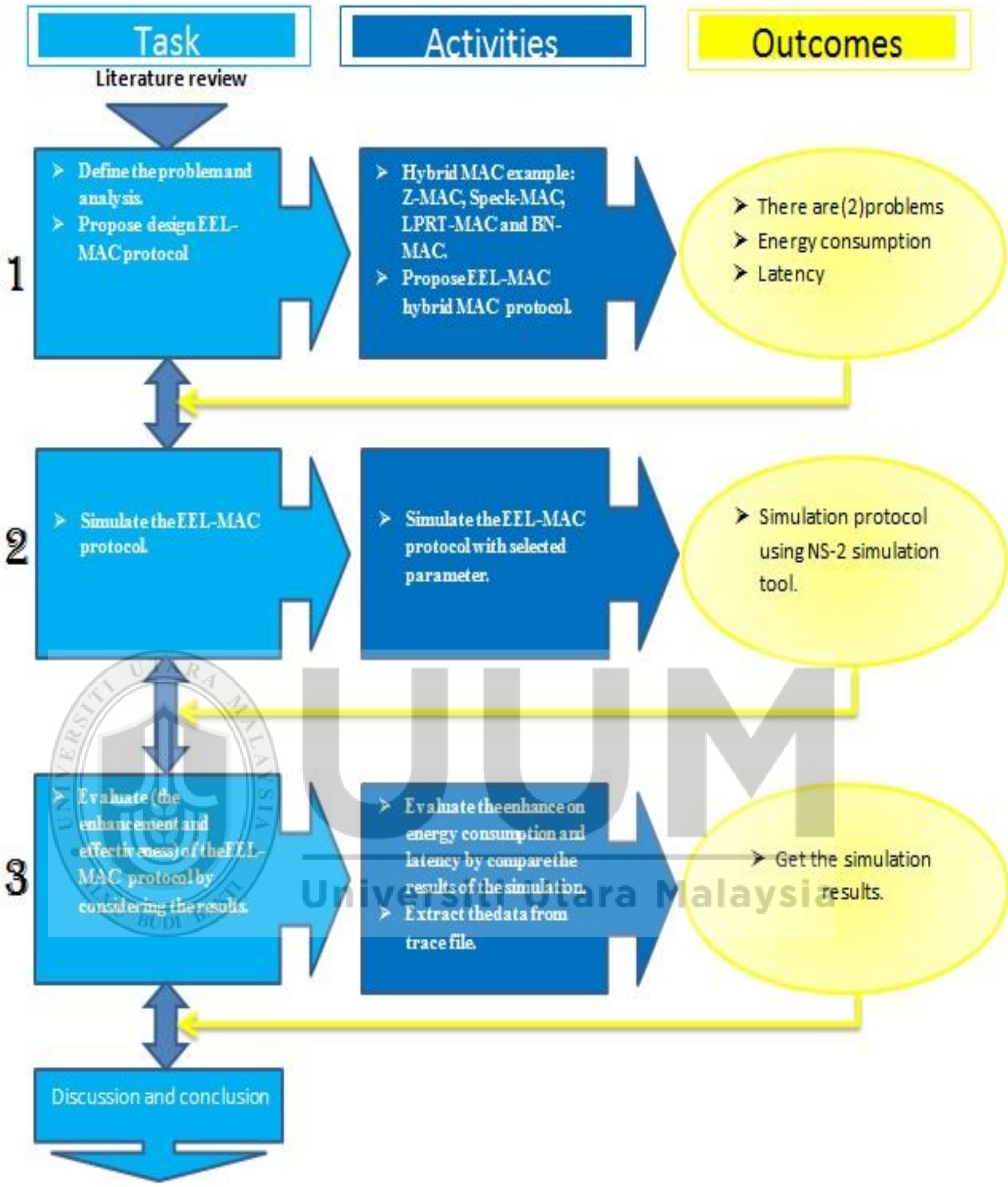


Figure 3.1 Methodology

3.3 The Proposed EEL-MAC Protocol Design

The MS-MAC is based on the S-MAC, MS-MAC protocol proposed for mobile sensors. It uses Carrier Sensing Multiple Access (CSMA) techniques and enhances the SYNC message by adding data about the Received Signal Strength Indicator (RSSI). Therefore, this is to support mobility while saving energy (Pham & Jha, 2005).

In this research, the MS-MAC protocol is enhanced by converting it into a hybrid-based protocol. Hybrid MAC protocols are of paramount importance because they have lower energy consumption and better scalability than other categories of MAC protocols (Razaque & Elleithy, 2014a). The hybrid MAC protocol was achieved by combining the TDMA and CSMA mechanisms in the operation. The sink node sends a broadcast message to the nodes in the sensor field for synchronization. All nodes reply by TDMA. Once it has established a connection with the nodes, the sink node can expect to receive messages from the nodes through CSMA. This is to collect data and update the schedule again. Then, switching to TDMA in certain time with these two phases can deal with any change in the topology of the network. Finally, the research makes a simulation of the design using NS-2 because it is close to the real environment.

3.3.1 Phases Proposed Design

The proposed enhancement to MS-MAC involves modifications to its current contention-based protocol. In this study, a hybrid protocol is proposed. The enhanced MS-MAC is named Enhance Energy and Latency (EEL-MAC).

First, the sink node sends broadcast messages to sensor nodes in the sensor field for synchronization. The duty cycle approaches all nodes which are assigned a time slot to reply TDMA to reduce idle time to save energy. TDMA can solve the hidden terminal problem without the extra message overhead because it can schedule transmission times of neighboring nodes to occur at different times and consider TDMA prefers a solution under high contention (high load) (Rhee et al., 2008). The sink node receives reply from the node and waites for a while to ensure all nodes reply. This part of design addresses in section 4.2.1 initialization phase.

One of the node has established a connection with the nodes, the sink node can expect to receive messages from the nodes through CSMA to collect data. If there is no change in topology within the certain time it should go back to continue communication in CSMA. This part of the design is the communication phase. For more detail go to section 4.2.2 in Chapter Four. Otherwise the sink node broadcast sensor nodes re-synchronize and the update schedule then go on. Finally, these two phases can deal with any change in the topology of the network.

However, Figure 3.2 shows the appropriate ways to switch the two phases to support the flowchart work when the cycles have a change in topology. The initialization phase starts with a SYNC message broadcast from the sink node to all nodes then replies to the node which receives this message using TDMA mechanism. The sink node wait for a while after the last message received in idle mode to ensure there is no node reply until this phase is completed.

The communication phase starts directly after the initialization phase. The sink node expects one of the nodes to start communication by sending RTS. The sink node then replies by CTS. In this time can node sends the data packets to the sink node. The communication between the sink node and the nodes continues until there is a need to re-synchronize in the initialization phase.

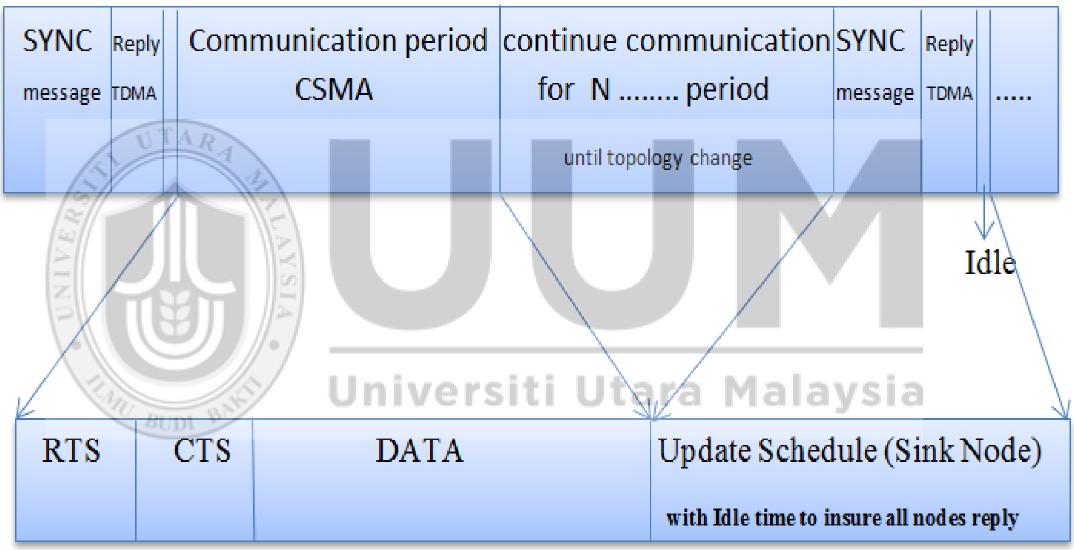


Figure 3.2 Ways to Switch The Work of The Phases EEL-MAC Protocol

Finally, more clarification be shown in the flowchart Figure 3.3. This flowchart gives us a clear picture to make the EEL-MAC protocol works.

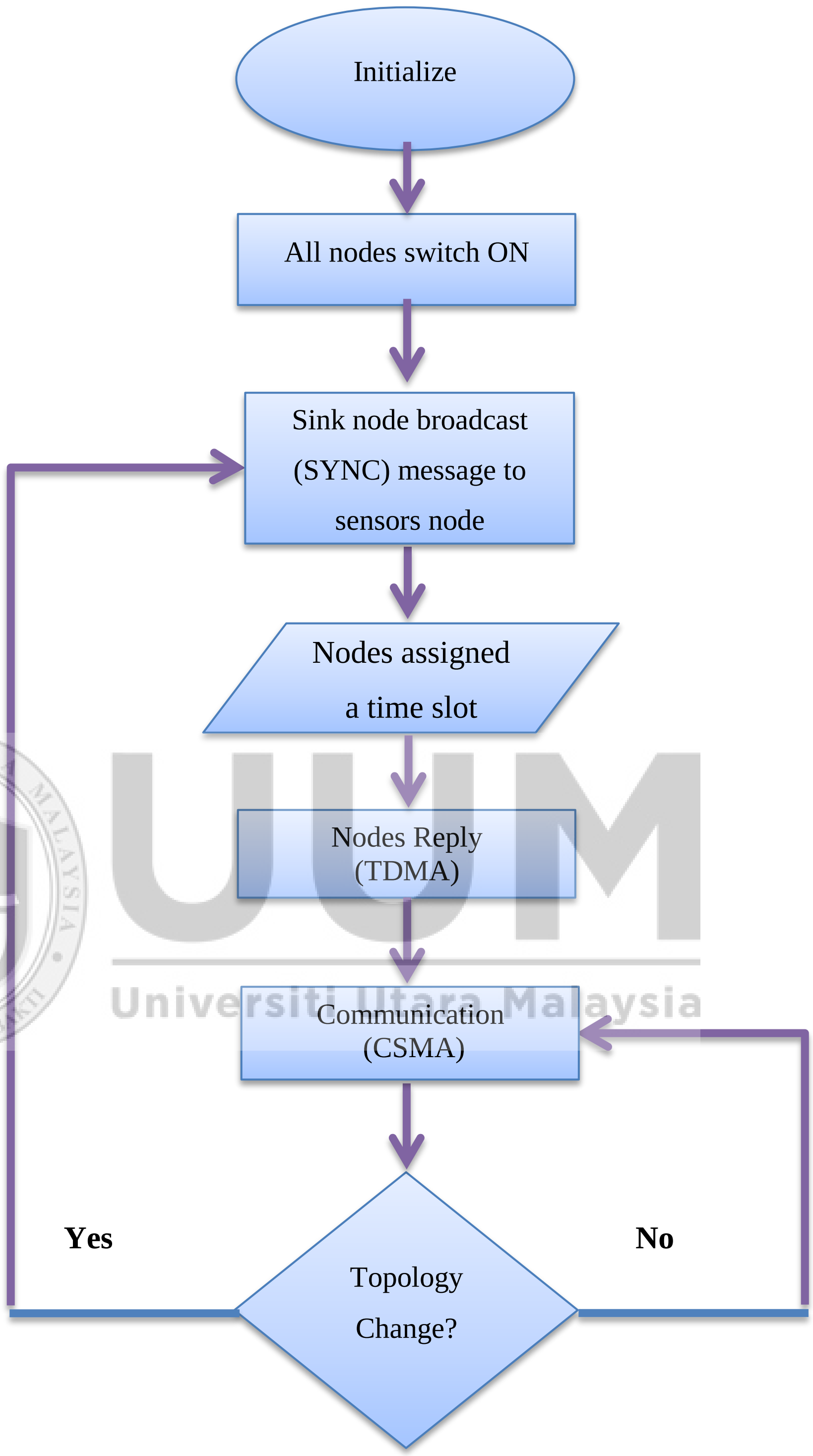


Figure 3.3 Flowchart of Procedure for EEL-MAC Protocol

3.4 The Simulation Parameter and Performance Metrics

It was necessary to evaluation the WSN. The selection of the network simulator is too important issue to ensure the simulation can be done efficiently. This is led to saving in cost and time. For experimental simulation setup, used Network Simulation 2 (NS-2) (McCanne, Floyd, Fall & Varadhan, 1997). because it produces results similar to a real environment and supports many network MAC protocol (Razaque & Elleithy, 2014a). In terms of cost, ns-2 is free to be used and available as the open source so that any simulate and modification can be done freely. Moreover, the NS-2 based simulation scripts are easy to write and modify with ease of parsing the trace file.

The main goal of the simulation is to evaluate the EEL-MAC protocol. The proposed EEL-MAC protocol was evaluated by comparing it with the MS-MAC protocol to determine the extent of the enhancement (Wu, Kumekawa, & Kato, 2010). Moreover the performance of the proposed EEL-MAC protocol was evaluated by comparing it with significant current protocols.

3.4.1 The Simulation Parameters

The extent of the enhancement was evaluated by comparing EEL-MAC with the MS-MAC protocol using the simple simulation parameters. The simulation parameters scenarios consist of six nodes. The sensor nodes are randomly deployed in a geographical area of 300 × 300 m^2. The bandwidth of the nodes is 50 kb/s, and the maximum power consumption for each sensor node is set at 16 mW. The sensing mode is 12 mW. The initial energy of each sensor node is set to 40 J. The total simulation time is 240 Sec. The presented results are an average of 10 simulation runs (Zhang, Li, Cui, Zhao, & Yin, 2009). The simulation parameters are illustrated in Table 3.1, as the most common parameters (Al-Yasiri & Sunley, 2007), (Rebahi, Mujica-V, & Sisalem, 2005), (Razaque & Elleithy, 2014a).

Table 3.1 Values of Parameters to Evaluate Enhance Used in The Simulation

Parameters	Description
Initial energy of node	40 Joules
Bandwidth of node	50 Kb/S
Number of sensors nodes	5 node
Size of network	300 × 300 square meters
Packet transmission rate	30 Packets/Sec
Simulation time	240 sec
Tx power	16 mW,
Rx power	12 mW

The performance of the proposed EEL-MAC protocol was evaluated by comparing it with other MAC protocols. The setup of the simulation parameters was based on (Razaque & Elleithy, 2014a) which is shown in Table 3.2

Table 3.2 Simulation Parameter to Evaluate Performance of EEL-MAC Protocol

Parameters	Description
Initial energy of node	250 Joules
Bandwidth of node	50 Kb/S
Number of sensors	105
Size of network	300 × 300 square meters
Packet transmission rate	30 Packets/Sec
Simulation time	35 minute
Tx power	16 mW,
Rx power	12 mW

After the simulation was executed, NS-2 generated a trace file that contained all the information of the simulation.

3.4.2 The Performance Metrics

To evaluate any protocol or algorithm it is necessory to performance metrics to evaluate the effectiveness of the proposed protocol with the current protocol depending on some of the performance metrics in WSN such as energy consumption and latency. The performance metrics in this research focused on the energy consumption and latency performance metrics for the MAC protocol (Sumathi & Srinivas, 2012).

To present, the results of the simulation it is necessary to extract the information from the trace file. The trace file is a huge file contains all the events which occurred during the simulation time. To deal with trace file it is necessary to use AWK script language the name is derived from the family names of its authors – Alfred Aho, Peter Weinberger, and Brian Kernighan. AWK language has the ability to filter the data from the trace file to extract the information about energy or latency. Two AWK files were used for extracting energy consumption and latency in the simulation network (appendix). From this AWK file Microsoft Excel, word and a text file from this comment can be generated.

awk –f "AWK file name".awk "trace file name".tr> "Excel file name".xls

Later get the data on Excel file where the results can be presented as a graph or table. It is a graphical tool for data presentation and has the ability to provide all the matrices which are required for the network performance study.

3.4.2.1 Energy Consumption Performance Metrics

Energy consumption is one of the most important performance metrics for wireless sensor networks as it directly relates to the operational lifetime of the network (Gao, 2002). To obtain the results for the first performance metrics energy consumption. It is necessary to collect the energy consumption in every node and the summation of all energy for every node and divide it by the number of nodes to get an average of energy consumption, as shown in this equation.

$$\textbf{Average energy consumption} = \sum \textbf{energy consumption} \div \sum \textbf{the nodes} \qquad (3.1)$$

On the other hand, the average energy consumption per second and can calculate from this equation (3.2).

$$\textbf{Average energy consumption per second} = \textbf{average energy consumption} \div \sum \textbf{time of simulation} \qquad (3.2)$$

3.4.2.2 Latency Performance Metrics

The second performance metrics it is the latency on EEL-MAC protocol was achieved using the same parameters. Latency is measured by the average end-to-end delay (Youssef & Younis, 2007). To calculate the average end-to-end delay should be first obtained the delayed for every packet sent from the source node to the destination node. Equation 3.3 was used to calculate the delay; it is :

The delay = time of received - start time transmission (3.3)

Furthermore, the average delay from a summation delay was calculated for all packets and divided by the number of packets, as shown in equation 3.4.

Average of delay = $\sum$the delay ÷ $\sum$number of packets received from sink node (3.4)

3.5 Summary

In this study, an enhanced MS-MAC protocol is proposed. The enhancement incorporates both TDMA and CSMA into current MS-MAC which is CSMA-based to obtain the EEL-MAC hybrid MAC protocol. This study measures the effectiveness of the enhanced MAC by measuring the energy consumption, as well as seeing its impacts on latency.

CHAPTER FOUR
PROTOCOL DESIGN AND SIMULATION RESULTS

4.1 Introduction

This chapter explains the design details and phases of the EEL-MAC protocol, as well as the simulation result, pseudocode for two phases. Energy consumption, latency and collision were then analyzed. Furthermore, the Enhance Energy and Latency (EEL-MAC) protocol were simulated and the energy consumption and latency results were analysed.

This chapter is organized as follows. Section 4.2 shows the phases of designing the protocol with a pseudocode for every phase. Section 4.3 analyses and calculate energy consumption. Sections 4.4 and 4.5 discuss the latency and collisions. Section 4.6 shows the energy consumption and latency simulation results. Section 4.7 summarizes the chapter.

4.2 Design Phases for EEL-MAC Protocol

There are two phases to design the EEL-MAC protocol. The EEL-MAC protocol is hybrid MAC protocol starts with TDMA then uses CSMA. Start with initialization phases then communicate phase to transmit packets. Next, the duty cycle continues with a two phases Initialization and communication.

4.2.1 The Initialization Phase

This phase start deploys nodes randomly in the sensing field. Every one of the nodes has a unique ID to recognizing it from the sink node. The sink node sends a SYNC message to all nodes in the field. The sink node then waits for the reply from nodes in the field depending on the schedule already whether has it or has received. It subsequently waits for a while in idle mode to ensure it receives all replies from the node by the TDMA mechanism. Next, the sink node updates the schedule depending on the reply from nodes in the field. After that, this phase is finished.

Sometime, it is needed to add new nodes to the field. These nodes restitute and replace the node if the battery is exhausted or to enhance the coverage inside the sensing field. When a new node is added to the network it stays in idle mode until a SYNC message from the sink node is received. Then, it waits a while to reply to the sink node depending on the receiving schedule. Therefore, the sink node updates the schedule by adding new nodes to the schedule and removes any nodes which do not reply to the SYNC message from schedule. If the node does not reply to the sink node it means that this node is disconnected. By itself, the disconnect happens for two reasons. Firstly, the battery might be exhausted as a result of consuming energy to send and receive packets and in idle mode. Secondly, some nodes, when they are deployed randomly, might be out of coverage. For these two reasons these nodes cannot reply to the sink node by TDMA in the first phase. Then the sink node updates the schedule and knows the number of nodes in a field. To demonstrate the initial phase these steps should be used.

Step 1: all nodes be active to receive a synchronization message from sink node.

Step 2: sink node sends broadcast a synchronization message to all nodes in the sensor field.

Step 3: all nodes received a synchronization message reply to sink node by using TDMA mechanism.

Step 4: sink node receives the reply from all nodes then stay in idle mode for a while to insure receiving all replies.

Step 5: sink node update schedule for all nodes in the sensor field.

For more details about the initial phase for the EEL-MAC protocol, the research assumes the example for five sensor nodes to explain this phase. The sink node broadcasts a SYNC message to all nodes in the sensor field (five nodes) at a time (T1), as shown in Figure 4.1.

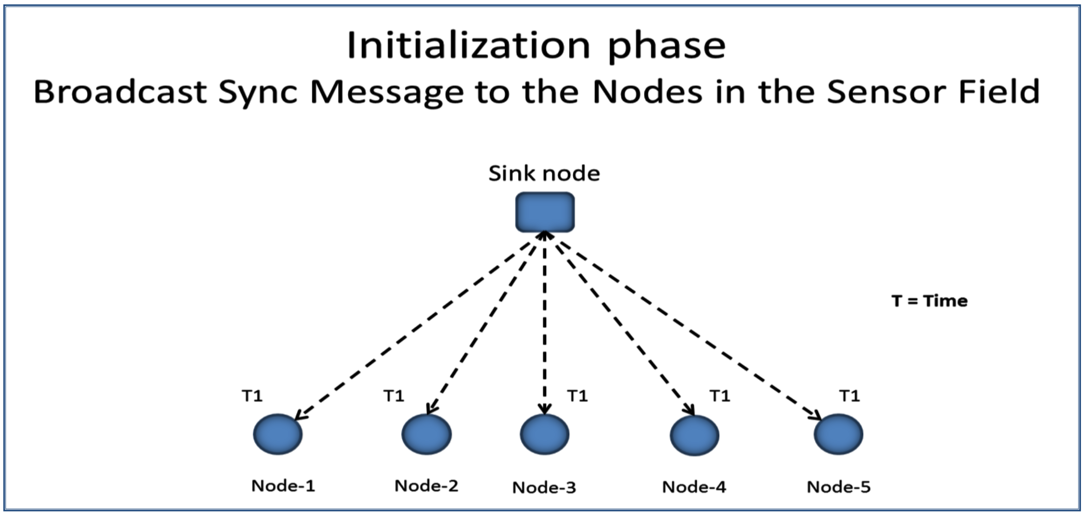


Figure 4.1 Broadcast SYNC Message in Initializtion Phase

After the broadcast SYNC message, the nodes reply to the sink node by TDMA. The node reply depends on the schedule of the sink node, as shown in Figure 4.2.

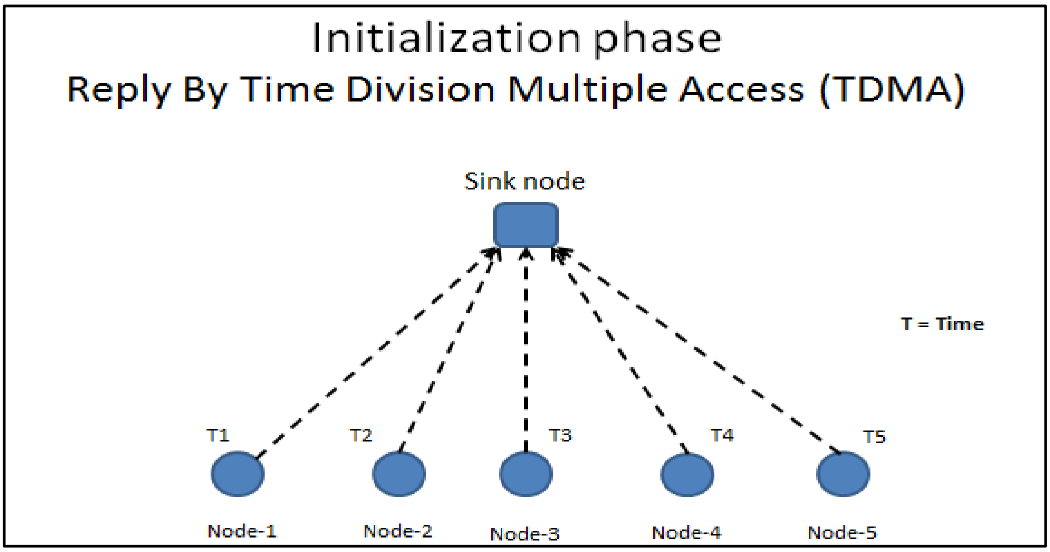


Figure 4.2 Replay By TDMA Initialization Phase

4.2.2 The Communication Phase

In this phase the sink node expects there is one of the nodes have a packet to send. The node which has the desire to send data should first check the channel and be sure that the channel is clear, then the Request To Send (RTS) is sent to the sink node. The sink node receives (RTS), then accepts the request and reply with Clear To Send (CTS). Therefore, the node starts to send data to the sink node. The channel is busy for this node if there any other node tries to send find the channel busy, then go back off to sleep for a while. After that, it checks again for the channel. If the channel is clear, the node sends (RTS) to the sink node. If the sink node is busy with another node, it neglects the request. If the sender node cannot receive the reply (CTS) it goes back off to sleep and does not send any packet.

From this, techniques (RTS, CTS) there is a reduction idle time and an increase in sleep time, as well as reduction collision. When idle time is reduced and sleep time is increased, it mean that there is saving in energy (Ye et al., 2002). Thus, the energy consumption in idle mode is greater than energy consumption in sleep time. By itself, the energy in sleep mode, is negligible. Hence, an expansion in sleep time at the expense of idle time leads to a saving in energy. Furthermore, an expansion in sleep time does not mean increased latency. The EEL-MAC design for the protocol depends on low duty cycle with high throughput. Thus, the EEL-MAC design depends on one hop communication between the nodes and sink node. Using one hop communication reduces delay and raises throughput. Therefore, the research reduces energy consumption with a saving in throughput. Figure 4.3 illustrates the communication phase and how the node can obtain the sink node using the CSMA mechanism. Furthermore, any node which tries to send RTS and cannot get a reply from a sink node goes to back off sleep. Instead of being in idle mode for a long time, thus leading to a saving in energy.

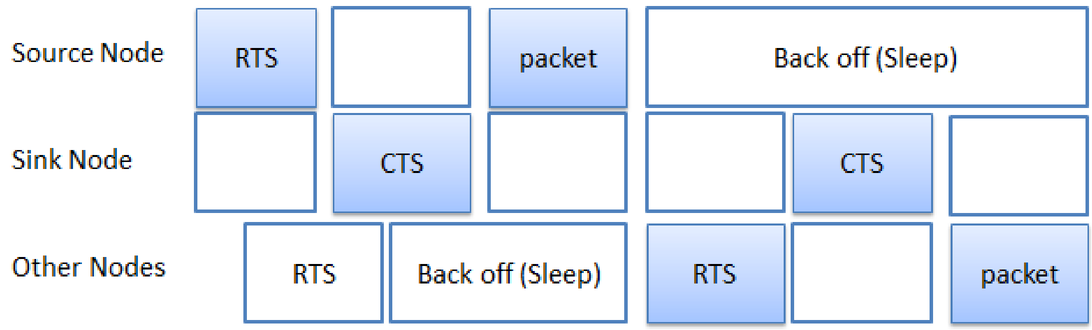


Figure 4.3 Packet Communication Using CSMA in EEL-MAC Protocol

To demonstrate clearly the communication phase these steps should be used.

Step 1: Node willing to send data send RTS first if the channel clear.

Step 2: The sink node receives the transmitted RTS and prepares the reply by sending CTS.

Step 3: The source node receives CTS and prepare for sending actual data.

Step 4: The source node sends the actual data packet.

Step 5: The sink node and channel busy with source node and cannot receive any packet from another node within communication time.

For more details about the communication phase, the research assumed the example to explain this phase. Suppose two nodes try to communicate with the sink node. The first one (Node-1) will can get the channel and sends RTS while another node (Node-2) back off (sleep). After that, Node-2 tries to send another time. The sink node replies to Node-1, the CTS. Then Node-1 can send a packet of data to the sink node as illustrated in Figure 4.4.

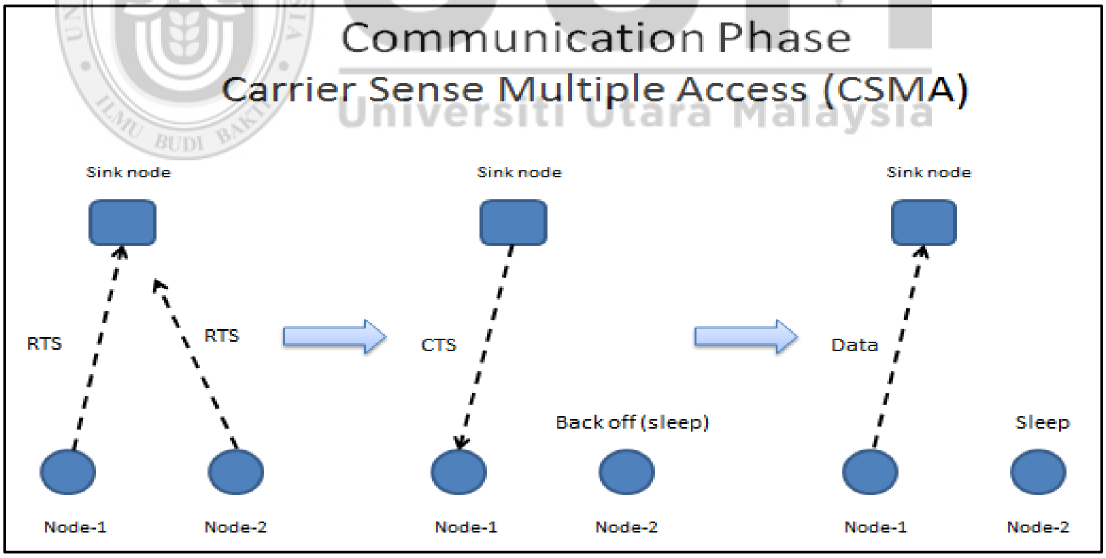


Figure 4.4 Communication Phase Using CSMA (a)

After the Node-1 finishes sending data it goes sleep. The Node-2 then tries to send RTS to the sink node. The sink node replies by CTS when Node-2 received CTS. At this time Node-2 can send the data packet to the sink node and this continues for all nodes which are willing to send data, as shown in Figure 4.5.

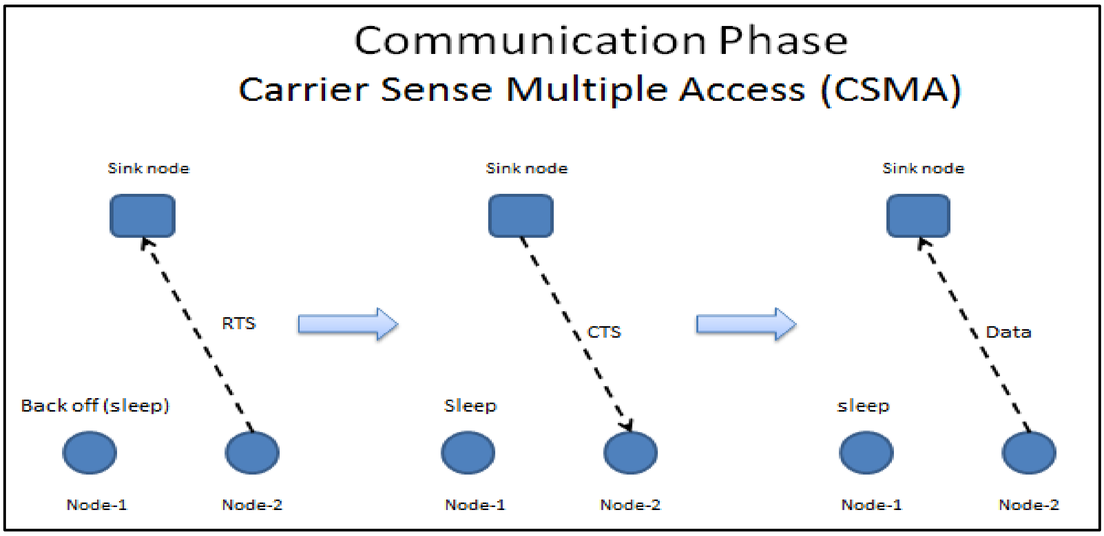


Figure 4.5 Communication Phase Using CSMA (b)

4.2.3 The Pseudocode for The EEL-MAC Protocol.

The pseudocode for the two phases starts with the initialization phase using TDMA mechanism then goes to communication phase using CSMA mechanism with RTS and CTS techniques.

```
      //For initializes phase
Node switch ON and Initializes all the parameters.
 Broadcast SYNC message with slot information.
 Node starts timer to wait random time for SYNC packet.
   If (Node received a SYNC packet)
     {
       Set Node in choose_schedule state & follow the schedule
in SYNC
       Set the TDMA_BDCST_Flag=1 for TDMA broadcast reply upon
timer expiry
     }
        Else
        Node State to IDLE until received a SYNC packet
               If (TDMA_BDCST_Flag is set)
                  {
             Sink node waits for a random delay time
```

```
              Broadcast Node's schedule by TDMA reply
              Set Sink node State to IDLE to ensure it receives
TDMA reply from nodes.
       }
      //For communication phase
        If  (Node timer counter value == SYNC period)
          {
             Sync time is over and node can send data in CSMA
now.
               If (Sink node Radio state != Sleep or Wait_Data)
                   Cannot send data and wait with the counter
time
                   Else
                       {
                        Start Scheduling Data
                        Start the Carrier sense timer with
random time.
                  Send RTS and set node status to WAIT_FOR_CTS
                  Set timer for CTS timeout
                  Receive CTS and send data
                  }
      }
      //For Sink node receiving data
      Receive RTS packet
            {
             If (( Radio state equal to IDLE) && No
transmission is   going on in channel)
                 {
                        Send CTS packet
                        Change Sink node status to
WAIT_FOR_DATA
                  }
              }
```


4.3 Energy Consumption Analysis

In this study the design of the proposed protocol depends on a one-hop communication because it reduces latency, increases delivery packets and saves energy (Ramchand & Lobiyal, 2011). Furthermore, the design depends on CSMA for translating data. Using this mechanism to help save energy by reducing idle time and increasing sleep times as long as possible. The phases of work in this design can overcome the energy consumption problem with high throughput with adaptive change in the topology. The research calculates the energy consumed in this design from these mathematical equations.

$$\mathbf{E_{Total} = E_S + E_R + E_{Idle} + E_{Sleep}} \quad (4.1)$$

From the first equation it is possible to calculate the energy consumption in this protocol. The E_S represents the energy consumed in the node when it tries to send one packet. E_R symbolizes the energy consumed in the node when it receives one packet. Furthermore, the E_{Idle} represents the energy consumed in the node when a stay waits to receive or send a packet. Finally, E_{Sleep} represents the energy consumed in the node as when it goes to sleep it is consuming negligible energy. Thus, the summation of this unit can obtain the total energy consumed in this protocol.

$$\mathbf{E_{Active} = E_S + E_R + E_{Idle}} \quad (4.2)$$

Actually, it is every node which switches between active and sleep mode. Depending on the design of this protocol. The active mode contains E_S, E_R and E_{Idle} and is shown in equation 4.2. Hence, the equation to calculate the total energy is in equation 4.3.

$$\mathbf{E_{Total} = E_{Active} + E_{Sleep}} \quad (4.3)$$

E_{Sleep}= very small and it is negligible.

Thus, can neglect E_{Sleep} then be active mode energy equal for total energy is shown in equation (4.4).

$$\mathbf{E_{Total} = E_{Active}} \quad (4.4)$$

This means that if increase sleep time and reduced active time can be increased by reducing idle time, energy consumption can be reduced (E_{Total}). The sleep mode energy saved is negligible and the network lifetime is prolonged.

4.4 Latency Analysis

Latency is the period from when the packet from the source node start to transmit in the direction of the sink node and receives the data (Youssef & Younis, 2007). This is the main reason that latency it used in a multi-hop transmission. That means if the packet needs to be sent from the source node to the sink node it is routed several times and has to wait to get the channel. Thus, every node which passes through it causes more of a delay. Due to, an increase number of node routes that increase total delay. The average end to end delay represents latency. If can be reduced, it will help to raise the network performance and achieve higher throughput and save more energy.

Therefore, the research depends on one-hop transmissions in the design to insure delivered packets for the sink node directly. Moreover, one hop communication reduces delay and energy consumption. Thus, leading to reduction in the percentage lost packets or delays in delivery and making latency remains in a minimum value.

4.5 Collision Analysis

Collusion in WSNs protocols often happens, which may result in two neighboring nodes transmitting a data packet simultaneously. This is called hidden station problem. As a result, both nodes are unable to complete their task of sending the packet (Tripathi & Kapoor, 2013).

When a collision happens it means that there is a delay and a reduction throughput, as well as a lost energy. When, there is a collision it means losing the packet sent, and the node tries to send it again. Therefore, it must wait a while to get the channel, then send a packet. This operation consumes, energy and adds time and causes a reduction the throughput.

To reduce the collision between packets in the EEL-MAC protocol, is designed to save energy. Employ features like (RTS) and (CTS) are useful in reducing collision (Ray, Carruthers, & Starobinski, 2003). This technique reduces expected collisions from occuring. To address the hidden terminal problem (Chiras, Paterakis, & Koutsakis, 2005), the RTS technique is used to check the channel busy before sending. Firstly, the permission is obtain by CTS to start to send the data packet. Using these techniques for the design reduces collision and enhances performance.

4.6 Initial Simulation Results

The research uses NS2.35 simulation to simulate the EEL-MAC design protocol to get the initial result for energy consumption and latency. Using performance metrics is energy consumption and latency.

4.6.1 Energy Consumption Results

Figure 4.6 shows the energy consumption in every node during the simulation of the EEL-MAC protocol. The initial energy of each the sensor node is set to 40 Joule. After finishing the simulation for 240 seconds, node-1 consumes 6.973 joule and node-2, 3, 4, 5 consume 7.046, 7.025, 7.126, 7.209 joule respectively as presented in Table 4.1. Thus the EEL-MAC protocol total energy consumed for five nodes is 35.379 joule.

Table 4.1 Energy Consumption for Every Node in EEL-MAC Protocol

Nodes	Time (Sec)	Energy consumption when finishes simulation (Joule)	Residual energy
1	236.5	6.973	33.027
2	235.8	7.046	32.954
3	238.5	7.025	32.975
4	239.5	7.126	32.874
5	237.5	7.209	32.791

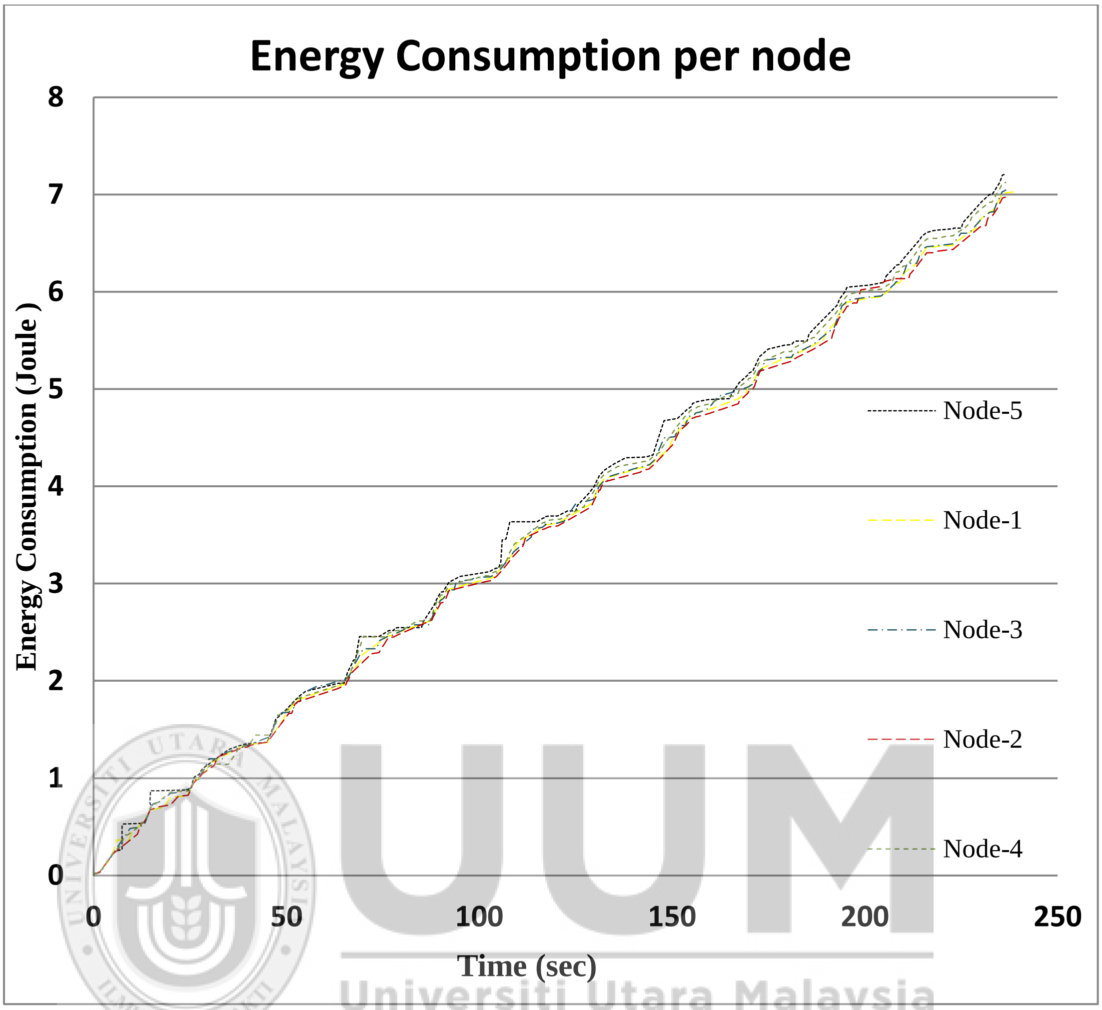


Figure 4.6 The Energy Consumption Per Node in EEL-MAC Protocol

Figure 4.7 shows the average energy consumption for all nodes in the sensor field. The X-axis is shown as the interval time in seconds for all simulation time 240 seconds. Otherwise, the Y-axis represents the average energy consumption for all nodes from the energy supplied with every node by 40 joule. Furthermore, from Table 4.2 it can be seen that the average energy consumption starts from zero with the beginning of simulation then gradually increases for the duration of the simulation until the end time reaches 7.1 joule. By using the equation 3.1 it is possible to calculate the average energy consumption in the EEL-MAC protocol.

Table 4.2 Average Energy Consumption for EEL-MAC Protocol

Time (Sec)	Average energy for EEL-MAC protocol (joule)
0	0
30	1.12
60	1.9
90	2.83
120	3.61
150	4.47
180	5.34
210	6.2
240	7.1

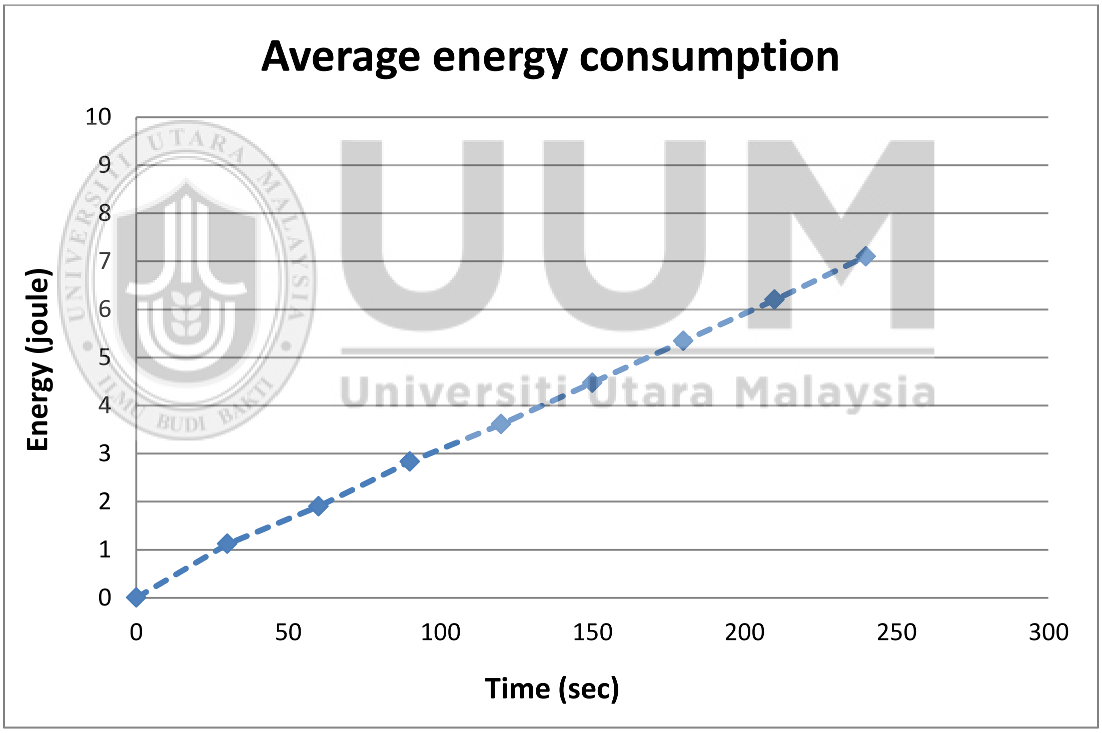


Figure 4.7 Average Energy Consumption in EEL-MAC Protocol

On the other hand, the Figure 4.8 illustrates the average energy consumption per second and can be calculated from equation 3.2.

From Figure 4.7 the average energy consumption has already been obtained at interval time every 30 seconds. The average energy consumption is divided for every period on the number of seconds in this period as in equation 3.2. After that, the results in Table 4.3 can be obtained. Figure 4.4 shows the X-axis interval simulation time and the Y-axis represents average energy consumption per second.

Table 4.3 Average Energy Consumption Per Second for EEL-MAC Protocol

Time (Sec)	Average energy (Joule)	Average energy consumption per Sec for EEL-MAC protocol (Joule)
0	0	0.0000
30	1.12	0.0373
60	1.9	0.0317
90	2.83	0.0314
120	3.61	0.0301
150	4.47	0.0298
180	5.34	0.0297
210	6.2	0.0295
240	7.1	0.0296

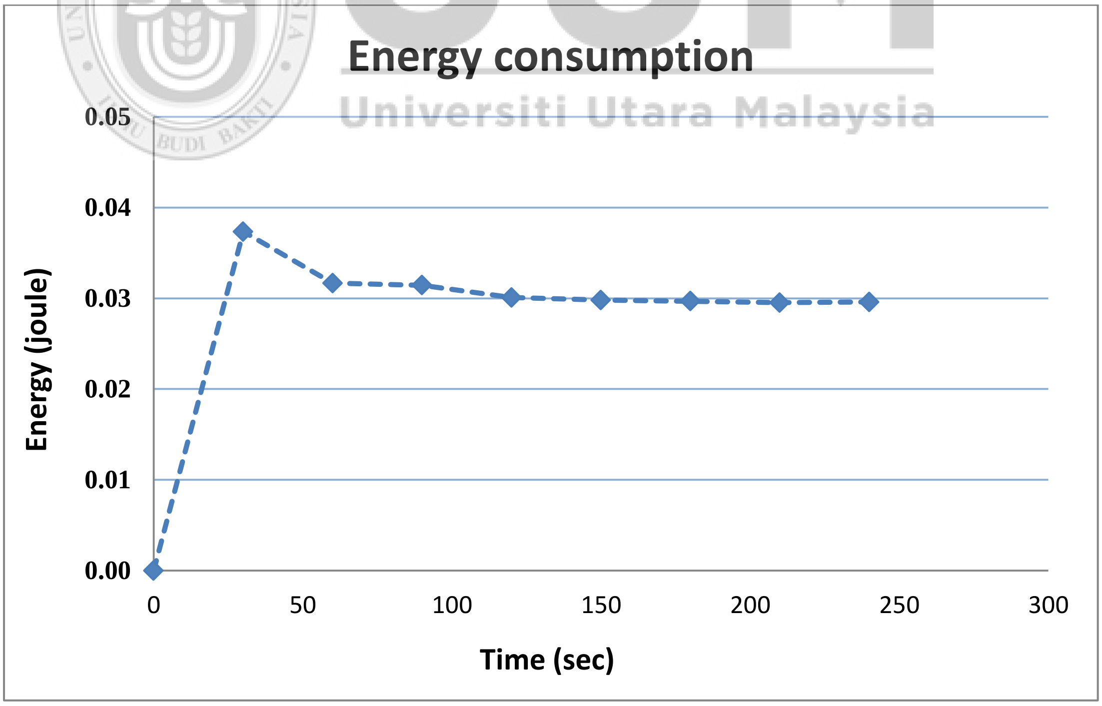


Figure 4.8 Average Energy Consumption Per Second At Interval Time in EEL-MAC.

4.6.2 Latency Results

To obtain these initial results from the simulation about how to calculate the average end-to-end delay should be first obtain delayed for every packet send from the source node to the destination sink node. The equation 3.3 is used to calculate the delay. Furthermore, it is necessary to calculate the average of delay from a summation delay for all packets and divide the number of packets, as shown in equation 3.4. In Figure 4.9 the X-axis represents the total time of the simulation of about 240 seconds and the Y-axis represents an average of delay for all nodes. The interval time is every 30 seconds, as shown in Table 4.4.

Table 4.4 Latency for EEL-MAC Protocol

Time (Sec)	Latency (Sec) for EEL-MAC protocol
0	0.000
30	0.324
60	0.315
90	0.388
120	0.390
150	0.364
180	0.375
210	0.350
240	0.374

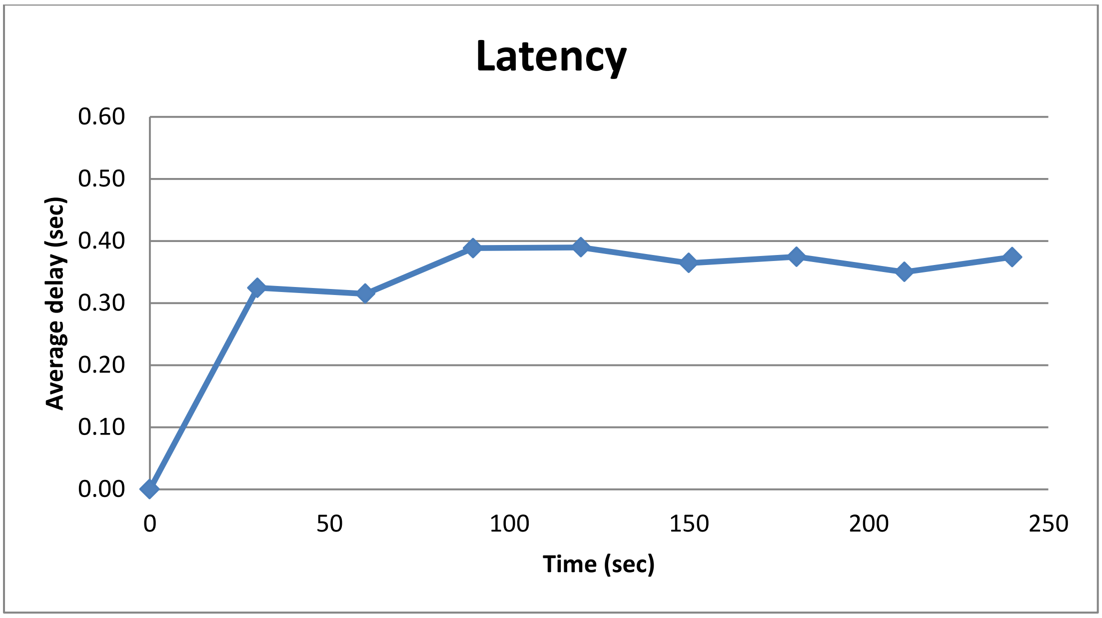


Figure 4.9 Latency in EEL-MAC Protocol

The result appears in Table 4.5 and is presented in Figure 4.10. The X-axis is the interval of packet generation. There is a gradual reduction in the period between packet generation which leads to heavier network load. This starts from the 18-second interval time between the generation of the packet which means the normal loads then reduce until reaching a one-second interval time which indicates that there is a higher network load (Klein, 2012). Therefore, it can be seen that the Y-axis raises the average delay, in conjunction with the reduced time interval packet generation. The results in Table 4.5 can be collected by simulating the EEL-MAC protocol by different interval generation packet time. The results are shown in Figure 4.10.

Table 4.5 Interval Time of Packet Generation for EEL-MAC Protocol

Interval time of packet generation (Sec)	Latency (Sec)
1	0.1172
2	0.104
4	0.0763
6	0.0556
8	0.0401
10	0.0312
12	0.0183
14	0.0144
16	0.0128
18	0.0131

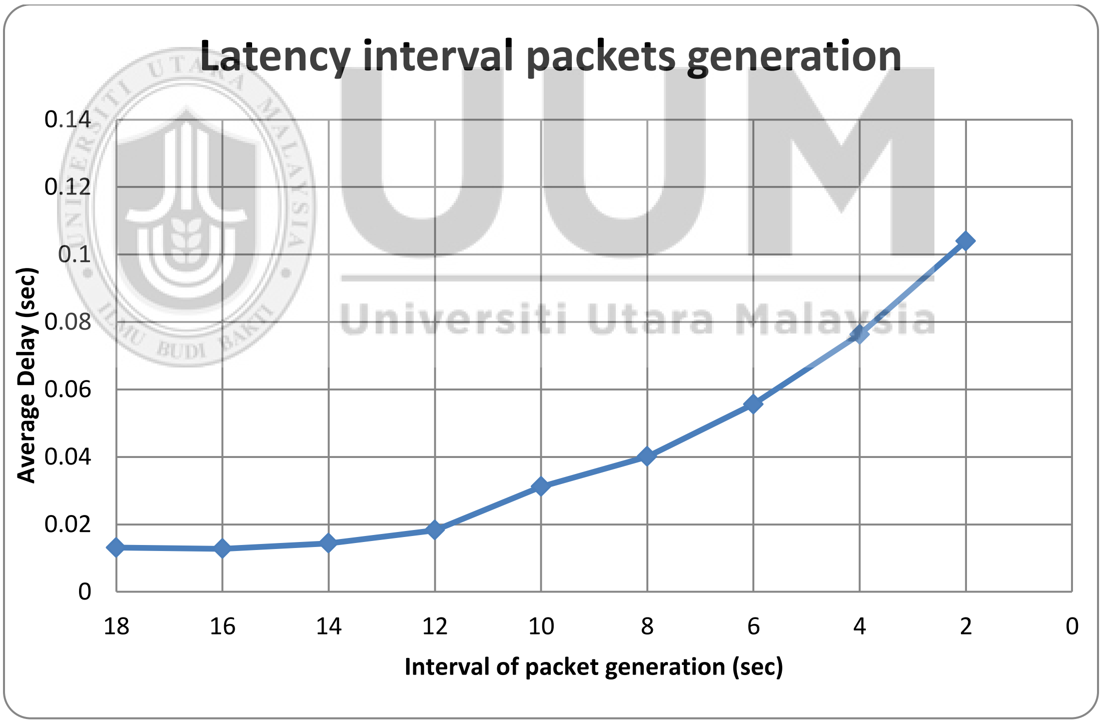
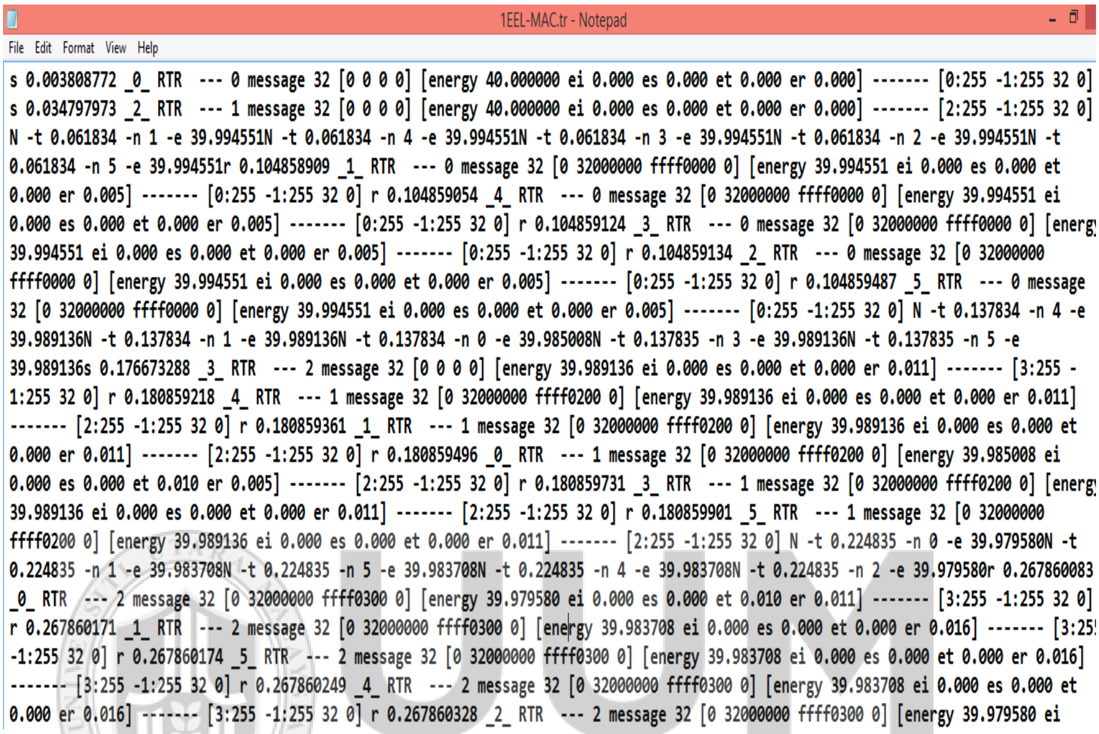


Figure 4.10 Latency The Interval Packets Generation in EEL-MAC Protocol

4.7 Trace File

This part from trace file to simulate the EEL-MAC protocol. The trace files very huge, therefore, will just put part from this file to illustrate the raw data before filtering by using AWK language and Microsoft Excel file. This is shown in Figure 4.11.




```
s 0.003808772 _0_ RTR  --- 0 message 32 [0 0 0 0] [energy 40.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [0:255 -1:255 32 0]
s 0.034797973 _2_ RTR  --- 1 message 32 [0 0 0 0] [energy 40.000000 ei 0.000 es 0.000 et 0.000 er 0.000] ------- [2:255 -1:255 32 0]
N -t 0.061834 -n 1 -e 39.994551N -t 0.061834 -n 4 -e 39.994551N -t 0.061834 -n 3 -e 39.994551N -t 0.061834 -n 2 -e 39.994551N -t
0.061834 -n 5 -e 39.994551r 0.104858909 _1_ RTR  --- 0 message 32 [0 32000000 ffff0000 0] [energy 39.994551 ei 0.000 es 0.000 et
0.000 er 0.005] ------- [0:255 -1:255 32 0] r 0.104859054 _4_ RTR  --- 0 message 32 [0 32000000 ffff0000 0] [energy 39.994551 ei
0.000 es 0.000 et 0.000 er 0.005] ------- [0:255 -1:255 32 0] r 0.104859124 _3_ RTR  --- 0 message 32 [0 32000000 ffff0000 0] [energ
39.994551 ei 0.000 es 0.000 et 0.000 er 0.005] ------- [0:255 -1:255 32 0] r 0.104859134 _2_ RTR  --- 0 message 32 [0 32000000
ffff0000 0] [energy 39.994551 ei 0.000 es 0.000 et 0.000 er 0.005] ------- [0:255 -1:255 32 0] r 0.104859487 _5_ RTR  --- 0 message
32 [0 32000000 ffff0000 0] [energy 39.994551 ei 0.000 es 0.000 et 0.000 er 0.005] ------- [0:255 -1:255 32 0] N -t 0.137834 -n 4 -e
39.989136N -t 0.137834 -n 1 -e 39.989136N -t 0.137834 -n 0 -e 39.985008N -t 0.137835 -n 3 -e 39.989136N -t 0.137835 -n 5 -e
39.989136s 0.176673288 _3_ RTR  --- 2 message 32 [0 0 0 0] [energy 39.989136 ei 0.000 es 0.000 et 0.000 er 0.011] ------- [3:255 -
1:255 32 0] r 0.180859218 _4_ RTR  --- 1 message 32 [0 32000000 ffff0200 0] [energy 39.989136 ei 0.000 es 0.000 et 0.000 er 0.011]
------- [2:255 -1:255 32 0] r 0.180859361 _1_ RTR  --- 1 message 32 [0 32000000 ffff0200 0] [energy 39.989136 ei 0.000 es 0.000 et
0.000 er 0.011] ------- [2:255 -1:255 32 0] r 0.180859496 _0_ RTR  --- 1 message 32 [0 32000000 ffff0200 0] [energy 39.985008 ei
0.000 es 0.000 et 0.010 er 0.005] ------- [2:255 -1:255 32 0] r 0.180859731 _3_ RTR  --- 1 message 32 [0 32000000 ffff0200 0] [energ
39.989136 ei 0.000 es 0.000 et 0.000 er 0.011] ------- [2:255 -1:255 32 0] r 0.180859901 _5_ RTR  --- 1 message 32 [0 32000000
ffff0200 0] [energy 39.989136 ei 0.000 es 0.000 et 0.000 er 0.011] ------- [2:255 -1:255 32 0] N -t 0.224835 -n 0 -e 39.979580N -t
0.224835 -n 1 -e 39.983708N -t 0.224835 -n 5 -e 39.983708N -t 0.224835 -n 4 -e 39.983708N -t 0.224835 -n 2 -e 39.979580r 0.267860083
_0_ RTR  --- 2 message 32 [0 32000000 ffff0300 0] [energy 39.979580 ei 0.000 es 0.000 et 0.010 er 0.011] ------- [3:255 -1:255 32 0]
r 0.267860171 _1_ RTR  --- 2 message 32 [0 32000000 ffff0300 0] [energy 39.983708 ei 0.000 es 0.000 et 0.000 er 0.016] ------- [3:25
-1:255 32 0] r 0.267860174 _5_ RTR  --- 2 message 32 [0 32000000 ffff0300 0] [energy 39.983708 ei 0.000 es 0.000 et 0.000 er 0.016]
------- [3:255 -1:255 32 0] r 0.267860249 _4_ RTR  --- 2 message 32 [0 32000000 ffff0300 0] [energy 39.983708 ei 0.000 es 0.000 et
0.000 er 0.016] ------- [3:255 -1:255 32 0] r 0.267860328 _2_ RTR  --- 2 message 32 [0 32000000 ffff0300 0] [energy 39.979580 ei
```


Figure 4.11 Part From Trace File

4.8 Summary

In this chapter the phases of the design of the EEL-MAC protocol containing the initialization phase and communication phase with pseudocode have been explained. Next, how to calculate energy consumption and latency has been illustrated. Furthermore, the EEL-MAC protocol was simulated and the initial results were obtained with part from trace file.

CHAPTER FIVE
EVALUATION OF EEL-MAC PROTOCOL

5.1 Introduction

The previous chapter introduced the design and initial implementation issues of the EEL-MAC protocol and the performance metrics used. This chapter has two goals:

Firstly, to evaluate the proposed EEL-MAC protocol by comparing it with the MS-MAC protocol as the EEL-MAC is to extents MS-MAC. This is to determine the extent of the enhancement (Wu, Kumekawa, & Kato, 2010). Furthermore, the design objective for the MS-MAC protocol to use energy efficiently in both stationary and mobile scenarios (Hameed, Shaaban, Faheem, & Ghoniemy, 2009). The performance metrics used in the comparison are energy consumption, latency and throughput.

Secondly, to evaluate the effectiveness of the proposed EEL-MAC protocol by comparing it with several significant protocols using two performance metrics; energy consumption and latency. The aim of this study is to reduce energy consumption and latency in wireless sensor networks by harnessing the potentials/benefits of TDMA and CSMA mechanisms, together by using the one hop communication technique, as discussed in Chapter Four.

The rest of this chapter is organized as follows. Section 5.2 evaluates the extent of enhancement achieved in EEL-MAC by comparing with its base protocol, i.e. the MS-MAC protocol. Section 5.3 evaluates the effectiveness of the proposed EEL-MAC by comparing it with other protocols, Section 5.4 discusses the results and gives an overall conclusion. Section 5.5 summarises the chapter.

5.2 Evaluating the EEL-MAC's Extent of Enhancement

The research to evaluate the enhancement of the EEL-MAC protocol with MS-MAC protocols compared base performance metrics; energy consumption, latency and throughput to achieve the first goal. This study uses NS-2 network simulation with operating system centos 7 as the environment for our experiment. The NS-2 is the open source and is based on language Object Oriented Tool Command Language (OTCL) and C++. Furthermore, the NS-2.35 produces results that are considerably closer to real environments (Razaque & Elleithy, 2014a).

Firstly, it was necessary to run the simulations with the MS-MAC and EEL-MAC protocol because the EEL-MAC protocol is based on the MS-MAC protocol and evaluates the enhancement by hybrid MAC design to reduce energy and latency (Raja & Su, 2008).

Secondly, investigate the performance metrics from it is necessary to the simulated scenarios comprised between them. The sensor nodes are randomly deployed in the area of 300×300 m^2. The initial energy of every sensor node was set to 40 joule. The total simulation time was 240 sec. The results shown are an average of 10 simulation runs (Zhang et al., 2009). Regarding the simulation parameters, the most common parameter to be used in the proposed scenario design are (Razaque & Elleithy, 2014a), (Al-Yasiri & Sunley, 2007), (Rebahi et al., 2005) are illustrated in Table 5.1.

Table 5.1 Values of Parameters for EEL-MAC and MS-MAC Protocol

Parameters	Description
Initial energy of node	40 Joules
Bandwidth of node	50 Kb/S
Number of sensors	5
Size of network	300 × 300 square meters
Packet transmission rate	30 Packets/Sec
Simulation time	240 sec
Tx power	16 mW,
Rx power	12 mW

5.2.1 Energy Consumption Analysis

Energy consumption is one of the performance metrics which is very important in this research. All nodes in this experiment were supplied by 40 joule energy. It was necessary to monitor energy consumption through simulation time 240 seconds for both the MS-MAC and EEL-MAC protocols. It is clear that the MS-MAC line in Figure 5.1 is greater than the EEL-MAC protocol. Thus, MS-MAC consumes more energy from the EEL-MAC protocol. When the simulation of the MS-MAC protocol was completed the average energy consumption of the nodes was 12 joule and the residual energy was 28 joule.

On the other hand, the EEL-MAC protocol saved more energy, having 32.9 joule residual energy and consuming just 7.1 joule. In addition, using a TDMA mechanism in synchronization phase to reduce idle time saves energy and uses one hop communication with RTS, CTS techniques reduce collision and save more energy thus outperforming the EEL-MAC protocol on the MS-MAC protocol. The percentage increase calculated by conserving the energy enhancement to EEL-MAC in equation 5.1 as follows:

[(Initial Energy - Energy Consumed) / (Initial Energy)] *100= % energy saved (5.1)

Equation 5.1 was applied to the EEL-MAC and MS-MAC protocols to obtain the energy consumption results. It was found that for the MS-MAC there was a 70% saving of energy, while for EEL-MAC there was an 82.25% saving of energy. In other words, EEL-MAC was 12.25% more efficient, as was be seen in Table 5.2 and Figure 5.1.

Table 5.2 Average Energy Consumption for EEL-MAC and MS-MAC Protocols

Time (sec)	**Average energy for EEL-MAC (joule)**	**Average energy for MS-MAC (joule)**
0	0	0
30	1.12	1.29
60	1.9	2.76
90	2.83	4.14
120	3.61	6.12
150	4.47	7.95
180	5.34	9.72
210	6.2	10.92
240	7.1	12

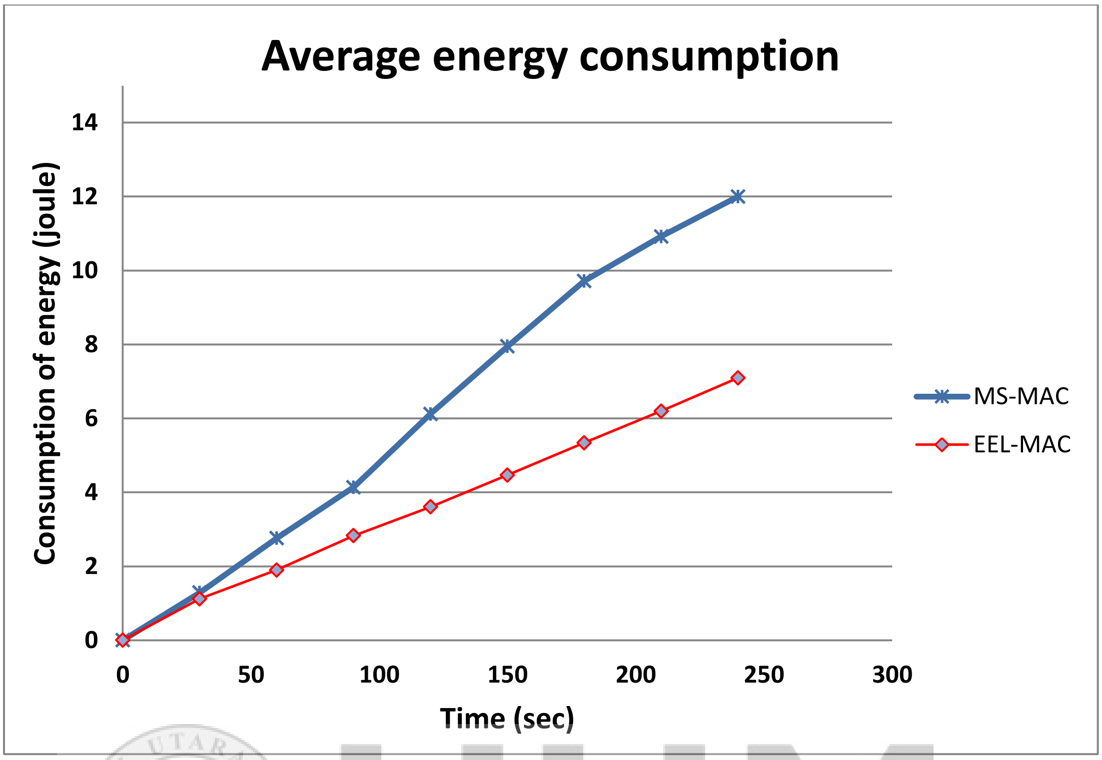


Figure 5.1 Average Energy Consumption for EEL-MAC and MS-MAC Protocols

The average energy consumption per second shows average energy consumption for every second for all nodes. The standard method is calculated to know energy consumption regardless of the energy supply. However, Figure 5.2 shows the energy consumption interval times for the MS-MAC protocol line. In the figure this starts from 0.043 joule at time 30 seconds the near area, to the EEL-MAC protocol. However, it rises gradually until the peak energy consumption reaches 0.054 joule at time 180 seconds. The simulation finishes at 0.050 joule at time 240 seconds.

On the other hand, the EEL-MAC protocol line in the figure is at an incline, which means it save more energy. Figure 5.2 illustrates stage energy consumption within the simulation time which starts from 0.037 joule at 30 seconds. It then gradually decreases smoothly and saves more energy until the simulation ends with 0.029 joule at 240 seconds. Finally, average energy consumption per second increases for EEL-MAC. Table 5.3 shows the EEL-MAC protocol outperformed MS-MAC protocol.

Table 5.3 Average Energy Consumption Per Sec for EEL-MAC and MS-MAC Protocols.

Time (sec)	Average energy consumption per Sec for EEL-MAC (joule)	Average energy consumption per Sec for MS-MAC (joule)
0	0	0
30	0.037	0.043
60	0.031	0.046
90	0.031	0.046
120	0.030	0.051
150	0.029	0.053
180	0.029	0.054
210	0.029	0.052
240	0.029	0.050

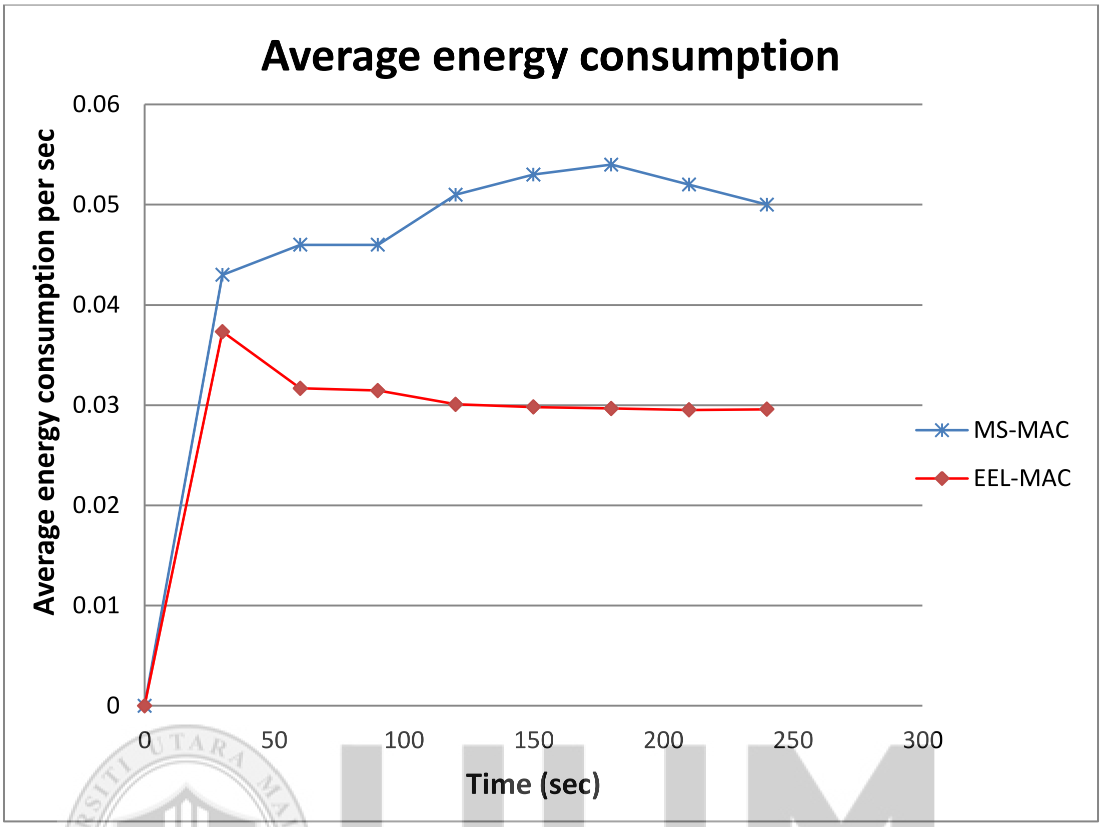


Figure 5.2 Average Energy Consumption Per Second for EEL-MAC and MS-MAC Protocols

5.2.2 Latency Analysis

Latency is represented by the average end-to-end delay. The delay time when the transmission starts from the source node until a packet is received by the sink node (Youssef & Younis, 2007). Figure 5.3 shows the end-to-end delay for both MAC protocols. It can be seen that the MS-MAC line in the figure fluctuates. Moreover, the MS-MAC protocol depends on multi-hop to communicate and send data. The main reason for the increase in the end-to-end delay is that it depends upon the number of hops. As a result, the multi-hop expands latency.

The simulation starts with an average delay from 0.708 sec at time 30 seconds, then reaches a maximum delay at 0.741 sec at time 90 and a minimum delay at 0.542 sec at time 210. The simulation time finished at 0.607 sec at 240 sec, as shown in Table 5.4.

However, the EEL-MAC protocol line in the figure was smoother and the average end-to-end delay was less than the MS-MAC protocol. In addition, the EEL-MAC protocol depends on one-hop communication. The line in Figure 5.3 average delay started from 0.324 sec then increased and finally levelled off until the simulation time of 240 sec with an average delay at 0.374 sec. Finally, the percentage to extend the improvement for EEL-MAC as equation (5.1) was applied as [(MS-MAC latency – EEL-MAC latency) / MS-MAC latency]*100.

It can be clearly seen that the EEL-MAC percentage which enhances reduced latency is 38.38%. The results outperformed EEL-MAC on the MS-MAC protocol in Table 5.4 and Figure 5.3.

Table 5.4 Presents Latency for EEL-MAC And MS-MAC Protocols.

Time (sec)	Average end-to-end delay for EEL-MAC (sec)	Average end-to-end delay for MS-MAC (sec)
30	0.324	0.708
60	0.315	0.608
90	0.388	0.741
120	0.390	0.78
150	0.364	0.598
180	0.375	0.731
210	0.350	0.542
240	0.374	0.607

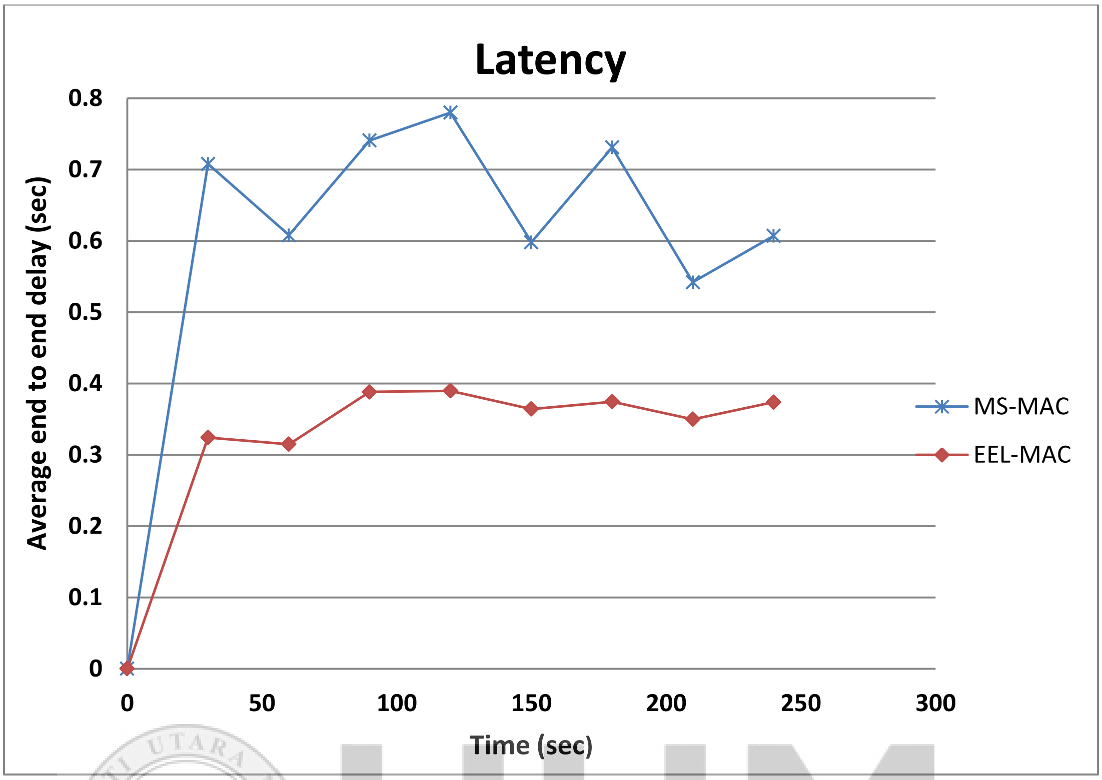


Figure 5.3 Latency for EEL-MAC and MS-MAC Protocols

5.2.3 Throughput Analysis

Throughput is represented by the number of packets generated and received for the sink node within a certain time (Yadav et al., 2009). Regarding this experiment, the EEL-MAC protocol can deliver more packets from the MS-MAC protocol. The EEL-MAC protocol started by delivering 73 packets in 30 seconds. However, the MS-MAC in the first 30 seconds was able to deliver just 69 packets, which is less than the EEL-MAC protocol. The simulation finished after 240 seconds with 535 packets.

Otherwise, the EEL-MAC protocol finished the simulation with 577 packets delivered. There is a clear difference between the throughput of both MAC protocols, which shows the enhanced EEL-MAC protocol. The percentage increased the enhancement for EEL-MAC 7.27% by applying the equation [(EEL-MAC packets - MS-MAC packets) / EEL-MAC packets] * 100. The EEL-MAC received packet per second was calculated using equation 5.2.

$$\sum \text{received packets} / \sum \text{time} = \text{received packet per second} \qquad (5.2)$$

equals 2.4 packets per sec, while the MS-MAC equals 2.22 packets per sec. This is because the EEL-MAC protocol used the one hop communication technique. This technique increased packets delivered and reduced latency. This in turn helped to boost throughput. The simulation results of throughput for EEL-MAC and MS-MAC protocol are presented in Table 5.5 and Figure 5.4.

Table 5.5 Throughput of EEL-MAC and MS-MAC Protocols.

Time (sec)	Packets received in EEL-MAC	Packets received in MS-MAC
0	0	0
30	73	69
60	139	130
90	219	202
120	283	259
150	355	330
180	429	391
210	501	461
240	577	535

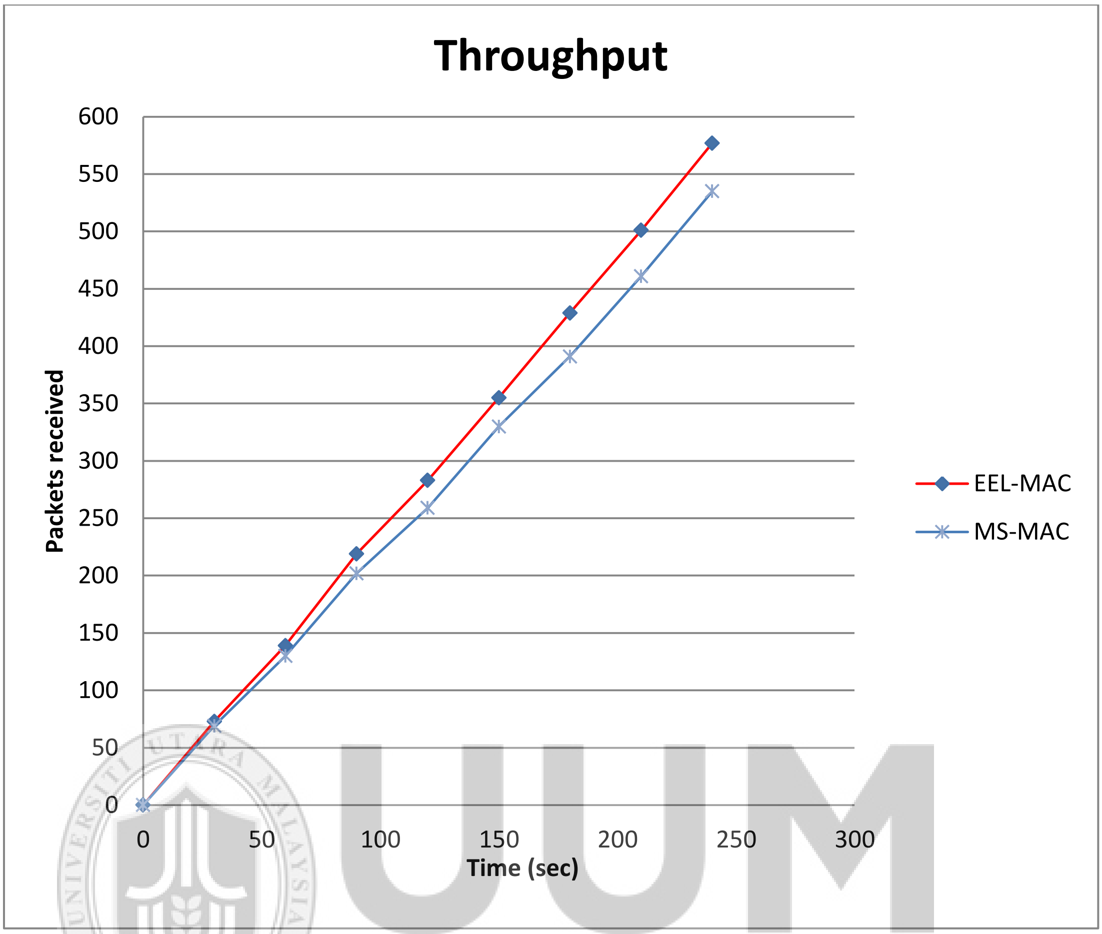


Figure 5.4 Throughput Comparison for EEL-MAC and MS-MAC Protocols

5.3 Evaluating EEL-MAC Effectiveness

The research to evaluate the effectiveness of the EEL-MAC protocol with other MAC protocols was compared based on two performance metrics; energy consumption and latency. The simulation parameters were based on (Razaque & Elleithy, 2014a), as shown in Table 5.6

Table 5.6 Simulation Parameters for EEL-MAC Protocl

Parameters	Description
Initial energy of node	250 Joules
Bandwidth of node	50 Kb/S
Number of sensors	105
Size of network	300 × 300 square meters
Packet transmission rate	30 Packets/Sec
Simulation time	35 minute
Tx power	16 mW,
Rx power	12 mW

5.3.1 Energy Consumption Analysis

In this section, research was perfarmed to evaluate the effectiveness of the EEL-MAC with BN-MAC, X-MAC (Buettner, Yee, Anderson, & Han, 2006) and Low Power Listening (LPL) (Polastre, Hill, & Culler, 2004) MAC protocols. The outcome of the comparison with the BN-MAC protocol is shown in Figure 5.5. The energy consumption in the EEL-MAC protocol line in the figure was superior to BN-MAC. The BN-MAC and EEL-MAC protocol consumed almost the same amount of energy, as shows in Figure 5.5. However, the BN-MAC protocol used a lot of models and techniques to reduce energy (Abdul Razaque, 2015) such as:

- The Least Distance Smart Neighboring Search (LDSNS) model.
- The Intelligence Decision Making (IDM) model.
- The Automatic Active and Sleep (AAS) model.
- The Intra Synchronized Communication model.
- The Lower Power Listening (LPL) technique. This uses the short preamble and semi-synchronized feature, as well as automatic buffering.

Furthermore, the BN-MAC protocol used other models to choose the boarder node from other nodes based on the energy level and memory allocation resources in order to improve Quality of Service (QoS) such as:

- The Dynamic Boarder Node Selection Process (DBNSP) model.
- The Level of Energy Information (LEI) algorithm.
- The Optimized Data Frame Format (ODFF) model.

Additionally, there are other models such as the Smart Queuing (SQ) model and the Adaptive Application Independent Aggregation (AAIA) model. The BN-MAC design used more than ten models and techniques (Abdul Razaque, 2015). This is very complex and requires special network content. The special nodes have the ability to implement all these models and techniques. Due to the fact that the special node is costly, this complexity of design and high cost are considered negative features for the BN-MAC protocol.

Furthermore, the energy consumed by EEL-MAC is less than the X-MAC and LPL protocols. Both X-MAC and LPL protocols reduce energy consumption by using the preamble, however LPL uses a long preamble. Moreover, X-MAC is based on LPL but uses a short preamble to reduce energy consumption. However, the comparison results in Table 5.7 and Figure 5.5 clearly show the superiority of EEL-MAC.

Otherwise, the EEL-MAC protocol uses simple mechanisms (TDMA, CSMA) and the one hop communication technique. The simple design of EEL-MAC can be implemented in the network with a simple node at low cost. Therefore, EEL-MAC is superior to BN-MAC due to its simplicity of design and low cost. EEL-MAC was able to achieve almost the same results as shown in Table 5.7. At the beginning, EEL-MAC consumed energy smoothly with little fluctuation depending on how the phase worked. When working with SYNC phases, the curvature increased and in phase communication, the curvature decreased. The EEL-MAC simulation ended with an energy consumption of 137.792 joule after 35 minutes, while the BN-MAC, X-MAC and LPL MAC protocol consumed energy at 140, 230, 245 joule respectively. The EEL-MAC performance was better than other protocols due to the fact that the was on energy saving of 45.2%. However, in the other protocols there was a saving of 44%, 8% and 2% respectively depending on equation 5.1.

On the other hand, the BN-MAC protocol energy consumption was not stable because a lot of models and techniques were used. Moreover, in every model different things like energy level, environment and memory resources were checked. All these responsibilities consumed more energy.

Table 5.7 Energy Consumption for EEL-MAC and Other MAC Protocols (Razaque & Elleithy, 2014a)

Time (minule)	**EEL-MAC (joule)**	**BN-MAC (joule)**	**X-MAC (joule)**	**LPL (joule)**
0	0	0	0	0
5	20	30	50	60
10	37	50	120	120
15	53	90	130	170
20	73	110	170	190
25	99	120	190	220
30	124	130	210	240
35	137	140	230	245

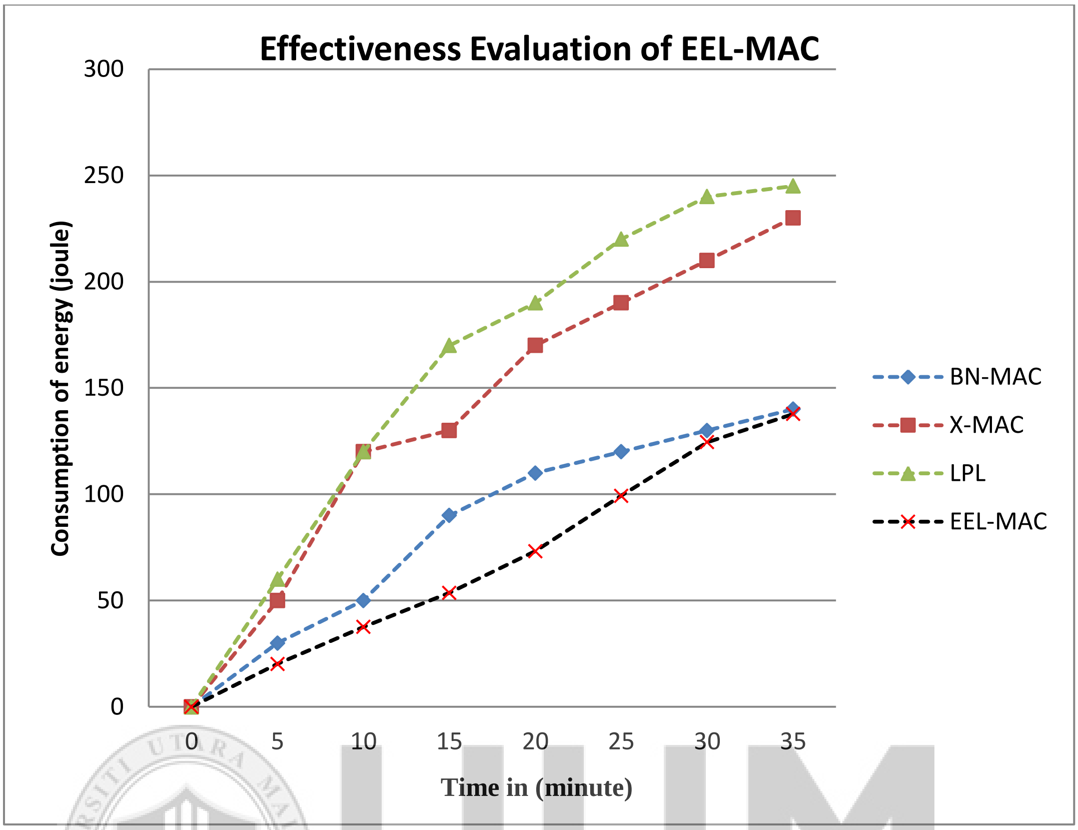


Figure 5.5 Effectiveness Evaluation of EEL-MAC and Other MAC Protocols

5.3.2 Latency Analysis

The research compared the latency of the EEL-MAC protocols with other MAC protocols such as BN-MAC, Z-MAC, LPRT-MAC, Speck-MAC, ADC-SMAC and A-MAC. Figure 5.6 shows the latency results for EEL-MAC and other MAC protocols depending on Table 5.8. The EEL-MAC and BN-MAC latency results were close to both EEL-MAC and BN-MAC using the same technique to reduce latency in the one hop communication technique.

In the EEL-MAC protocol the latency ranged from a minimum of 0.43 sec and a maximum of 0.65 sec, depending on the number of packets sent, while with BN-MAC the minimum was 0.6 and the maximum 0.7, as shown in Table 5.8. Moreover, this result refers to EEL-MAC performance compared to other MAC protocols like (BN-MAC, Z-MAC, ADC-SMAC, LPRT-MAC, A-MAC and Speck-MAC), respectively. This was done by using equation 5.3, which was applied to all MAC protocols.

[(Other-MAC latency - EEL-MAC latency) / Other-MAC latency] * 100 =The percentage of reduce latency (5.3)

The percentage was 17.14%, 27.5%, 35.55%, 88.4%, 90.33% and 93.55%. Table 5.8 shows the superiority of the EEL-MAC protocol and the effectiveness of reduced latency compared with other MAC protocols.

Table 5.8 Latency For EEL-MAC and Other MAC Protocols(Razaque & Elleithy, 2014a)

Packet generation interval (sec)	Delay BN-MAC (sec)	Delay ADC-SMAC (sec)	Delay Z-MAC (sec)	Delay A-MAC(sec)	Delay LPRT-MAC (sec)	Delay Speck-MAC (sec)	Delay EEL-MAC (sec)
3	0.7	0.6	0.8	1	3	7	0.64
6	0.6	0.7	0.7	2	3	8	0.43
9	0.7	0.9	0.9	2	2	9	0.53
12	0.6	2	0.6	4	4	11	0.44
15	0.6	0.8	0.9	5	0.9	11	0.59
18	0.6	2	0.7	6	4	11	0.49
21	0.7	0.8	0.6	5	3	12	0.65
24	0.7	0.9	0.8	6	5	9	0.58

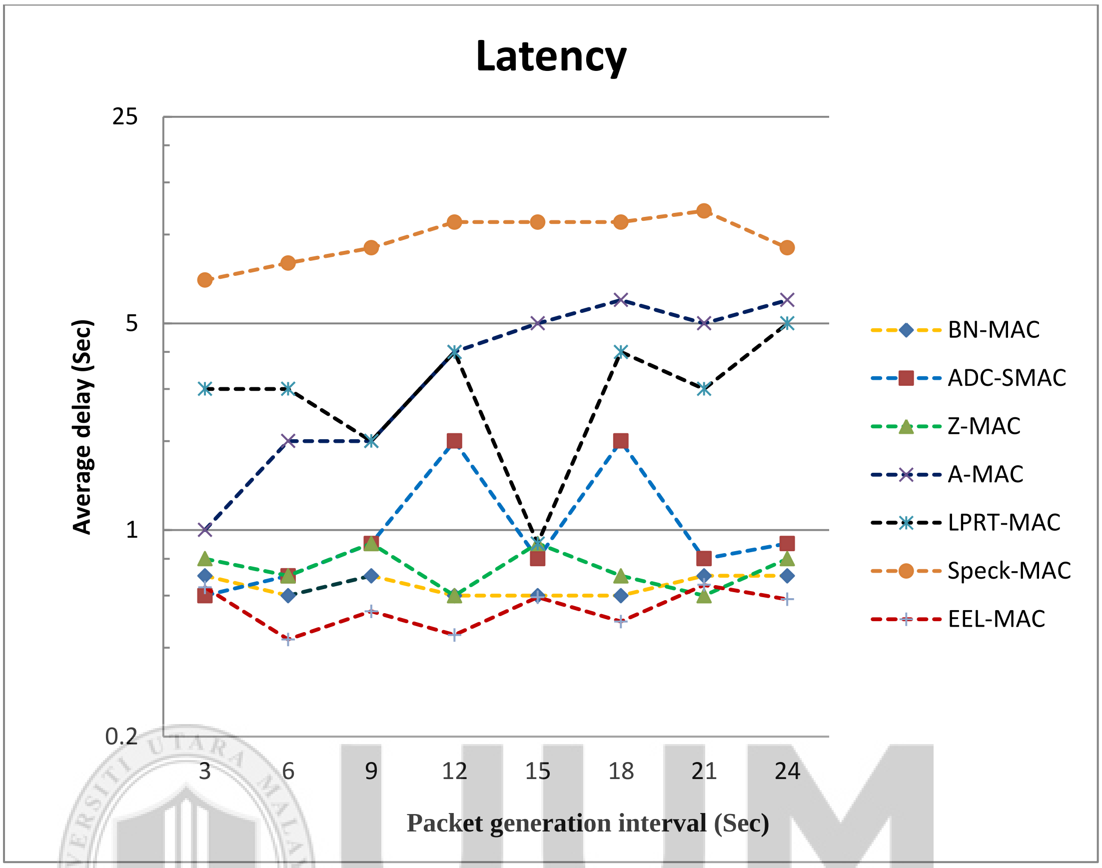


Figure 5.6 Latency Evaluation Effectiveness for EEL-MAC and Other Protocols

5.4 Discussion

The main purpose of this research is to prolong WSN lifetime by reducing energy consumption. Therefore, it is based on the EEL-MAC design content on the two-phase start with a TDMA mechanism used by the synchronization phase. The CSMA mechanism is used by the communication phase. By using this two mechanism the hybrid MAC protocol is obtained.

Furthermore, latency can be reduced depending on the one-hop communication technique which helps to decrease latency and enhances the performance of the EEL-MAC protocol, even during high throughput.

Regarding energy resulting from the first comparison of average energy consumption, the EEL-MAC protocol consumption was superior at 7.1 joule, which means a saving of 82.29% from the battery. However, MS-MAC consumed 12 joule, which means a saving of just 70 % from the battery. The EEL-MAC protocol was superior to MS-MAC in reducing energy consumption. This means that the original MS-MAC protocol can be improved greatly. At the same point, (the average energy consumption per second) the EEL-MAC protocol consumed 0.029 joule per second, while MS-MAC consumption was 0.05 joule per second. That means the EEL-MAC protocol clearly outperformed the MS-MAC in terms of energy consumption.

The second objective of this research is to reduce latency. Distinction the EEL-MAC protocol using one-hop in communication data technique gives it short average end-to-end delay and reduces the latency problem. However, MS-MAC depends on the multi-hop communication technique, which increases latency. As a result, the EEL-MAC protocol achieved an average end to end delay of 0.373 seconds, while the MS-MAC achieved an average end to end delay of 0.607 seconds. This proves the EEL-MAC protocol is superior to MS-MAC.

Finally, it is necessary to discuss the throughput results. This is important because it is one of the performance metrics. The EEL-MAC protocol can deliver 577 packets more from the MS-MAC protocol which delivered only 535 packets. By comparing the results, the EEL-MAC protocol is superior to the MS-MAC protocol in terms of performance. The results were evaluated to enhance MS-MAC. This indicates that the EEL-MAC has the ability to enhance MS-MAC by reducing energy consumption and latency by achieving high throughput.

However, evaluating the effectiveness of the EEL-MAC protocol by comparing it with other MAC protocols depends on energy consumption and latency performance metrics. The energy consumption for the EEL-MAC and BN-MAC protocol is almost the same but the EEL-MAC protocol is distinct due to its simple design. It has just two mechanisms, TDMA and CSMA, and one technique (one hop communication). However, the BN-MAC protocol has a very complex design, BN-MAC has more than ten models and techniques. Because of the complexity of the design it is necessary for the special nodes to be employed with all models and techniques. Furthermore, the complexity of the design can be considered a negative feature because of its high cost and difficulty to be implemented in a network. Furthermore, the EEL-MAC out performed other MAC protocols such as X-MAC and LPL MAC protocols, which completed the energy consumption simulation with 230 and 245 joule, respectively. However, the EEL-MAC finished the simulation with only 137 joule.

The latency results for both EEL-MAC and BN-MAC are also similar because the two protocols used the same technique to reduce latency. One hop communication. Overall, the comparison results between EEL-MAC and BN-MAC showed little progress with the simple the design of the EEL-MAC protocol, which supports the idea of the superiority of EEL-MAC compared to the BN-MAC protocol (Bera, 2011).

Finally, the EEL-MAC protocol was clearly superior to other protocols such as Z-MAC, ADC-SMAC, A-MAC, LPRT-MAC and Speck-MAC. This means the EEL-MAC has proven its effectiveness compared to other MAC protocols.

5.5 Summary

In this chapter, the research achieved two objectives. Firstly, the evaluation improved the EEL-MAC on MS-MAC based on performance metrics such as energy consumption, latency and throughput. Secondly, the effectiveness of EEL-MAC was evaluated with other MAC protocols based on two performance metrics, energy consumption and latency.

CHAPTER SIX
CONCLUSION AND FUTURE WORK

6.1 Introduction

In Chapter Five EEL-MAC was evaluated on two levels. Firstly, the extent of the enhancement of MS-MAC by comparing was evaluated it. Secondly, the performance of EEL-MAC with other MAC was evaluated protocols. In this Chapter Section 6.2 gives an overview of the research and how the objectives of the research have been achieved by reducing energy consumption and latency due to the simple design of the EEL-MAC hybrid protocol. Section 6.3 discusses the contributions of this research to support the WSN by the EEL-MAC protocol in order to prolong network lifetime. Section 6.4 details some issues, as well as potential openings for further research resulting from this research. The limitations which may be addressed in separate research in the future are also discussed.

6.2 Conclusion

The enhancment of the MS-MAC protocol by the proposed EEL-MAC protocol helps to reduce energy consumption and to prolong the lifetime of the network. Moreover, it depends on the hybrid MAC protocol design which starts with an initialized phase TDMA mechanism used to SYNC the sensor nodes in a sensor field. It then uses the CSMA mechanism in the second phase to communicate between nodes and the sink node. This simple design enables the EEL-MAC protocol to reduce energy consumption. Additionally, the EEL-MAC protocol uses the one hop communication technique to achieve a high response by reducing latency. To evaluate EEL-MAC protocol, the NS-2.35 simulation tool was used. The research evaluated the EEL-MAC protocols by making many comparisons between the EEL-MAC protocol, and other MAC protocols. The evaluation of the EEL-MAC protocol was two-pronged. Firstly, the extent of the enhancement with the MS-MAC protocol was evaluated. Secondly, the effectiveness of EEL-MAC was compared with other MAC protocols using performance metrics like energy consumption and latency.

The EEL-MAC protocol outperform MAC protocols by reducing energy consumption and prolonging the lifetime of the network by saving more energy and enhancing the response by reducing latency time. As a result, the EEL-MAC protocol is superior based on performance metrics compared to the other MAC protocols. The limitations of this research are that it focuses on the stationary node scenario. It is out of the scope of this research to focus on mobility node issues.

6.3 Contribution

The contribution of this research is that it helps to solve one of the most important problems in WSN, a energy consumption. Energy consumption is considered to be a big obstacle and saving energy helps to prolong network lifetime. The EEL-MAC protocol was designed to work with WSN to prolong the network lifetime, as well as reducing latency. Reduced latency was due to the response of the network and the performance of the EEL-MAC protocol.

From these results, the EEL-MAC protocol was considered to be more efficient in a wide range of applications. Recently, WSN applications have been widely used in daily life. Thus, it is necessary for the protocol to achieve efficient energy consumption and reduced latency.

6.4 Limitations and Future Work

The research only considered static sensor nodes. In future studies, mobility nodes should be considered. Moreover, it will be necessary to address energy issues related to mobile WSN which have been recently deployed in many applications.

Furthermore, the issues of the heterogeneous sensor node must be taken into consideration. Due to the fact that some protocols apply sophisticated designs and perform different functions to meet some of the requirements, there may need to be special sensing attributes, battery capacity, and functionalities. Employing a small amount of heterogeneous nodes in a WSN field is an efficient method to maximize network lifetime and reliability to achieve high WSN protocol performance.

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