A PROPOSED ENERGY EFFICIENT MEDIUM ACCESS CONTROL PROTOCOL FOR WIRELESS SENSOR NETWORKS

YASSER KAREEM HUMMADI AL-RIKABI

UNIVERSITI UTARA MALAYSIA

2014

A Proposed Energy Efficient Medium Access Control Protocol for Wireless Sensor Networks

A dissertation submitted to Dean of Research and Postgraduate Studies Office

In partial Fulfillment of the requirement for the degree

Master of Science (Information Technology)

Universiti Utara Malaysia

By

Yasser Kareem Hummadi AL-Rikabi

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Abstrak

Nod-nod Rangkaian Sensor Tanpa Wayar (WSN) digunakan secara meluas dalam pelbagai sector. Nod-nod ini walaubagaimananpun berdepan dengan pelbagai masalah pengoperasian khususnya pelanggaran paket data, nod terlindung dan lain-lain yang memberikan impak besar ke atas jangka hayat bateri. Nod-nod WSN amat bergantung ke atas jangkahayat baterinya dan penambahan kuasa bateri nod-nod ini adalah sukar kerana nod-nod kerapkali tersusun dalam keadaan *ad-hoc.* Oleh demikian, kuasa bateri dalam nod-nod WSN menjadi factor penting dalam kebolehgunaannya. Satu pendekatan untuk menjimatkan penggunaan kuasa ialah merekabentuk protokol *Medium Access Control* (MAC). Kajian terdahulu telah dijalankan untuk mengatasi masalah yang memberi kesan ke atas jangkahayat bateri. Disertasi ini bertujuan merekabentuk protokol MAC hybrid, Energy Efficient MAC (EE-MAC) untuk mengatasi masalah yang berkaiatan penggunaan kuasa oleh nod-nod WSN. EE-MAC mampu mengurangkan masalah *idle-listening* serta mempercepatkan masa penghantaran data sekaligus menjimatkan kuasa. EE-MAC dibangunkan menggunakan simulator ns-2. Keberkesanan protokol ini disahkan menggunakan model matematik serta dibandingkan dengan piawaian IEEE 802.11 Power Saving Mode (PSM). Simulasi yang dijalankan menunjukkan protokol yang dicadangkan mencapai prestasi yang lebih baik berbanding IEEE 802.11 PSM.

Abstract

Wireless Sensor Network (WSN) nodes are broadly used in various sectors nowadays. WSN nodes experience a lot of problems that impact on battery life for sensor node such as, overhearing, collision, hidden node, idle listening, schedule drifts, and high latency. Moreover, WSN nodes are strongly dependent on its limited battery power, and replenishing it again is difficult as nodes are organized in an ad-hoc manner. Energy consumption is the most vital factor to determine the life of a sensor network because sensor nodes are driven by low battery resources. An approach to conserve energy in WSN nodes is to carefully design its Medium Access Control (MAC) protocol. Several previous work has been carried out to mitigate many problems that impact on battery life for sensor node such as overhearing, collision, and hidden node. This dissertation attempts to design, a hybrid Energy-Efficient MAC (EE-MAC) protocol to address the energy issues that are related to WSN nodes. This protocol aims to reduce idle listening times as well as lowering the latency time thus reducing the energy consumption. The proposed protocol has been developed and analysed using the ns-2 simulator. A mathematical model was used to verify and prove the efficiency of the proposed protocol. We have compared our proposed EE-MAC protocol with the existing contention-based IEEE 802.11 PSM protocol. The simulation results illustrate EE-MAC has achieved better energy conservation than the IEEE 802.11 PSM protocol.

Keywords: EE-MAC, WSN, Medium Access Control, Energy-efficiency, ns-2, IEEE 802.11 PSM.

Acknowledgement

“In the name of Allah the Most Beneficent and Most Merciful”

All praises and thanks to the Almighty, Allah (SWT), who helped me to finish this dissertation. Allah gave me the opportunity, strength and the ability to complete my study for Master degree after a long continuous work. 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 mentor for me. I would like to thank you both for encouraging and advising in both research as well as my career have been priceless.

I sincerely thank my evaluators, Dr. Mohd Nizam Omar and Dr. Shahrudin bin Awang Nor, and thanks to Dr. Norliza Binti Katuk, Dr. Faudziah Binti Ahmad, and other committee members, for graciously reviewing this work and giving me valuable suggestion and comments for my work. I am indebted and thankful to all Malaysian people who are very friendly and make us feel that we are not strangers in Malaysia.

Last but not least, the words cannot express my gratitude to my family, especially my dear father who is my teacher, friend, philosopher all in one who supported me in all ups and downs. My mother for her infallible love and support emotionally, my twin soul dear brother Mohammed Abu-jaafar and my other dear brothers, Ali, Hussain, Abbas, Hassan and sisters. The patience and understanding shown by my wife and my sons Sajjad and Muntadhar during these years is greatly appreciated. Words cannot describe their constant love, care, concern, patience, throughout the two years of my study abroad. I am forever thankful, grateful, and indebted to all of them.

I dedicate the accomplishment of this dissertation to my dear father my affectionate mother, and to the twin of my spirit, my dear brother Mohammed.

"Thank you UUM"

Yasser AL-Rikabi

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List of Abbreviations

ACK	Acknowledgment
AS-MAC	Asynchronous Scheduled MAC
B-MAC	Berkeley-MAC
CCA	Clear Channel Assessment
CSMA/CD	Carrier Sense Multiple Access/ Collision Detection
CSMA/CA	Carries Sense Multiple Access/Collision Avoidance
DRAND	Distributed Randomized
EB-MAC	Event Based MAC
ECN	Explicit Congestion Notification
EE-MAC	Energy Efficient MAC
HCL	High Contention Level
LCL	Low Contention Level
LPL	Low Power Listening
MAC	Medium Access Control
µOS	Micro Operating System
P-MAC	Pattern-MAC
PSM	Power save Mode
RSS	Received Signal Strength
TDMA	Time Division Multiple Access
WiseMAC	Wireless Sensor MAC
WSN	Wireless Sensor Network
Z-MAC	Zebra-MAC

CHAPTER ONE

INTRODUCTION

1.0 Introduction

Wireless Sensor Network (WSN) nodes are compact-sized, low-power autonomous devices with wireless communication capabilities that are widely used in various real world applications today. Advancement in technology world wide witness applications of WSN nodes in various pace of life, such as military, health care, environmental issues and many more which needs monitoring. These nodes are basically used in various sectors which need close monitoring, hence deployed in a sensor field to measure environmental conditions such as temperature, pressure, humidity, movement, etc. WSN nodes are powered by limited power sources and often exhibit strong dependency on battery life making replenishment an arduous or impossible task as most nodes are positioned in an ad-hoc manner. Energy in WSN node, though often insufficient and limited in supply, is the most important parameter that determines the WSN lifetime. In designing a WSN energy efficiency is required, and the radio is distinguished as a main source of the power consumption in sensor nodes (Jang, Lim, & Sichitiu, 2013).

In WSN operation, energy can be dissipated by either “useful” or “wasteful” means. For example, as a part of useful operation, node requires energy to transmit or receive data messages, and processes query requests through which energy is consumed. On the contrary, energy consumption by means of overhearing, retransmitting due to rough environment, handling with the redundant broadcast overhead messages, as well as idle listening to the media are wasteful energy consumption (Chhabra & Sharma, 2011; Saharan & Pande, 2013). Three main activities involved in energy consumption are distinguished in sensor node, namely sensor sensing, computation and radio operations contributed to energy loss. In the radio operation, besides transmitting cost, more than half of the energy is consumed by receiving and scanning of the wireless channel for communication (Riaz, Qureshi, & Mahboob, 2013).

A sensor node is useless without energy. Operation of sensor nodes on limited battery power justify that energy usage is an important concern in WSN design. There has been significant number of research studies that revolve around minimizing use of energy by sensor node. It is obvious that when a sensor node become exhausted of energy, it will break down and disconnect from the network. Disconnection can cause significantly negative effect on the performance of the application. Depending on the number of active nodes and connectivity of the network, lifetime of sensor network is determined. Therefore, solution to maximizing the lifetime of WSN and efficient use of energy is by possibly reducing energy consumption (Yick, Mukherjee, & Ghosal, 2008). 'Without human interaction' is one of the most important characteristics of WSN entails that WSNs are often deployed in an area without close monitoring of human being, making it self-organizing and self-regulating system. As a result, WSN does not require advance configuration, and the sensor nodes can establish into a network automatically on deployment. In addition, self-healing is another characteristics of WSN concerns with automatic reconfiguration of the network on dying off of some nodes or new nodes are added (Yang, 2011).

In recent years, numerous energy-efficient mechanisms for wireless sensor Medium Access Control (MAC) protocols models, especially the asynchronous protocols to reduce energy consumption have been developed. This dissertation will focus on hybrid Medium Access Control protocols which include Zebra-MAC (Z-MAC), Wireless Sensor MAC (WiseMAC), Crankshaft and Asynchronous Scheduled MAC (AS-MAC). The research intents to illustrate the mechanism of work for each one, which contain a lot of the problems that cause energy waste. It will also propose ways of solving the problems by designing a new MAC protocol in order to achieve reduction in energy consumption.

1.1 Background

Wireless Sensor Nodes are compact-sized, low power autonomous devices with wireless communication capabilities that have gained the attention of industry and researchers for their support for broad applications.

Wireless Sensor Networks (WSNs) can be used to sense various types of data, process them and communicate wirelessly to one or more central unit called a sink. Within the sensor field, data from sensor nodes are collected and sent to sink node. Also a sink node can send queries, program updates, or control packets to sensor nodes. Sensor nodes detect events in the sensor field, perform local data processing and then transmit data to the base-station. Sensor nodes are fabricated with different hardware components which can be seen in Figure 1.1.

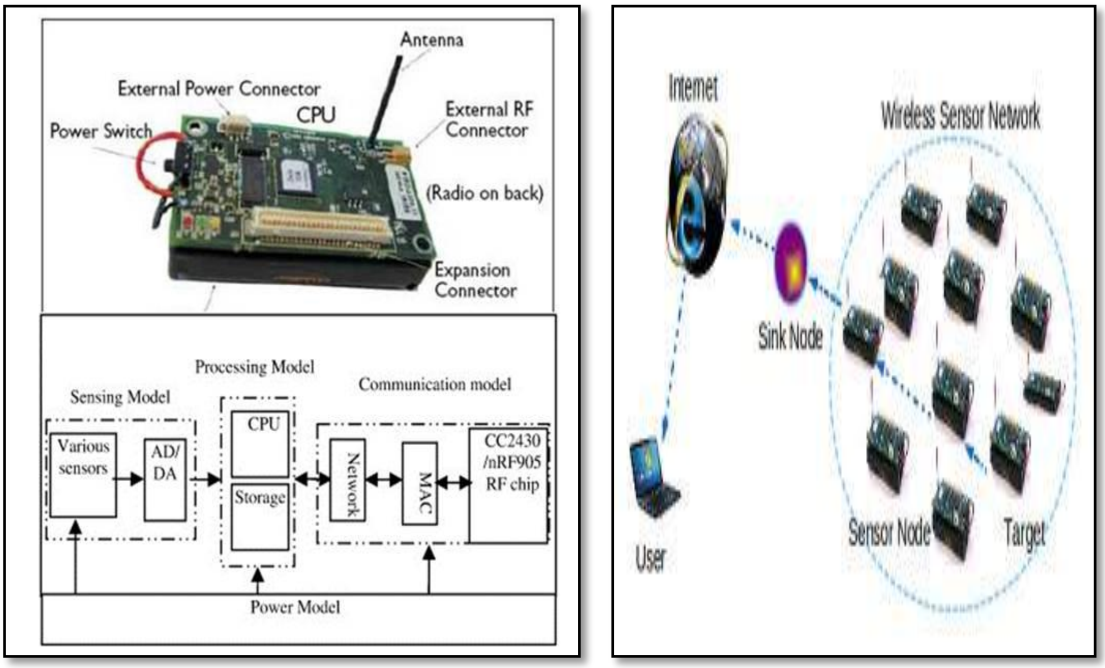

Figure 1.1. A Typical Wireless Sensor Node and Its Architecture (Dubey & Agrawal, 2013).

The transceiver, contained in the communication block receives and transmits data from the sink. Communication is an energy expensive task thus making the transceiver a major power consumer (Aslam, Farooq, & Sarwar, 2009; Shinghal, Noor, Srivastava, & Singh, 2011). It is estimated that the energy cost for the process of transmitting single bit or thousands of instructions in sensor nodes is the same. The energy source components of sensor nodes store and supply energy to power consumer components. The most widely used energy storage component is a battery with a flexibility of rechargeable or non-rechargeable. Limitation of power of battery makes energy has a restriction in sensor nodes. It is not feasible to change the batteries in WSN nodes, it is challenging to design a long life-spanned sensor networks with energy constraint. Each hardware component is controlled by a Micro Operating System (μOS) (Aslam et al., 2009).

While most argue that energy efficiency is a crucial issue within the wireless communication, the issue faced by WSN is different. Due to the advancement of ICT, WSN is now deployed in various applications and are often powered by limited power sources. While advancement in ICT is proliferating, light-weight battery technology remains stagnant and a breakthrough is yet to be seen. Furthermore, WSN nodes are often deployed in a scattered and ad-hoc manner organizing themselves into the communication network rather than careful planning. This makes changing batteries for all the nodes an arduous task. In addition to that, some WSN nodes are mobile. Finally, communication between a node and a sink is triggered by a sensing event and due to the inevitable network conditions (interference, attenuation, fading etc), data needs to be retransmitted further draining the already limited power supply.

1.2 Problem Statement

WSN node is widely used in various sectors nowadays to transmit and collect data which are often placed at remotely. However, WSN nodes are strongly dependent on its insufficient battery power, and refilling again is difficult as nodes are deployed in an ad-hoc manner. In addition, WSN nodes experiences a lot of problems that impact on battery life for sensor node such as, overhearing, collision, hidden node, idle listening, schedule drifts, and high latency. These problems lead to consume more energy.

Previous work has been carried out to mitigate some of these problems that are related to the contention-based protocol like overhearing, collision, and hidden node.

This dissertation is going to focus on three major problems that lead to dissipate energy (idle listening, schedule drifts, and high latency), that are related to hybrid medium access control protocols in order to get energy efficient in WSN nodes.

Idle listening: It has been identified by many studies as the main source of energy waste (Cano et al., 2009; Dutta et al., 2010; Jang et al., 2013; Ye et al., 2006), because nodes are not aware of the reception of message and will be in receiving mode. In case of sensor node listens to the channel for a possible traffic but no packet is received.

Schedule drifts: According to Ahn et al. (2006) and Bachir et al. (2010) it leads to consume more power through sending and receiving data in WSN nodes, schedule drifts have been identified in Z-MAC protocol (i.e., when the schedule allocated by DRAND (Distributed Randomized) to nodes drifts out of sync because of various time varying radio impairments).

High latency: It is another major issue in study that reduces the energy efficiency to know how the higher latency occurs (Demirkol et al., 2006; Roy & Sarma, 2010; Saharan & Pande, 2013). It is clear with the Wireless Sensor MAC (WiseMAC) protocol, is that decentralized sleep–listen scheduling results in different sleep and wake-up times for each neighbour of a node. This is an important problem especially for broadcast-type communication since broadcasted packets will be buffered for neighbours in sleep mode and delivered many times as each neighbour wakes up. However, this redundant transmission will result in higher latency.

1.3 Research Questions

In this dissertation, there are three main questions in Wireless Sensor Network (WSN) nodes try to find an energy efficient way to maximize the network lifetime in order to efficiently conserve energy. Energy is conserved when the node goes to sleep or whenever it is idle. The main questions are:

i. How to overcome schedule drifts?
ii. How to reduce idle listening?
iii. How to reduce latency in WSN communication?

1.4 Research Objectives

The main objective of this dissertation is to investigate energy efficiency in Wireless Sensor Network (WSN) nodes by designing Medium Access Control (MAC) protocol for WSN in order to save energy, thus stretching the battery life in WSN nodes. This dissertation embarks on the following specific objectives:

(i) To reduce schedule drift in Wireless Sensor Network.
(ii) To reduce idle listening in Wireless Sensor Network.
(iii) To reduce latency in Wireless Sensor Network.

1.5 Motivation

Energy consumption is the most important factor to determine the life of a sensor network because usually sensor nodes are battery driven with low energy resources. This makes energy optimization more complicated in sensor networks because it involves not only decline of energy consumption, but also enhances the life of the network as much as possible.

The energy consumed by the sensor nodes can be reduced by the design of MAC protocol, with energy consumption conscious in WSN.

The purpose of designing the MAC Protocol in this dissertation is to solve the problems which are related to the energy issues to achieve the objective of the research that is, improve energy efficiency by reducing energy consumption in WSN nodes.

1.6 Contributions

The expected contributions of this dissertation based on solutions to the specific problems mentioned above are:

(i) Designing a hybrid MAC protocol for Wireless Sensor Network by using programming language C++.

(ii) Implementing the MAC protocol in ns-2 where simulations will be conducted to seek for the results.

(iii) Evaluating the performance of the hybrid MAC protocol by comparing against the standard IEEE 802.11 Power Saving Mode (PSM) and using a mathematical proof.

(iv) Improving energy efficiency by reducing the energy consumption in WSN.

This work has been accepted for publication in the Knowledge Management International Conference and Exhibition (KMICe) 2014.

Yasser Kareem Al-Rikabi, S. Chareen & M.H. Omar (2014). *EE-MAC: An Energy Efficient MAC Protocol to Conserve Energy in Wireless Sensor Networks* (accepted for publication at KMICe 2014)

1.7 Scope

The scope of this dissertation shall be the consideration of design a hybrid Medium Access Control (MAC) protocol, called Energy Efficient MAC (EE-MAC). This protocol addresses the energy issues that are related to Wireless Sensor Network (WSN) nodes. The conservation of energy in the WSN is the main point of our research. The EE-MAC is proposed to avoid the schedule drifts, minimizing the idle listening time and providing low latency. The EE-MAC protocol will conserve energy if a node goes to sleep when no packets arriving from sink / or no packets to be transmitted. The proposed EE-MAC protocol will be implemented using ns-2 simulator. Finally, to evaluate the performance of the EE-MAC protocol we have to compare our EE-MAC protocol with the existing contention-based IEEE 802.11 Power Saving Mode (PSM) and through a mathematical proof.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents the previous works that are specifically focus on the Medium Access Control (MAC) protocol and the related issues. The energy resources are limited in Wireless Sensor Network (WSN) nodes, so it is the main obstacle for sensor network protocol design. The basic function of MAC protocol is to organize access to a shared medium to please some application that depends on performance requirements. The MAC protocols in the literature mainly focus on decreasing power consumption because of the shared medium contention. There are three major schemes of MAC protocol; contention-based, schedule based and hybrid protocols. The rest of this chapter is organized as follows. In the Section 2.1 a brief overview of the Medium Access Control Protocol is presented, focusing on hybrid CSMA/TDMA protocols. Section 2.2 presents the contemporary researchers that are related to this study are carefully reviewed and discussed in this chapter are referred to as the related studies. In Section 3.3 this study will justify the need for hybrid MAC and conclude the chapter.

2.1 Medium Access Control (MAC) Protocol

There have been a significant number of researches that revolve around minimizing the use of energy by sensor node. Short network lifetimes can cause significantly negative effect on the performance of the application. The lifetime of sensor network is determined by the number of active nodes and connectivity of the network. Therefore, efficient use of energy by possibly reducing energy consumption is the solution to maximize the lifetime of WSNs (Yick, Mukherjee, & Ghosal, 2008). In this study, the focus is mainly on the MAC protocols.

The primary function of MAC protocol is to organize access to a joint medium over the network. Recent efforts have been carried out within the MAC protocol to conserve energy. This include MAC protocols which regulate the duty-cycle of the radio interfaces on a WSN node, whereby a radio interface will switch into active, idle or sleeping mode depending on the network conditions (Cano Bastidas, 2009)**.**

Generally, the MAC protocols used in WSN nodes can be categorized into three; contention-based protocols, scheduled-based protocol and hybrid-based protocol.

2.1.1 Contention-Based Protocols

In a contention-based protocol, nodes transmit or receive data whenever the medium is idle. This scheme however, leads to collisions as two or more nodes may transmit at the same time. The collision problem had received wide attention and many techniques for immediate mitigation if not total eradication have been proposed. One prominent technique for mitigation of collision is known as Carrier Sense Multiple Access (CSMA). CSMA requires a node to 'listen' to the channel before transmitting data. Data is transmitted if the channel is idle, otherwise the node will have to wait for a period before transmitting. In the event of a collision, nodes need to retransmit at a random interval known as the back-off mechanism. There are two different approaches to minimize the collision of transmission of data in contention-based schemes, which are Carrier Sense Multiple Access/ Collision Detection (CSMA/CD) and Carries Sense Multiple Access/Collision Avoidance (CSMA/CA) (Younis & Nadeem, 2006).

2.1.2 Scheduled-Based Protocols

Scheduled-based MAC protocols controls the duty-cycle of nodes. A WSN node is scheduled to be only active at a specified time to access the channel. Through this approach nodes possess equal time for receiving or transmission of data. An example of the scheduled-based protocol is Time Division Multiple Access (TDMA) which is prominent in the earlier wireless communications.

2.1.3 Hybrid-Based Protocols

The prime function of hybrid-based protocol is to integrate the contention-based and schedule-based protocols by giving the recognition to their strength and provide solutions to their existing weaknesses. The hybrid-based MAC protocol incorporates the merits of contention-based MAC and the schedule-based MAC together. The hybrids MAC acquaint with two types of packets namely the control packets and the data packets. The control packet is always introduced into the random access channel. The random access channel is used for synchronization purposes only while the data packet performs the function of transmitting the scheduled channel. Hybrid protocols are known provide better scalability and flexibility than both contention- and schedule-based protocols. The rest of this chapter discusses four kinds of hybrid MAC protocols which are Zebra-MAC, WiseMAC, Crankshaft, and Asynchronous Scheduled MAC**.**

As explained in the following points in terms of how it works, advantages, disadvantages, and summary.

2.1.3.1 Zebra-MAC (Z-MAC) Protocol

The research has shown that Z-MAC provides panacea to advance the throughput in network with variance traffic patterns. Therefore, Z-MAC could be defined as a hybrid technique that requires lower traffic for running CSMA and provides switches to TDMA at higher traffics (Bachir et al., 2010). Besides that, like CSMA, Z-MAC is capable of obtaining combination of high channel utilization and low-latency with little contention. In a related development, like TDMA, Z-MAC is found with attributes of having high channel utilization with high contention and reduced collision between two or more neighbour at low cost. Indeed, Z-MAC is found to be robust in its performance with less error in synchronization, low slot assignment failure as well as channel conditions varying with time. Hence, the Z-MAC performance always resulted to the CSMA.

Obviously, Z-MAC is found to possess a phase for running the sequential operation which is known as setup phase and comprises of neighbour discovery, slot assignment, local frame exchange. In other words, there are nodes that require picking of time slot which should be decided on the period of time slot for ease transmission this period is called time frame of the node, and global time synchronization. Rhee et.al (2008) emphasized that the operation of Z-MAC occurs only one time during the setup phase until there are significant differences in the network topology. Meanwhile, nodes are found to run by using a distributed slot allocation algorithm, called DRAND (Distributed Randomized) for assigning a slot to different nodes.

Accordingly, the Z-MAC algorithm ensures the integration of slots in such a way that hidden nodes collisions are avoided when even a node and the two-hop neighbourhood share the like time slot. The facts that slots are assigned to the node are large to provide transmission of multiple packets, there should be no path for strong synchronization. Meanwhile, the node uses assigned slots for transmission after the scheduling of the TDMA. The nodes prepare to make use of unused slots in its neighbour whenever node needs more than one slot. Thus, utilization of unassigned slots require a random retreat at the commencement of the slot. Whenever there is expiration of random retreat of the nodes and there are still elements of unused slots by the owners, the nodes seizes a slot for transmission. Hence, the large random retreat allows the owner of slot to gain access to the slots before other users. Consequently, Bachir et al., (2010) stressed that Z-MAC encourage scheduled drifts which could be re-run DRAND algorithm periodically in order to resolve the scheduled drift and mitigate usage of energy.

In summary, Z-MAC is defined as a hybrid technique that requires lower traffic for running CSMA and switches to TDMA at higher traffic (Bachir et al., 2010). Like CSMA, Z-MAC is capable of obtaining combination of high channel utilization and low-latency with little contention. Z-MAC is found with attributes of having high channel utilization with high contention as shown by TDMA. The work of Z-MAC depends on the DRAND (Distributed Randomized) algorithm to assigns a slot to each node. The Z-MAC algorithm ensures the integration of slots in such a way that hidden nodes collisions are avoided when even a node and the two-hop neighbourhood share the like time slot occurs. Z-MAC however poses a problem known as the schedule drift. Data transmission sometimes exceed the time slot allocated thus encroaching into time slots meant for other nodes. This will result in another node switching into awake node, and possibly result in collisions.

2.1.3.2 Wireless Sensor MAC (WiseMAC) Protocol

According to Hurni and Braun, (2008), the Wireless Sensor MAC (WiseMAC) protocol is regarded as major efficient energy medium for creating access control protocols for Wireless Sensor Network(WSN). Researchers have stressed that minimisation of energy during the idle listening is always achieved by using WiseMAC preamble approach (Demirkol et al., 2006; El-Hoiydi, Decotignie, Enz, & Le Roux, 2003; Saharan & Pande, 2013).

Moreover, the main function of WSN is energy efficiency and has been adopted in some Medium of Access Control (MAC) applications in designing, implementation and evaluation of WSN. Thus, the energy efficiency has been attributed to the WiseMAC based on its functionality (Hurni & Braun, 2008). This is as a result of its ability to utilise low duty cycles, periodic wake-ups and preamble sampling.

In addition, WiseMAC is free from set-up signalling, failure of network-wide time synchronization and always on with many traffic load. Pursuing this further, WiseMAC allows an ultra-low average power consumption with low traffic conditions and provides high energy efficiency in accordance with high traffic conditions. Indeed, WiseMAC has attribute to mobilise sporadic, periodic and busty traffic which make it to be efficient in supporting transportation of locally synchronise information (El-Hoiydi et al., 2003). Besides, mitigation of energy consumption in WiseMAC becomes visible through the use of the preamble sampling approach. The preamble sampling approach is useful as prefix of each data packet in order to prevent receiver’s node from hibernating while receiving a new frame.

For the sending data, the sensor nodes periodically check the availability of the channel by sense the medium; this processing shows the sampling process. When the sensor nodes find the sampled medium busy, it will listens to the channel until received the data frame or wait the medium becomes idle.

Furthermore, the WiseMAC ensures that there is direct neighbour schedule sample in order to mitigate the size of the wake-up preamble. Whenever a node fails to understand its neighbour's wake patterns, preamble duration of transmit has to be passed to be release so as to obtain achieve a sampling interval of the closed nodes. The work of Saharan and Pande, (2013) emphasized that after successful receiving of frame, the receiver node would release the acknowledge message. Thus, a table is maintained to keep the neighbouring nodes’ relative schedule offset from nodes own wake pattern. A node can determine the next wake-up of all its respective neighbours, and reduce the preamble length for all upcoming future frames as a result of the existing node. Figure 2.1. presents the WiseMAC concept.

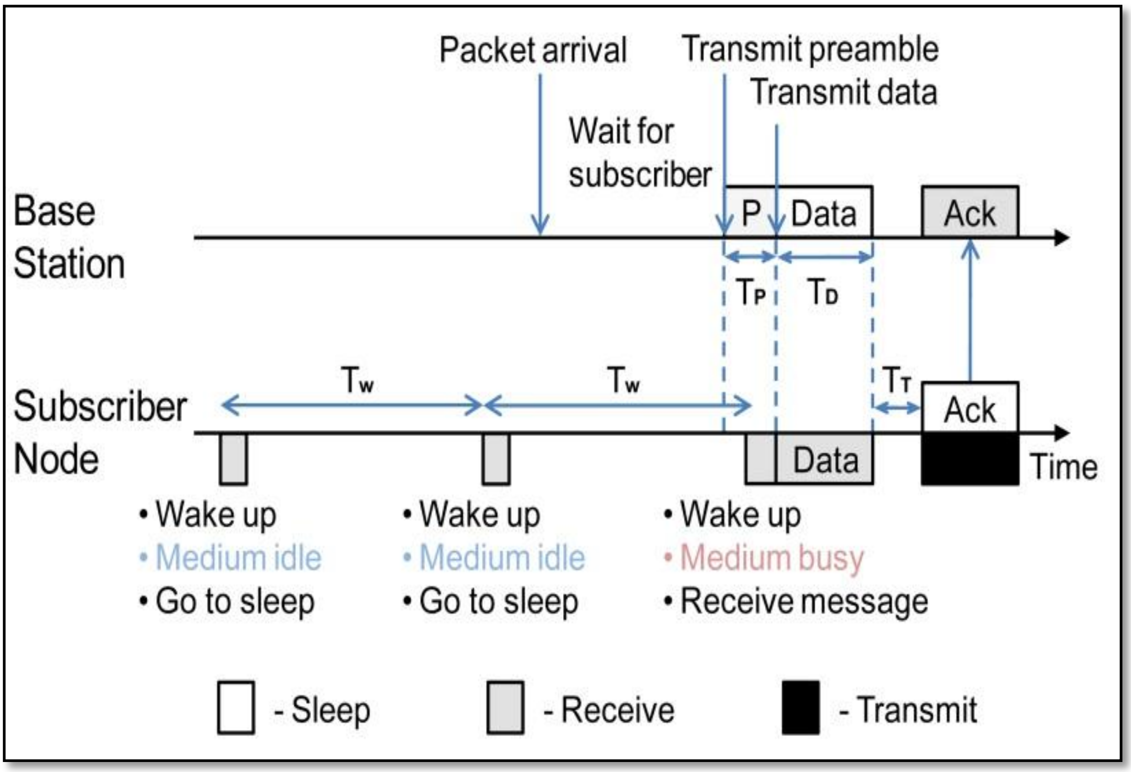

Figure 2.1. The WiseMAC Concept (Klein, 2012).

In summary, the WiseMAC uses a preamble approach to achieved minimisation of energy during the idle listening. Besides, mitigation of energy consumption in WiseMAC becomes visible through the use of the preamble sampling approach. Also WiseMAC allows an ultra-low average power consumption with low traffic conditions and provides high energy efficiency in accordance with high traffic conditions. WiseMAC performs optimally on the WSN nodes only when it is applied on single-hop networks. In high traffic conditions, WiseMAC is prone to consume more energy as the nodes need to sample the medium more frequently, resulting in idle listening.

2.1.3.3 Crankshaft Protocol

Another hybrid MAC protocol is known as Crankshaft which is mainly made for expansion WSN (Cano Bastidas, 2009). The Crankshaft performs on fixed offsets from the beginning of the frame, functions of igniting receiving messages (Halkes & Langendoen, 2007; Kaan & Yang, 2008). Indeed, the Crankshaft protocol divides time into frames while each of the frames is divided into slots. Besides, slots are classified into two as broadcast slots and unicast slots. Moreover, all the incoming messages wake-up at the broadcast slots. Meanwhile, node that has a broadcast message sends contend with all other nodes in order to effortlessly sending of message. Though, a frame that starts with all the unicast slots follows by the broadcast slots making a node of slot to be listened to by determined the node's MAC address. Hence, the intended node for sending a message is aware of destination wake-up slots. Halkes and Langendoen, (2007); and Pramanik and Sharma, (2013) stressed that Crankshaft utilizes a DATA/ACK sequence for unicast messages while the lengthen slots tenable to accommodate them. Therefore, a designated allocation is made for base-station or sink nodes which would listen to the unicast slots. This is a result of classifying sink as the location for most traffic in the network and requires efficient received bandwidth. Moreover, the sink is found with attribute of tied while considering a spent energy (Halkes & Langendoen, 2007; Kaan & Yang, 2008). In other words, the communication in a slot is frequently found of contention-based and a node that wishes to expel data computes a random Back off for the fact that channel is empty.

Following this further, an integration of crankshaft is needed to achieve good energy efficiency and the waking up of nodes do not warrant in the rest of the slots (Halkes & Langendoen, 2007). Besides, there are need to shut down the radio resolve contention in the process of slots from the beginning to the end. Indeed, a node chooses a moment in the contention window in order to transmit message in an exact slot. According to Pramanik and Sharma, (2013), the sent node work for a while while selecting some nodes for contending for the slots. Whenever some nodes fail to transmit, a preamble nodes beginning transmitting an intended nodes and thus the receiving nodes start transmitting the start symbol and the authentic message.

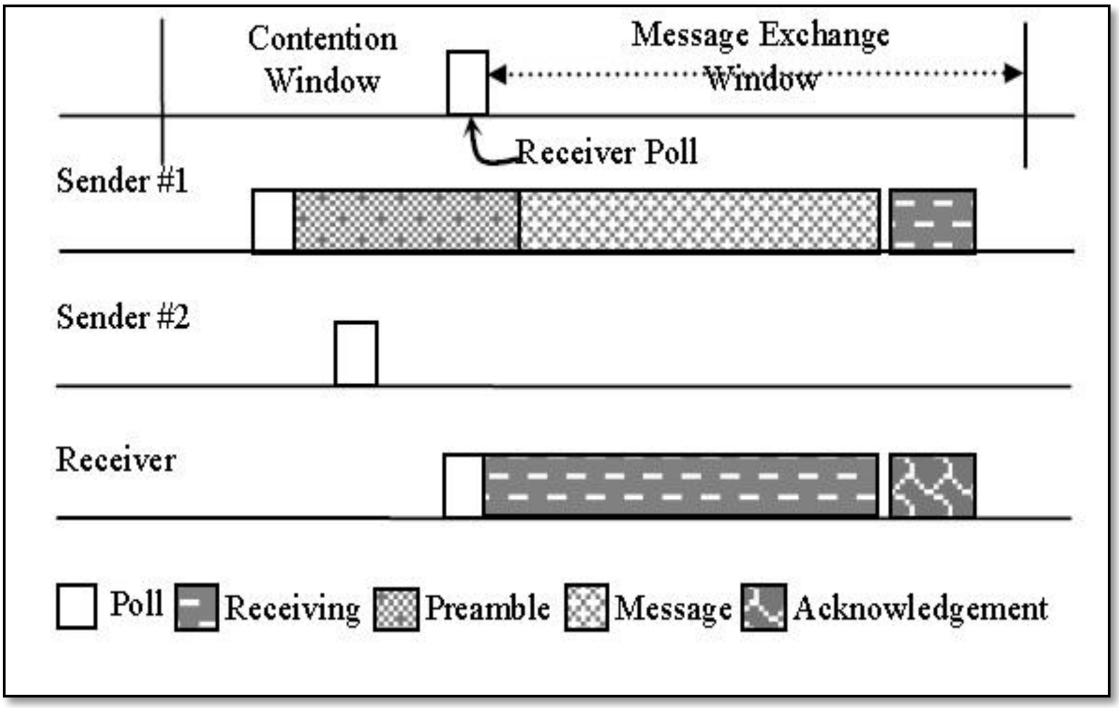

Figure 2.2. Contention and Message Exchange in Crankshaft (Pramanik & Sharma, 2013).

To sum up, Crankshaft is a hybrid MAC protocol, which is mainly made for expansion of WSNs. The Crankshaft protocol splits time into frames while each of the frames is split into slots. Besides, the slots are classified into two namely broadcast slots and unicast slots. The communication in a slot is contention-based and in the event of a collision, the node computes a random back-off for retransmission. A node chooses a moment in the contention window in order to be able to transmit message in an exact slot. The Crankshaft utilizes a DATA/ACK sequence for unicast messages while the lengthen slots tenable to accommodate them. Therefore, a designated allocation is made for base-station or sink nodes which would listen to the unicast slots. Though the Crankshaft focuses on expansion of sensor networks, it is non-scalable and not statistically allocated resulted in poor performance. Furthermore, the frequent shift to active mode to listen to the air interface causes idle listening.

2.1.3.4 Asynchronous Scheduled MAC (AS-MAC) Protocol

The AS-MAC comprises of two different properties which is the energy consumption that continuously reduces as the wakeup interval increases (Jang et al., 2013). The other property of AS-MAC is known as the energy consumption located at each wake-up interval and lower than the previously proposed protocols. AS-MAC asynchronously coordinates the wakeup times of neighbouring nodes to reduce overhearing, contention and delay unavoidable in synchronous scheduled MAC protocols. Therefore, AS-MAC adopts duty cycling in order to prevent idle listening and Low-Power-Listening (LPL).

Undoubtedly, the study of Pramanik and Sharma, (2013) emphasized that AS-MAC protocol is grouped into the initialization phase and the periodic listening and sleep phase.

- **Initialization Phase**:

The initialization process begins whenever a new node joins a WSN that produces information that enables the neighbour table and possesses information about the neighbour. In order words, the initialization phase of AS-MAC and the current nodes may be found with initialization or the periodic listening and sleep phase. Some studies have revealed that nodes in the periodic listening and sleep phase perform Low Power Listening (LPL) at every wake-up interval, thereby release signal for its existence. Therefore, computation of lined quality indicator requires authorization of receiver. Hence, there are some multiple integer beacon that are used for response from the receiver (I wake up and I hello) for proper functioning of beacon-based MAC (Anwar & Lavagno, 2010; Jang et al., 2013; Pramanik & Sharma, 2013).

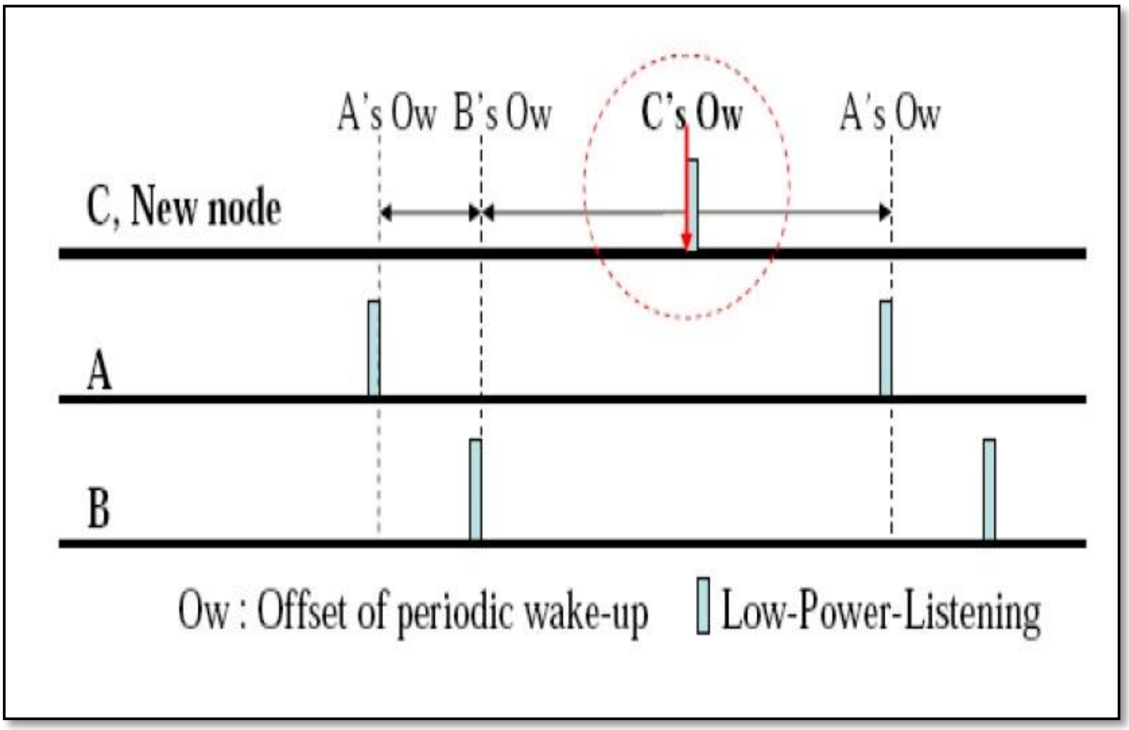

Figure 2.3. Initialization Phase Finding Its Offset (Jang et al., 2013).

- **Periodic Listening and Sleeping Phase**:

This is the phase where node would set up the wake up interval timer (I wake up) after the completion of initialization and creation of built local lookup table. Meanwhile, failure of current time to indicate 'Hello' time would lead to receiving of incoming packet by the channel together with preamble. Besides, the nodes search its lookup table whenever it has some packets to send and when the wakeup time of the receiver signifies 'Hello' time, the node the node receives the 'Hello' packet and then sends the packet. However, it would send the packet with a preamble to compensate clock drift. Consequently, the node is capable of computing the remaining time from the initial time to the upcoming wake up time of the receiver and compensate highest clock drift between neighbour nodes with small guard time (Anwar & Lavagno, 2010; Jang et al., 2013; Pramanik & Sharma, 2013).

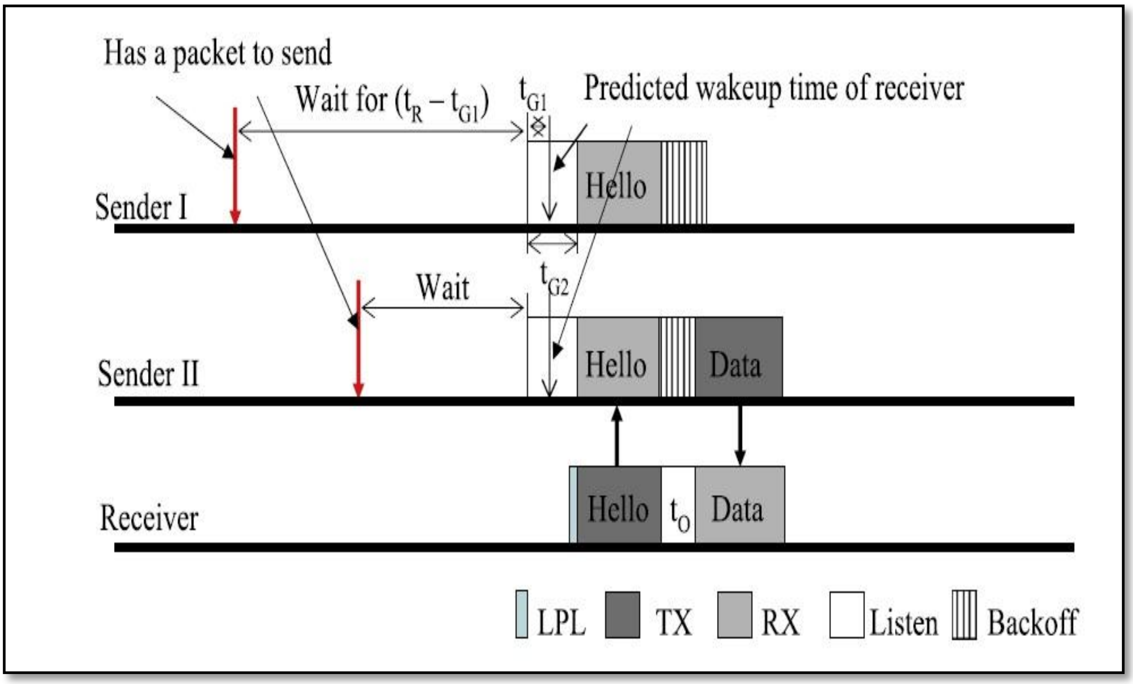

Figure 2.4. Communication at Hello Time (Jang et al., 2013).

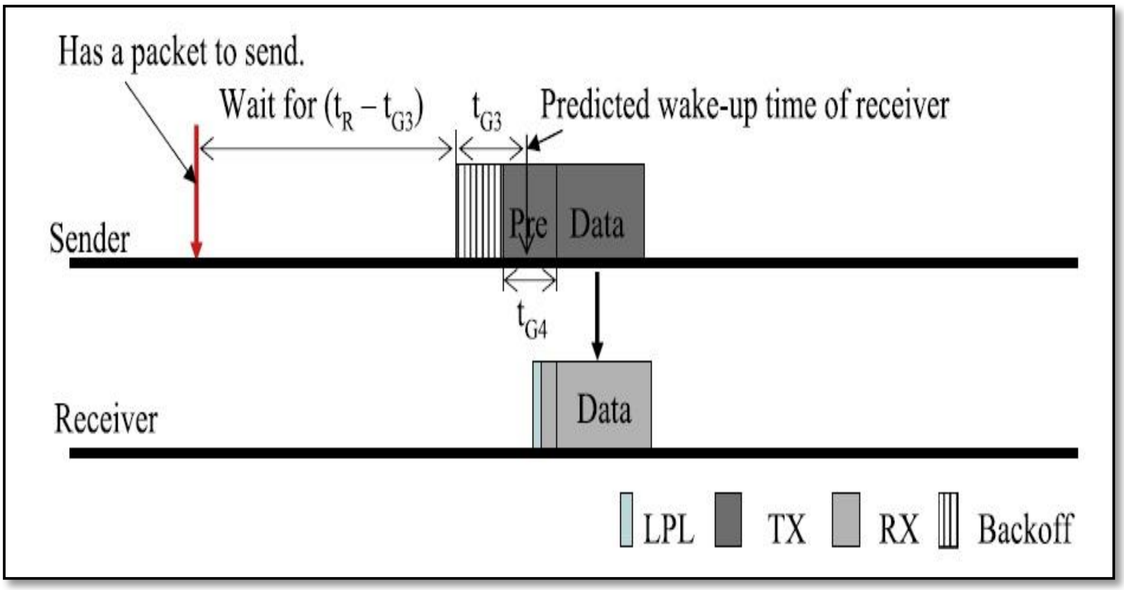

Figure 2.5. Communication at Wakeup Time (Jang et al., 2013).

In conclusion AS-MAC asynchronously coordinates the wakeup times of neighbouring nodes to reduce overhearing, contention and delays unavoidable in synchronous schedule-based MAC protocols. Therefore, AS-MAC adopts duty cycling in order to prevent idle listening and Low-Power-Listening (LPL). AS-MAC protocol is grouped into the initialization phase and the periodic listening and sleep phase. The initialization process begins whenever a new node joins a WSN that produces information that enables the neighbour table and possesses information about the neighbour. In the Periodic Listening Phase (PLP), the receiving node wakes up periodically perform PLP. A node in active state will shift into sleep state after data is successfully transmitted. The problem with the schedule-based MAC protocol AS-MAC is the sudden switch to active mode when the time slot arrives, which results in energy leakages if the circuitry is not properly designed. Table 2.1 below shows the advantages and disadvantages each one of hybrid MAC protocols mentioned earlier.

Table 2.1

Advantages and Disadvantages of Hybrid MAC Protocols.

MAC	Advantages	Disadvantages
Z-MAC	• Z-MAC mitigate the influence of collision by rescheduling the transmission periods and slots between the nodes. • Z-MAC ensures there panaceas in order to increase the throughput in the network with different patterns of traffic. • Z-MAC is robust in nature free from synchronization errors, failure in assigning of slot and variation in time channel.	• Z-MAC is vulnerable to the unauthorized owner of slots when even the slots are available. • Z-MAC allows schedule drift to reduce efficiency of energy. • The problem of non-performance of Z-MAC goes to CSMA.
WiseMAC	• WiseMAC allows reduction in the frequency of sensor nodes transmission and sensor node overhear message. • WiseMAC enjoys ease integration of MAC protocols for achieving formidable applications. • WiseMAC encourage smooth preamble length adjustment in the domain of variable traffic situations. • WiseMAC transportation allows smooth and ease traffic load.	• WiseMAC operates on single hop networks. • There is frequent unnecessary higher latency and power consumption. • Constant terminal collision issues at the commencement of transmission of the preamble of the node.

Crankshaft	• Crankshaft uses both node synchronization and offset wake-up schedules for achieving overhearing by neighbouring nodes. • Crankshaft as the branch of MAC protocol focuses at expansion sensor networks. • It encourage many energy savings through efficient channel polling Further energy savings are gained by using combination of efficient channel polling and contention resolution techniques.	• The crankshaft MAC protocol is non-scalable and not statistically allocated. • The crankshaft MAC protocol is independent of traffic load. • Crankshaft MAC protocol resulted in poor performance whenever there are high density applications.
AS-MAC	• AS-MAC is capable of collaborating with base MAC protocols in order to induce its attributes while adding energy efficiency.	• Transmitting of packet is done one time after the other in AS-MAC. • AS-MAC lacks overhear of packet due to the individual peculiar OW. • AS-MAC allows only senders to transmit to a specific receiver at their wakeup time.

2.2 Related Studies

Generally, some of MAC protocols were designed for WSN with some selection of protocols that are similar to the Energy Efficient-MAC (EE-MAC). Thus, Z-MAC is attributed to the use of the Distributed Randomized (DRAND) (Rhee, Warrier, & Xu, 2004). Nevertheless, DRAND is regarded as a complex algorithm which assigned time slots to every node by ensuring that there are no two nodes among a two-hop neighbourhood with respect to the TDMA. Z-MAC does not categories as traffic adaptive due to DRAND running overhead.

Moreover, many of the MAC protocols are not functionalized for the acquisition of data sensor network applications. Indeed, Z-MAC is believed to be attributed to the switching of between CSMA and TDMA based on the traffic (Rhee et al., 2008). Therefore, the implementation of Z-MAC in Tiny OS called for the evaluation of channel utilization, energy, latency and fairness over single-hop, two-hop and multi-hop sensor network topologies constructed using a third generation mote module (Mica2). Hence, a collision free slot is obtained by the distributed slot selection algorithm. For instance, the whenever a node as data to transmit when it has slot, there would be back off between To (time-owner) and Tno (time non-owner).

In a related development, researchers have divided the contention level into Low Contention Level (LCL) and High Contention Level (HCL). The LCL allows nodes in the network to compete in any time slots, while only the owner and one-hop neighbours of the owner can compete for the slot to reduce collision HCL. Meanwhile, the Z-MAC uses Explicit Congestion Notification (ECN) messages to reduce hidden terminals in high contention networks. Thus, whenever a node detects heavy traffic there would be propagation of the ECN message to its two-hop neighbourhood. Moreover, the Z-MAC discovered to be built on the TDMA structure found at the domain of B-MAC's back off mechanism, Clear Channel Assessment (CCA) and Low Power Listening (LPL). Lastly, Z-MAC produces a known attention throughput other than existing sensor MAC protocols during utilization of similar energy.

Ahn et al., (2006) submitted that Z-MAC mitigate volume of hidden terminal issues by preventing two nodes in two-hop distance to transmit data at the same time. Therefore, unauthorized owner of the slot are always allowed to agitate for the slots when rendered useless by the right authentic owner while trying to improve utilization of Z-MAC. The usefulness of Z-MAC becomes possible during the global time synchronization at the initial phase, while they are allowed to perform local synchronization through sending of periodic sync packets between nodes (Rhee, Warrier, Min, & Xu, 2006). Nevertheless, the implementation of DRAND becomes possible whenever there is a robust real wireless setting. Though, DRAND always gives more efficient slot assignments which may result in better channel utilization and energy saving.

In addition, the long preamble over the data frame leads for the repeating of data frame in lieu of the extended preamble by the WiseMAC for low traffic load. Thus, the data frame is processed by the receiver end and get it returned if the intended recipient found sleep. Moreover, the node would be kept awake till the completion of transmission whenever the node is kept in the position of recipient and the acknowledgement is released. Indeed, WiseMAC provides solution to the associated problem with energy communications but does not possess capacity for the nodes to adapt returned traffic patterns. In other words, the use of WiseMAC has been suggested for achieving synchronized preamble sampling so as to overcome downlink infrastructure sensor network (El-Hoiydi & Decotignie, 2004).

Pursuing this further, WiseMAC is useful as the preamble sampling in order to obtain low power communications in infrastructure sensor networks. In other words, WiseMAC still allows use of similar technique to Berkeley-MAC (B-MAC). However, the receiver awake periods is adjusted and transmission is allowed to mitigate the duration of the extended preamble. Whenever the transmitter intends to send to the receiver, the preamble starts before awaking of the receiver and considers the available clock skew leading to reduction of transmitted energy when realizing the preamble.

The study of El-Hoiydi et al., (2003) that was based on the power consumption delay trade-off which was analysed in low traffic conditions through the use of the IEEE 802.15.4 ZigBee standard. The output indicates that WiseMAC is capable of providing a low energy consumption during the same delay. Besides that, WiseMAC provides avenue to mitigate the preamble length at the end of initial unicast packet with a long preamble. Therefore, the receiver provides the send opportunity to transmit the next packet with little preamble. In order words, a long preamble is necessary to be used whenever a node sends broadcast packets provided there is knowledge of polling of their neighbours. This is because nodes disperse the entire poll channels and provides chances to the long preamble in order for the packets to be captured.

At this level, the produced protocol that is made up of combination of two or more protocols is regarded as Pattern-MAC (P-MAC) protocol and is systematically switch the sleep-wake up roles depending on the local traffic (Zheng, Radhakrishnan, & Sarangan, 2005). However, the usages of traffic patterns are sensitive to commit mistakes due to the occurrence of interference signals that may be affecting the existing nodes. According to Liu and Elhanany, (2006), protocol is bound to increase in its functionality through the employment of technique called patterns schedules which would be used to mitigate the idle listening periods that is the spring of energy waste. Moreover, P-MAC makes use of part of a node's sleep-wake up schedules based on the personal traffic and the contemporary while the knowledge of anticipated channel are always recorded.

Chao and Lee (2010) emphasized that the shortcoming of the P-MAC protocol is that its functionality relies on pattern exchanges of the sensor nodes. Researchers have emphasized that there are two sensor nodes that may not be able to meet if they do not receive the other's schedule correctly. This produces idle listening and wasted transmissions. Meanwhile, P-MAC may also suffer from long transmission latency. The study of Halkes & Langendoen, (2007) submitted that the P-MAC protocol is similar to the Crankshaft protocol in that it also schedules nodes to be awake for reception on a slot basis. Hence, the P-MAC protocol requires nodes to exchange and store schedules.

According to Cano Bastidas, (2009), the crankshaft is purposely designed for dense WSN and is a send initiated protocol that separate time for frames in a slots strata. Crankshaft assumes global synchronization and assigns a wakeup slot to each receiver as its MAC address module. Therefore, every receiver can use only a fixed slot in each frame, making Crankshaft inflexible in handling busty traffic that may occur in sensor networks (Halkes & Langendoen, 2007). Besides, the usage of a particular of scheduling of receiver ignites slots which leads to the repeatedly ignition of packet collisions (Halkes & Langendoen, 2007; Kaan & Yang, 2008).

The fundamental or basis of crankshaft nodes depend on the ignition of receiving messages at a particular stance from the inception of frame (Saharan & Pande, 2013). One of the functions of crankshaft is the usage of DATA/ACK sequences for unicast messages with the length of slot for accommodating them. Researchers have viewed crankshaft as compatible long-lived monitoring applications that can allow throughput in lieu of energy efficiency (Halkes & Langendoen, 2007). Moreover, crankshaft protocol is sometimes dedicated for contention resolution improvement which make use of sift distribution for the commencement of sending the messages. Therefore, sift distribution is referred to as the important truncated geometric distribution that ended up in fewer collisions rather than using a uniform distribution. Thus, the usage of sift distribution always mitigates the time interval between the initial and ignited moment of sending the message and retains some energies.

In a related development, Anwar and Lavagno, (2010) describes AS-MAC that is always consumes efficient energy protocol. The researchers have explored the AS-MAC through the state flow model for power simulation using AvroraZ and Markov chain model for performance comparison with other protocol. The AS-MAC utilizes small memory (RAM and ROM) as a result of its performance. The study of Jang et al., (2013) reveals that AS-MAC uses duty cycling in order to prevent idle listening and uses LPL for mitigating frequent wake up time ignition. Moreover, Event Based (EB-MAC) Protocol is traced to event based systems that is capable of handling both high and low traffic situations (Merhi, Elgamel, & Bayoumi, 2009). The performance of EB-MAC is subjected to the Received Signal Strength (RSS) of the detected event. Therefore, the more the RSS reading, the earlier the slot is given to a node. Table 2.2. below shows summary of related research studies.

2.3 Primary Causes of Energy Wastage in WSN

Primary causes of energy wastage in WSN are fundamentally of four types (Solehria & Jadoon, 2011).

Collision: Firstly, the collision. Collision happens when a transmitted packet is dropped due to the interference. Retransmission is required and often retransmissions lead additional energy consumption.

Overhearing: Secondly, the overhearing. The meaning of that a node chooses up packets that are destined to different nodes.

Packet Overhead: Thirdly, the control packet overhead. Overhead is the cost that is incurred when nodes change their location within the network. The routing table need to be updated accordingly which leads to unnecessary routing overhead.

Idle listening: Idle listening is the last prime source of energy waste, because of the low traffic loads typically found in WSN. Idle listening happens when a node listens to the channel for a possible traffic but no packet is received.

Table 2.2

Summary of Related Research Studies.

Researcher(s)	Topic	Description	Result
(Rhee et al., 2004)	Randomized dining philosophers to TDMA scheduling in WSN**.**	Applied DRAND algorithm for Z-MAC protocol to compute time slot assignments.	Z-MAC does not categories as traffic adaptive due to DRAND running overhead.
(Bachir et al., 2010)	MAC essentials for WSN.	Run a distributed slot allocation algorithm DRAND to assign a slot to each node in Z-MAC protocol.	Z-MAC experiences schedule drifts and thus, it would be necessary to periodically re-run DRAND to resolve the schedule drift, which reduces its energy efficiency.
(El-Hoiydi et al., 2003)	WiseMAC, an ultra low power MAC protocol for the Wisenet WSN.	Using WiseMAC preamble sampling technique	Different packets are buffered for neighbours in broadcast-type communication in sleep mode and delivered many times as each neighbour wakes up, this causes higher latency and unnecessary power consumption.
(Saharan et al., 2013)	A Survey on Energy efficient Asynchronous WiseMAC protocol for WSN	Proposed adaptive WiseMAC protocol with both of duty cycle and contention window	High throughput but with the limited energy efficiency.
(Halkes & Lange doen, 2007)	Crankshaft: An energy-efficient MAC-protocol for dens WSN**.**	Use Crankshaft protocol in dense network	Time Synchronization mechanism absent and multiple receiver wakeup. That leads to idle listening.
(Jang et al., 2013)	An asynchronous scheduled MAC protocol for WSN	Has been implemented AS-MAC in TinyOS.	The experimental results show that (AS-MAC) considerably reduces energy consumption while providing good delay and packet loss.

2.4 Conclusion

This chapter has presented the Medium Access Control Protocol and the three major schemes of MAC protocol; contention-based, schedule based and hybrid protocols. In addition, explained the benefit from design MAC protocol and presented the review of previous studies in the domain of Zebra MAC Protocol and their works, advantages, disadvantage, and summary. This chapter also emphasized on the Wireless Sensor MAC protocol and the related protocols. Lastly, Asynchronous Scheduled MAC (AS-MAC) protocol together with their phases were also reviewed. Each one of these protocols is a hybrid MAC protocol, We have chosen the hybrid MAC protocols because of the prime function of hybrid protocol is to integrate the Carries Sense Multiple Access (CSMA) with Time Division Multiple Access (TDMA) by giving the recognition to their strength and provides the solution to their existing weaknesses and the hybrid protocol allow energy savings provides better scalability and flexibility which is more than contention-based MAC or called TDMA-based MAC.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

This research intends to solve the problems that are related to energy issues in Wireless Sensor Network (WSN) nodes, which have been mentioned in the previous chapter. These problems are scheduling drifts, idle listening time, and high latency that occur as a result of uncontrolled and the lack of regulation during the transmission and reception of data in WSN which lead to energy wastage.

This research aims to design a MAC protocol called Energy Efficient MAC (EE-MAC). This protocol will be discussed in the Section 3.2 of this chapter. Besides, the study will analyse the performance of this protocol that will be explained in the same section.

In addition, the study has to compare our hybrid (EE-MAC) protocol with the existing contention-based IEEE 802.11 PSM protocol and the research will carry out simulation to evaluate the performance of the (EE-MAC) protocol, the details of evaluation at the Section 3.3 of this chapter. Indeed, this chapter going to explain the methodology outlines five tasks to be performed as the following: 1) Task 1 – Understand the protocols; 2) Task 2 –Design a (EE-MAC) protocol; 3) Task 3 – Implement (EE-MAC) protocol; 4) Task 4 – Analysis; and 5) Task 5 – Evaluation.

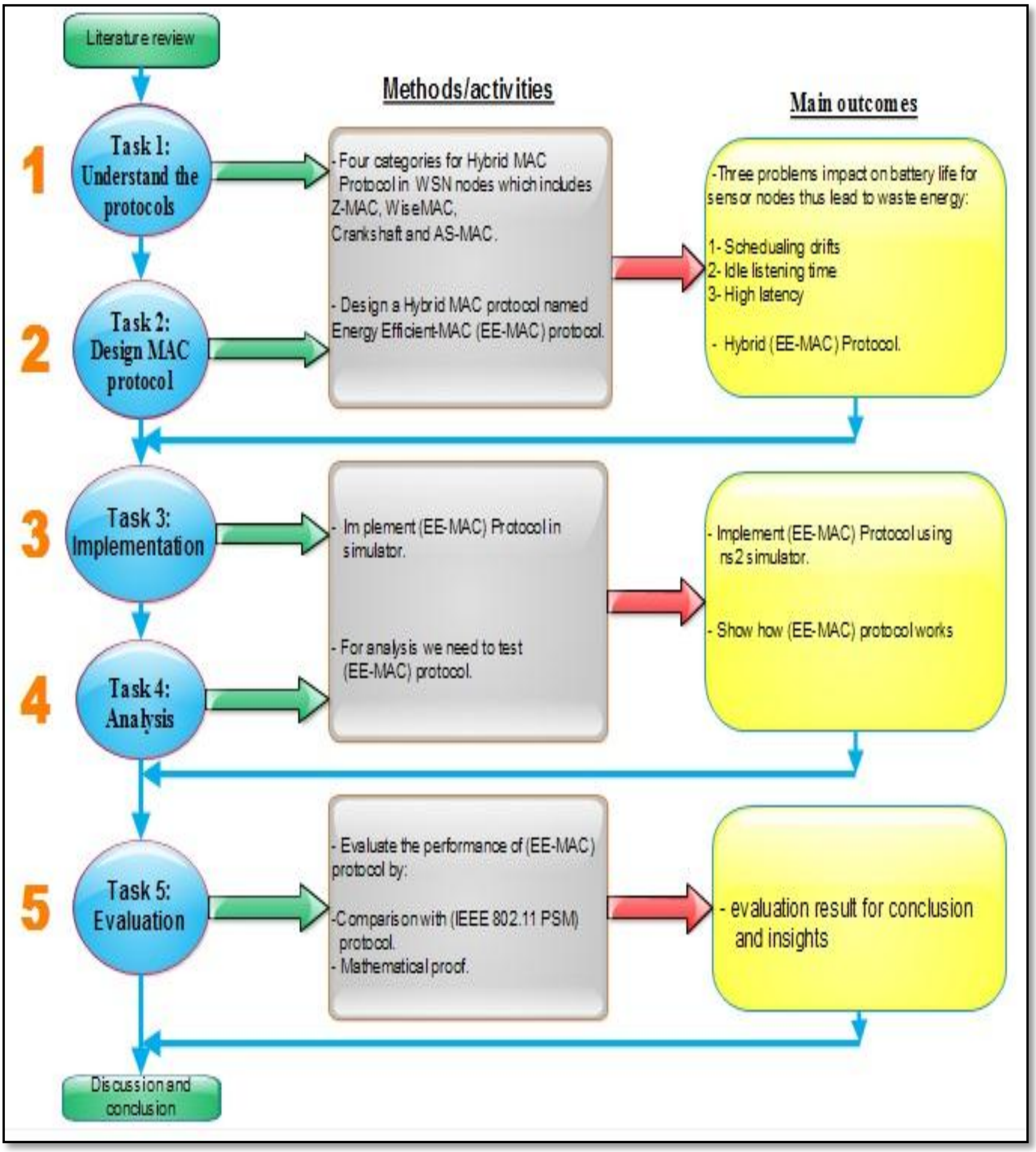

Figure 3.1. Methods and the Main Outcomes Encapsulated in the Research Framework.

3.1 Understand the protocols and design (EE-MAC) protocol

Hybrid protocols play very important roles in improving the energy efficiency in WSN nodes in order to reduce the energy consumption. This study aims to designing a hybrid Energy Efficient MAC (EE-MAC) Protocol for Wireless Sensor Network nodes. The EE-MAC protocol will be modeled using simulator ns-2. The purpose of designing the EE-MAC is to make the battery life longer for WSN nodes by controlling the sending and receiving data in WSN.

3.2 Implement (EE-MAC) protocol and analysis

For implementation, the study will implement the EE-MAC protocol in ns-2. ns-2 simulator mainly developed on Fedora OS to support sensor network simulations. The main advantage of ns-2 is it is open source. Analysis will be the next step, by using tests for the EE-MAC protocol. Furthermore, simulations will be conducted to seek results. The EE-MAC procedure takes care the scheduling and synchronization during the transmission and reception of data in WSN nodes in order to improve energy efficiency. The procedure is explained in algorithmic form in Figure 3.2.

```
Sink=0
Input 'number of nodes' N
// initialize other nodes
For (int k, k<=N, k++)
        node(k)= 1;

//Set the Sink node for connection
Sink = 1
k=1
While k < N
        //Send other nodes to sleep apart from the current
        For (int j, j<=N, j++)
        If (j!=k)
                node(k)= 0;

        Notify node(k) for message
        If node(k) is ready
           Sink send data to node(k)
        Node(k) notifies node(k+1) for messages
        If node (k+1) has messages
           node(k) send data to node (k+1)
           // Current node goes to sleep
        node(k)=0
        k++

Loop
```

Figure 3.2. Algorithmic Form of EE-MAC Procedure.

3.2.1 Pseudo Code

Neighbor Discovery Module

1: func Neighbor discovery ()

2: Broadcast the RTR packet with source information

3: end func

Receive RTR Packet Module

1: func Receive RTR ()

2: Obtain the sender (S) location from RTR packet

3: Obtain the receiver (N) location

4: Compute d (S, D), d (N, D), where D is destination location

5: if (d (S, D) < d (N, D)

6: if (Packet type != broadcast)

7: Add the entry to neighbor table with forward flag 1

8: return;

9: else

10: Add entry to Neighbor table with forward flag 0

11: Send RTR reply packet to sender S with receiver info

12: end if

13: end func

Data forwarding

1: func forward_data ()

2: num_entries = Count the number of entries in neighbor table

3: dest = check whether destination entry exist in neighbor table

4: if (num_entries == 0 && dest == 0)

5: Neighbor discovery ()

6: elseif(dest !=0)

7: send data to destination

8: else

9: nxt_hop = Best Next_hop ()

10: if (nxt_hop != 0)

11: send data to nxt_hop

12: else Neighbor discovery ()

13: end if

14: end if

15: end func

Note: RTR is the router packets and S is the sender location and N is receiver location.

3.2.2 Mechanism of the EE-MAC Procedure work.

The steps below demonstrate the mechanism of the EE-MAC procedure work is as follows:

Table 3.1

The Mechanism of the EE-MAC Procedure Work.

EE-MAC Procedure work mechanism		
Step No	**Step name**	**Description**
Step1	**Initialize**	In the initialize step, the Sink node needs to be ON to initialize. All nodes are in ON mode too to receive sync messages.
Step2	**Sink** Switch ON	In this step the sink node in the switch ON mode that's mean the sink node ready to be contacted with the other nodes in the sensor field in Wireless Sensor Network.
Step3	**Sink sync With nodes**	Here, nodes synchronous with the sink on their awake time and go to sleep. In order to sort the time, which leads to conserve energy by controlling the sending and receiving data?
Step4	**Nodes go to sleep except node number N**	The process in this step going to force the nodes to go to the sleep mode except the node number one which is after the sink. For example, if the study have (20) nodes, the n=20, in this step the nodes from number 2 until the node number 20 go to sleep mode, just node number 1 will be a wake to be ready to starting the contact after the sink node directly.

Step5	**Sink Send Notification**	Through this step, sink notifies node number one if it has messages to send. The sink has the priority for starting contact in the WSN nodes.
Step6	**Sink Send data**	According to, this step if the notification accepting, then the sink node will have a chance to send the data. After the sink send data it direct going to step7.
Step7	**Node Send notification**	After the sink node finish sending data the priority in this step for the node number one. The node number one will notifies node number two if it has messages to send.
Step8	**Node send data**	In this step node number one will sending data after receiving accepted the notification. Node number one waiting the time finish for sending data to go to the sleep mode in the next step.
Step9	**Node goes to sleep**	With this step the node number 1 finished sending and goes to sleep mode and never be a wake again until all the other nodes sending and receiving the data. Node number 2 will start sending notification to notify node number 3if it has messages to send. Furthermore, the other nodes will start sending and receiving directly one by one after the node number two goes to sleep.
Step10	**Wait the time finish**	During this step after last node sending and receiving data and goes to sleep mode and waiting the time completed will back for starting again in step 3.

3.3 Evaluation

Evaluation task is targeted to achieve the objectives which are to reduce the energy consumption by reducing schedule drift, idle listening and latency time to achieve better energy efficiency. This research will evaluate the performance of the (EE-MAC) protocol based on the comparison between our protocol (EE-MAC) and the contention-based MAC IEEE 802.11 PSM Protocol. In addition, this study aims to proof the energy efficiency on the sensor nodes by using mathematical equations. The mathematical equations which will be used to calculate the energy efficiency are:

$$\sum E_{total} = E_{Active} + E_{Idle} + E_{Sleep} \quad \text{........................} \quad \textbf{(1)}$$

$$\sum E_{total} = E_{Tx} + E_{Rx} + E_{Idle} + E_{Sleep} \quad \text{........................} \quad \textbf{(2)}$$

Operation of sensor nodes on limited battery power justify that energy usage is an important concern in WSN design and it is the prime factor that determines WSN lifetime. The total energy consumed by a wireless sensor node is includes the energy consumption during active mode, energy consumption during idle mode and energy consumption during sleep mode. When the frame in active mode this means that the nodes are in a position to sending, receiving and sensing. A node remains in idle or sleep mode when there is no data transfer. However, a node in idle state periodically senses the air interface for incoming data, and over a long period of time will consume a significant amount of energy. The node during idle mode consumes more energy and it is therefore important to keep a node in the sleep mode as much as possible. This dissertation attempts to reduce the energy consumption through the idle mode in order to achieve energy efficiency in WSN nodes.

3.4 Summary

This research adheres of using single-sink node in WSN nodes. The framework of this research consists of three tasks which are performed to achieve the objectives as specified in chapter one, Section 1.4. Firstly, understand the protocols through the previous chapter by four types of hybrid MAC protocols and design (EE-MAC) protocol. Secondly, implement (EE-MAC) protocol in ns-2 simulator and analyse it by testing different scenarios. Following this further, the (EE-MAC) protocol will apply the Energy Efficient MAC Procedure to show how it works. Thirdly, this study will evaluate the performance of (EE-MAC) protocol by compare EE-MAC with IEEE 802.11 PSM Protocol and measuring of the Energy-efficiency on the sensor nodes by using mathematical equations. Finally, this study expects the performance of the EE-MAC protocol ensures avoid the schedule drifts and reduce both of idle listening and latency time by reducing energy consumption. Thus, investigations improve energy efficiency in WSN nodes.

CHAPTER FOUR

SIMULATION AND DESIGN

4.0 Introduction

The main objective of this dissertation is to conserve the energy of the wireless sensor network nodes by reducing idle listening thus reducing total energy consumption in order to extend the battery life in WSN nodes. Battery life plays very vital role in WSN nodes functioning. To achieve this objective, the study has proposed EE-MAC protocol. This chapter details the various implementation issues while setting up the simulation in ns-2 with Fedora OS, followed by a section on the designed EE-MAC protocol.

4.1 Simulation Setup and Parameters

The study has implemented the EE-MAC protocol using ns-2 simulator on Fedora OS. Through this exercise the study intend to develop the proposed protocol, simulate the energy saving scheme and evaluate the performance of our (EE-MAC) protocol. ns-2 simulator mainly developed on Fedora OS to support sensor network simulations. The main advantageous of ns-2 is open source and discrete event simulator. This is based on languages Object Oriented Tool Command Language (OTCL) and C++. IEEE 802.11 Power Saving Mode (PSM) protocol compatibility for energy consumption measurements is offered by ns-2 for both wired and wireless networks.

This research has simulated the proposed EE-MAC protocol using ns-2 version 2.32. The EE-MAC simulation has defined 100 nodes within a sensor field of 500x500 meters and the simulation time is set at 200 seconds. The EE-MAC is compared against the standard IEEE 802.11 Power Saving Mode (PSM). Briefly, the parameters of the simulation for both EE-MAC protocol and IEEE 802.11 PSM protocol are as tabulated in Table 4.1 (Udayakumar et al., 2013).

Table 4.1

Simulation Parameters and Setup.

Parameter	**EE-MAC**	**IEEE 802.11 PSM MAC**
Deployment zone	500 m^2	500 m^2
Number of nodes	100 nodes	100 nodes
Initial Energy	100 Joules	100 Joules
Tx Energy	0.02 Joules	0.02 Joules
Rx Energy	0.01 Joules	0.01 Joules
Idle Energy	<0.01Joules	<0.01 Joules
Simulation time	200sec	200sec

4.2 Performance Metrics

This study need to measure the parameters quantitatively so performance metrics are required. Following are the performance metrics used during this EE-MAC protocol study that are standard measure mentioned by Oppenheimer (2004).

Energy Consumption: The amounts of energy consumed by a node during active, idle and sleep modes. Considering all these information energy efficiency of the WSN nodes need to be calculated.

Average energy consumption= Total energy consumption /Number of nodes

Joules is the unit used for energy consumed. This performance metrics gets affected by all major sources of energy waste in wireless sensor network nodes such as idle listening, schedule drifts and latency.

Latency: It is calculated as a time between a ready frame to transmit from a node and deliver the frame to destined node which is elsewhere in the network.

Packet Delivery Ratio: The average packet delivery ratio is calculated as the, total number of packet received to the number of packets sent over all nodes.

Packet Delivery Ratio= (∑No. of packets received/∑ No. of packet sent) * 100

Delay: It is the total time taken during the transmission of packet from one node to another. It is calculated by taking the difference between the sending and receiving time of the data.

Delay= Packet receive time – Packet send time

Throughput: It is the total number of packets delivered at the sink node per unit. Amount of error free data transferred successfully between the nodes. Usually in seconds.

Throughput = Total amount of data received/ Total time.

Dropping Ratio: It is the average number of packets dropped during the transmission from one node to another divided by total number of packets transmitted multiplied by 100.

Dropping ratio = (Total number of packets transmitted – total number of packets received)/ Total number of packets transmitted *100

Normalized Routing Overheads: Overhead is the cost that is incurred when nodes change their location within the network. The routing table need to be updated accordingly which leads to unnecessary routing overhead.

Normalized Routing Overhead=Control overhead/received packets

4.3 Design Energy Efficient MAC (EE-MAC) Protocol

This section describes the proposed Energy Efficient MAC (EE-MAC) protocol. Because energy is a limited resource in WSN nodes, energy consumption must be minimized while satisfying given scheduling requirements for enhanced lifetime.

Generally, the total energy consumed by a wireless sensor node is given as below:

$$\sum E_{total} = E_{Active} + E_{Idle} + E_{Sleep} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where, E_{Active} is the amount of energy consumed when the node is in its active mode. E_{Idle} is the amount of energy consumed when the node listens to the air interface for incoming messages, while E_{Sleep} is the amount of energy used basically for circuitry purposes when the node is in its sleep mode.

The amount of energy consumed by a node in active mode can further be divided into $E_{Tx,}$ the amount of energy consumed for data transmission, and $E_{Rx.}$is the amount of energy consumed for data receipt. Equation (1) can therefore be expanded and written as

$$\sum E_{total} = E_{Tx} + E_{Rx} + E_{Idle} + E_{Sleep} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

The energy requirement for data transfer is far larger than the combined amount of energy required for data receipt, scanning the air interface and in the sleep mode.

However, most nodes are in idle mode most of the times and a significant amount of energy is wasted during this period. Therefore it is important that the amount of time a node remains in idle mode is reduced so as to reduce the energy consumption. By reducing the E_{Idle}, the total energy consumed can be reduced.

In the following section, the scheduling mechanism in EE-MAC is discussed to illustrate how to reduce the idle listening in WSN nodes.

4.3.1 Scheduling

Scheduling is a technique used in most schedule-based MAC protocols. Each node is assigned a specific slot of which it can receive and transmit data. Similar technique is employed in EE-MAC. During initialization, all nodes are active to receive a synchronization message from the sink node. The time slot assigned for each node is divided into two slots, one for notification of data arrival, and another for the nodes to transmit to the sink. If a node has data to transmit, it transmits during the time slot assigned, otherwise it switches to sleep mode immediately. The procedure of EE-MAC is illustrated in Figure 4.1.

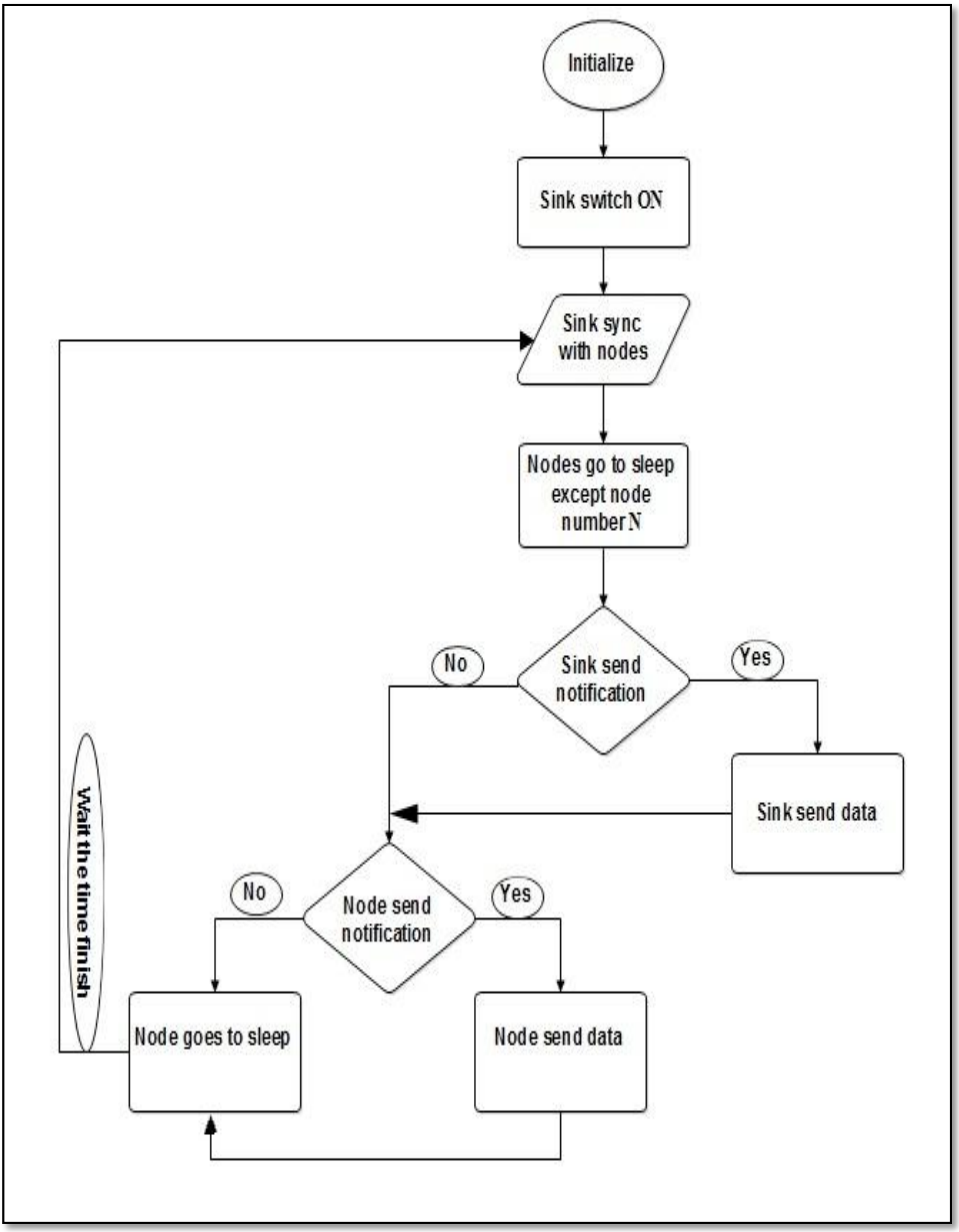

Figure 4.1. The EE-MAC Procedure**.**

The steps below demonstrate the EE-MAC procedure:

Step1: Initialize: In the initialization step, all nodes are awake to receive synchronization message from the sink node.

Step2: Send synchronization message Nodes receive synchronization message from sink node.

Step3: Synchronize with sink: Nodes synchronizes with sink. Nodes know the slot they are assigned to

Step4: Nodes go to sleep except node number N: All nodes, except node N switches to sleep mode. Node N is ready to receive data

Step5: Sink send notification: Through this step, sink notifies node number N if it has messages to send.

Step6: Sink sends data: Sink node sends messages to Node N.

Step7: Node send notification: If the sink has message to send, then Node N notifies the sink if it has data to send. Otherwise node N goes to sleep immediately.

Step8: Node send data: In this step node N will send data after receiving accepted the notification from Step 7. Node N will sleep when it finishes data transfer of the time slot expires.

Step9: Node goes to sleep: Node goes to sleep under the following circumstances: (i) Node N has no data to be sent, (ii) Node N finished sending data, or (iii) Node N's time slot expires**.**

Figure 4.2 shows the EE-MAC scheduling procedure.

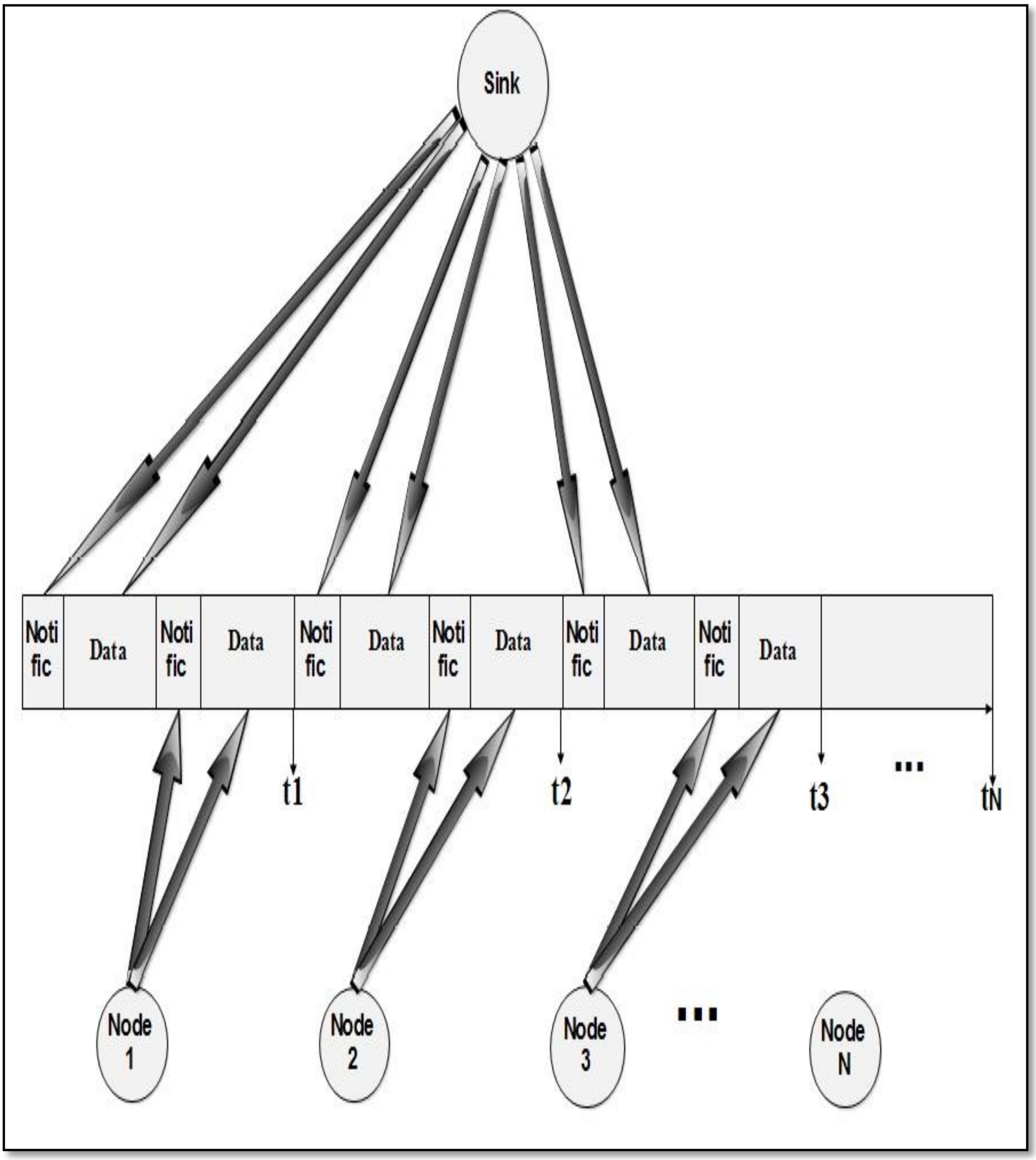

Figure 4.2. The EE-MAC Scheduling Procedure.

CHAPTER FIVE

ANALYSIS AND EVALUATION RESULTS

5.0 Introduction

This chapter presents the results of our ns-2 simulation in accordance with the goal of the thesis, which mainly aims to improve energy efficiency in WSN nodes by simulation, implemented to compare the energy consumption between the EE-MAC protocol and IEEE 802.11 PSM protocol. The mathematical modeling is represented in Chapter 4 through the equations (1) and (2). The simulation is carried out according to the simulation setup and parameters explained in previous chapter. Results pertaining to the mentioned performance metrics are provided in this chapter with the screenshots and graphs. Section 5.1 contains the analysis performance results of EE-MAC protocol. Section 5.2 contains the EE-MAC performance evaluation. Section 5.3 contains the energy saving. Section 5.4 contains the results and discussion.

5.1 Analysis Performance Results of EE-MAC Protocol

In this dissertation, simulation carried out for measuring the performance of the EE-MAC protocol and IEEE 802.11 PSM protocol. Performance metrics such as packets delivery ratio, dropping ratio, throughput, jitter, average energy consumption and normalized routing overheads for both the protocols were measured and evaluated. Table 5.1 summarizes the simulation results.

This study has implemented proposed EE-MAC protocol using ns-2 simulator to evaluate the performance. The IEEE 802.11 PSM protocol also implemented for comparison purpose. In EE-MAC simulation, 100 sensor nodes were randomly placed within the radius of 500 * 500 meters. Comparison of EE-MAC with 802.11 PSM protocol is done. The implementation can be seen in Figure 5.1 and 5.2 respectively.

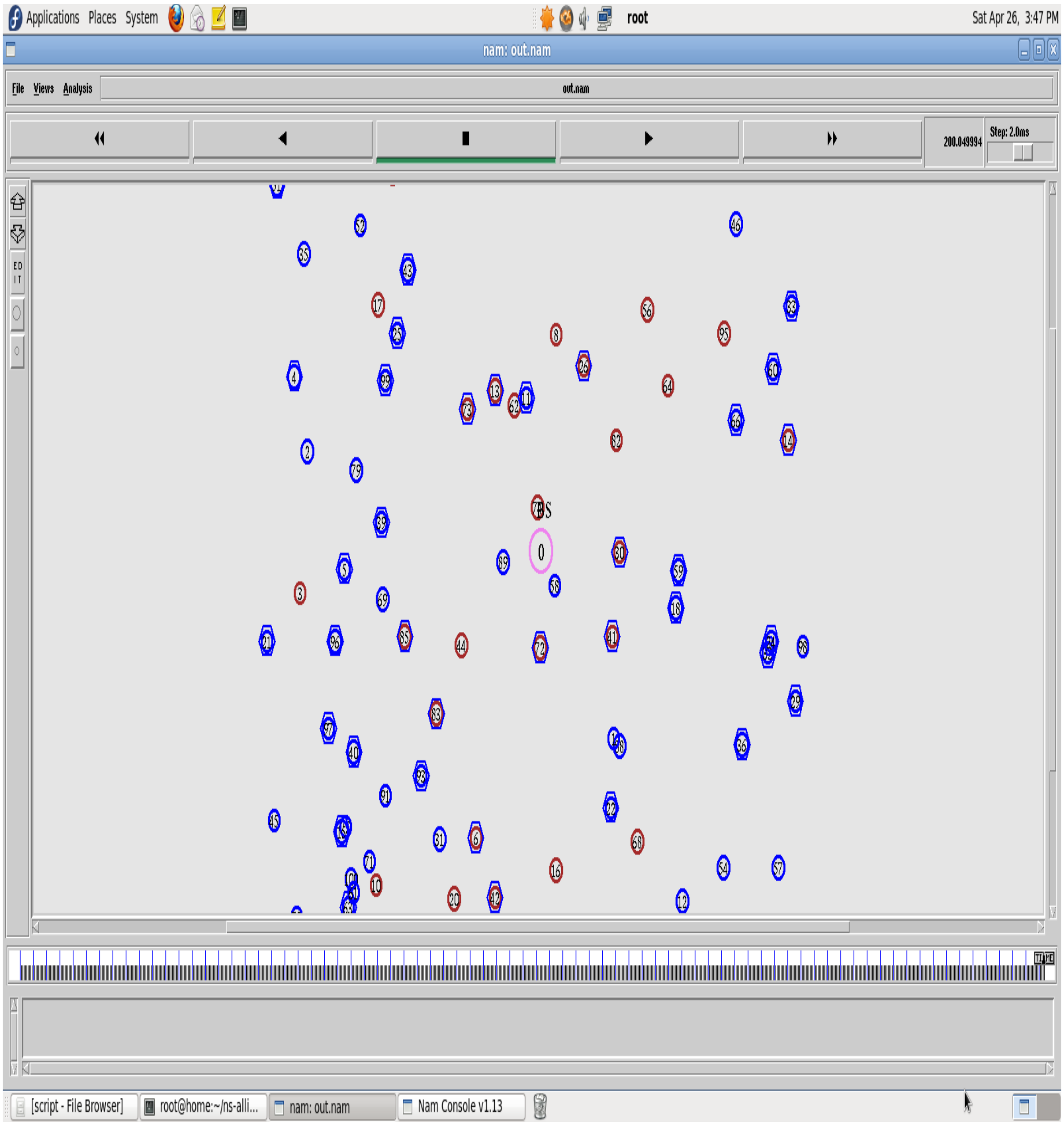

Figure 5.1. Implementation of Sensor Node for EE-MAC Protocol.

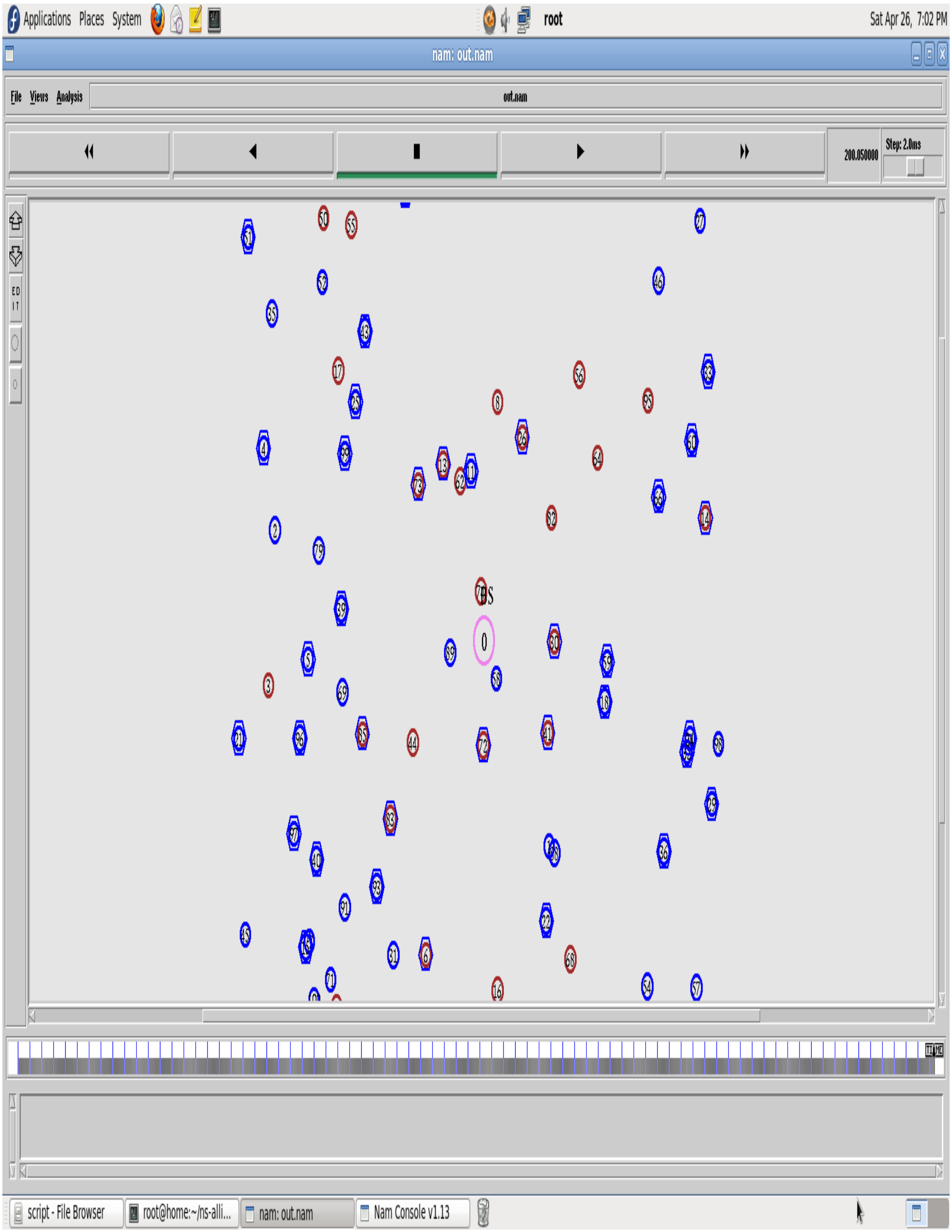

Figure 5.2. Implementation of Sensor Node for IEEE 802.11 PSM Protocol.

Table 5.1

Simulation Results of EE-MAC and IEEE 802.11 PSM Protocols.

Simulation metrics	**Results of (EE-MAC) protocol**	**Results of IEEE 802.11 PSM**
No. of packets sent	3100	3100
No. of packets received	3085	3070
No. of Packets dropped	15	30
Dropping-Ratio	0.483871	0.967742
Packets delivery ratio	99.5161	99.0323
Delay	2.51999	2.47014
Throughput	84241.1	83831.5
Jitter	0.0502109	0.0504694
Total Energy Consumption	105.2	379.466
Average Energy Consumption	1.052	3.79466
Control Overhead	7835	7491
Normalized Routing Overheads	2.53971	2.44007
Overall Residual Energy	7419.8	9620.53
Average Residual Energy	74.198	96.2053

5.2 EE-MAC Performance Evaluation

This study has evaluated the performance of the proposed EE-MAC protocol and the contention-based IEEE 802.11 PSM protocol using ns-2 version 2.32. The results are elaborated as follows:

Figure 5.3 shows the rate of delivered packets for EE-MAC and IEEE 802.11 PSM protocol. The packet delivery ratio of EE-MAC is calculated as total number of packets received from all nodes and delivered to other nodes, which are divided by total number of packets sent multiplied by 100. On basis of simulation, the simulation validate that EE-MAC outperforms to the IEEE 802.11 PSM protocol. The vector of EE-MAC shows remarkable improvement. EE-MAC provides delivery ratio of 99.5% because delivery ratio remains stable with different network packets. The reason of high delivery rate is the scheduling technique used. EE-MAC applied technique which is divided the frame into slots and each node is assigned a specific slot of which it can receive and transmit data. During initialization, all nodes are active to receive a synchronization message from the sink node. The time slot assigned for each node is divided into two slots, one for notification of data arrival, and another for the nodes to transmit to the sink. EE-MAC prevents nodes to use their neighbor time slots. If a node has packet to transmit, it transmits during the own time slot assigned this led to avoid the collision, otherwise it switches to sleep mode immediately which led to reduce idle listening. According to the mechanism of EE-MAC, EE-MAC has proved lower latency time because it has a smart master selection.

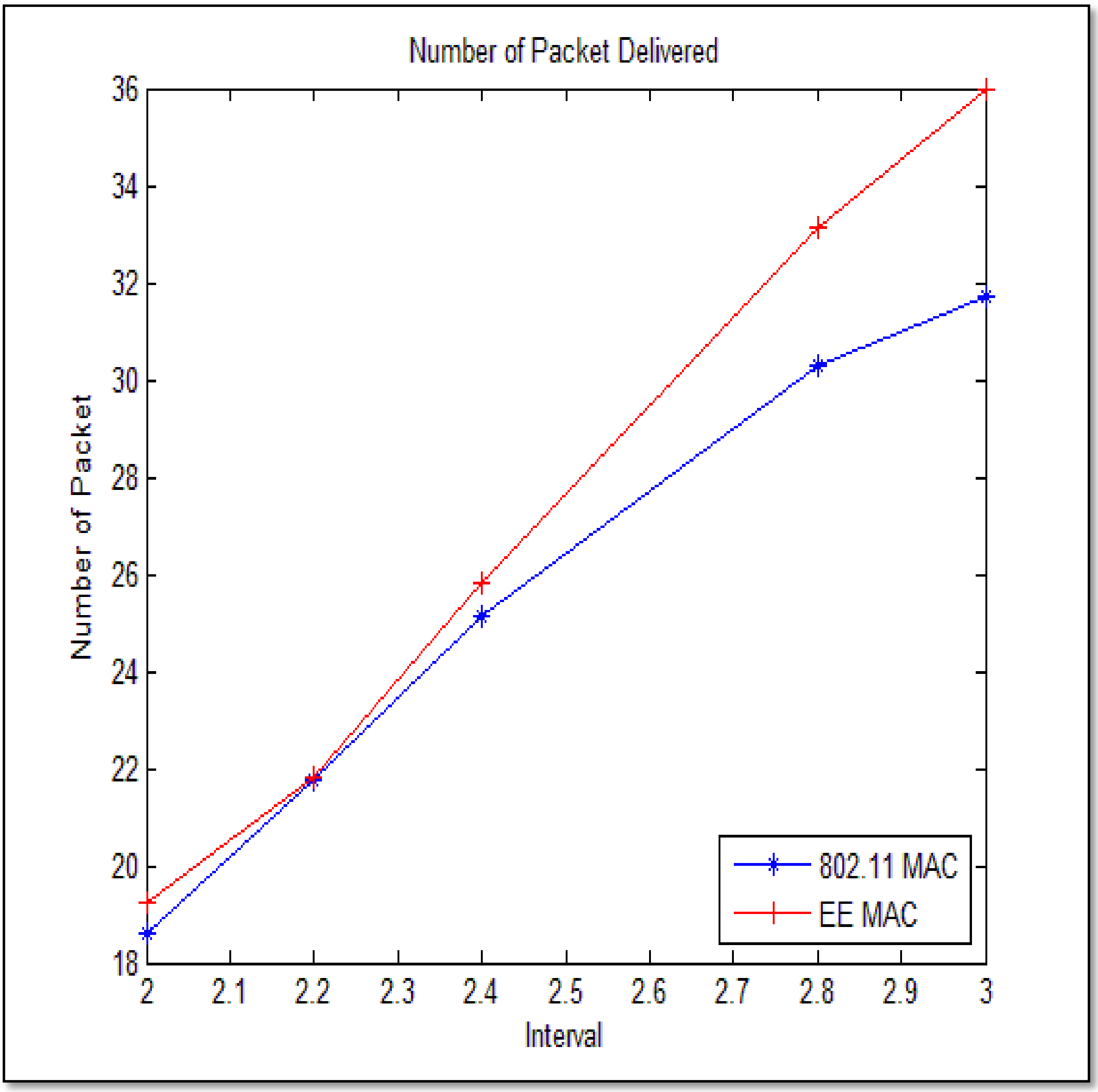

Figure 5.3. Packets Delivery Ratio for EE-MAC and IEEE 802.11 PSM.

The proposed EE-MAC performs better when is compared to the IEEE 802.11 PSM. Of the 3100 packets sent, 3085 were received packets, so only 15 packets were dropped. From this can see clear the dropping rate is very low in case of EE-MAC. In this case EE-MAC behaves like CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance). Because of this technique the collisions are reduced between the nodes by preventing the nodes from access to the network at any time. Therefore is no more than one node transmits the packets at the same time due to the scheduled procedure of EE-MAC protocol thus, there is less chance of dropping data packet because of the nodes are used their time slots to transmit the packets this is lead to avoid the retransmitting packets and in the end, the collisions do not occur. Figure 5.4 depicts the simulation result of EE-MAC pertaining to packets dropped.

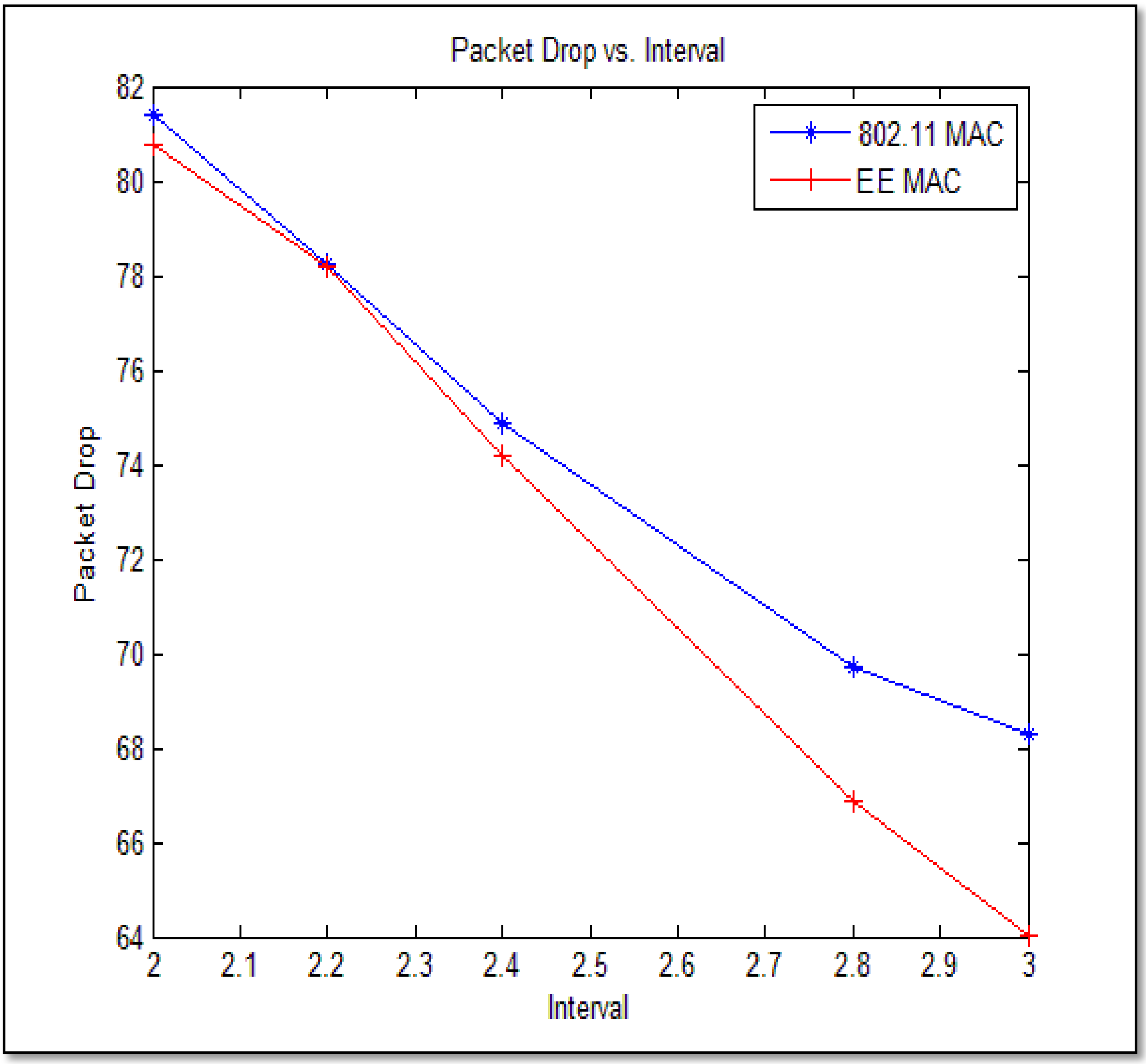

Figure 5.4. Dropping Ratio for EE-MAC and IEEE 802.11 PSM.

EE-MAC also produced a higher throughput when is compared against the IEEE 802.11 PSM as shown in Figure 5.5. In the case of EE-MAC, the nodes follow the synchronized schedule that is reason there is no variation (jitter) that results in improvement of throughput. In EE-MAC, energy is saved to bring sensor node into sleep mode. The duty cycle regulation feature of EE-MAC also achieves energy perfection without sacrificing the throughput and latency significantly. EE-MAC also performs localized time slot allocation without changing time slots of already existing nodes. This feature of re-use slot allocation improves throughput and reduces the latency of nodes.

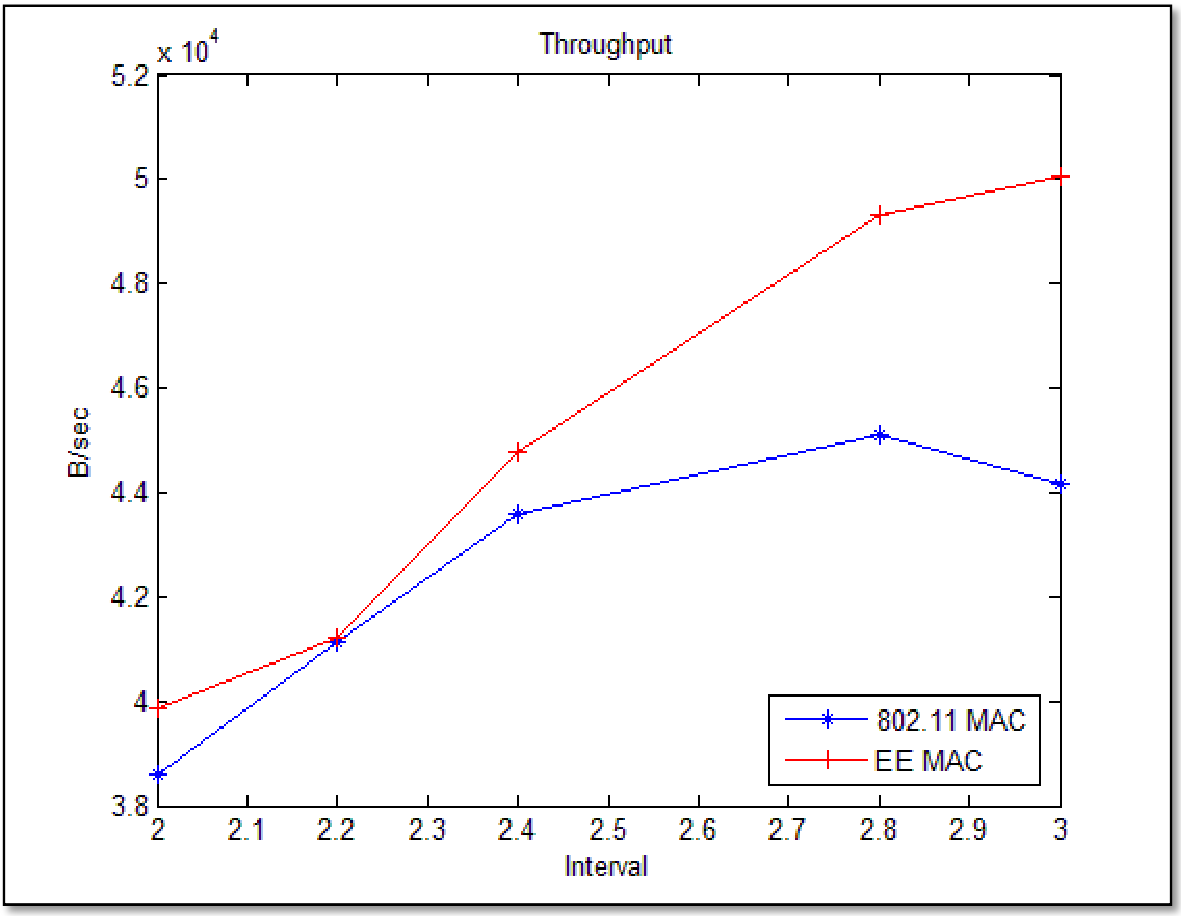

Figure 5.5. Throughput for EE-MAC and IEEE 802.11 PSM.

Indeed, MAC protocol registers the next frame period as a timer event, but delays in the registration and deletion of timer events caused jitters. In case of EE-MAC, jitter is low as shown in Figure 5.6. EE-MAC has reduced the variation in latency. Latency can be lower due to fairness in synchronization. If each node follows them synchronization schedule then there is having low latency. Another reason of lower jitter is the all nodes are active during initialization to receive a synchronization message from the sink node with this case, the nodes know their destination.

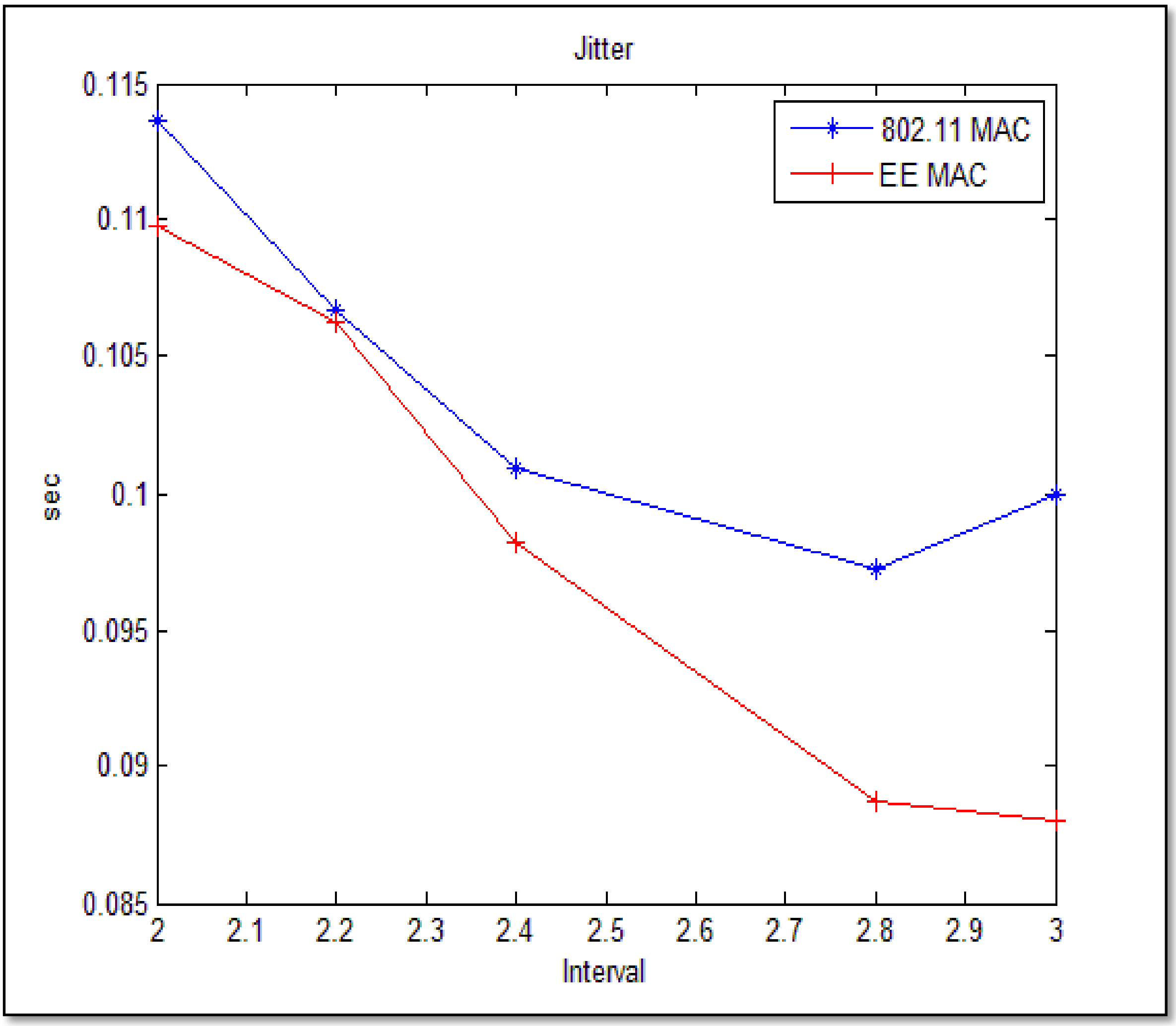

Figure 5.6. Jitter for EE-MAC and IEEE 802.11 PSM.

5.3 Energy Saving

In a network, nodes in awake state are costly and unnecessary when some nodes do not have traffic to carry. For example, MAC protocols usually try to find a shortest path from sources to destinations. It is likely that some nodes will over-serve the network and their energy will be drained quickly. To save this scenario this study proposed EE-MAC protocol. Here in EE-MAC it chooses master nodes from overall nodes in the network. Master nodes stay awake all the time and act as a virtual backbone to route packets in the network. Other nodes, called slave nodes, remain in an energy-efficient mode and wake up periodically to check whether they have packets to receive. As all the nodes in EE-MAC is not awake it save energy.

The simulation reveals that the proposed EE-MAC consumes less energy as compared with IEEE 802.11 PSM protocol. The reason of less energy consumption is to control idle listening time because sensor node consumes maximum amount of its energy without doing anything on frame. The scheduling of EE-MAC brings the sensor nodes into sleep mode after finishing its monitoring process of events. Thus, EE-MAC helps to maintain the fairness of energy in network during the events have shown to be energy efficient. The slot assignment mechanism as well as the reduction of idle times has improved energy consumption to more than 40%. This is a significant improvement on energy conservation. The simulation result is shown in Figure 5.7.

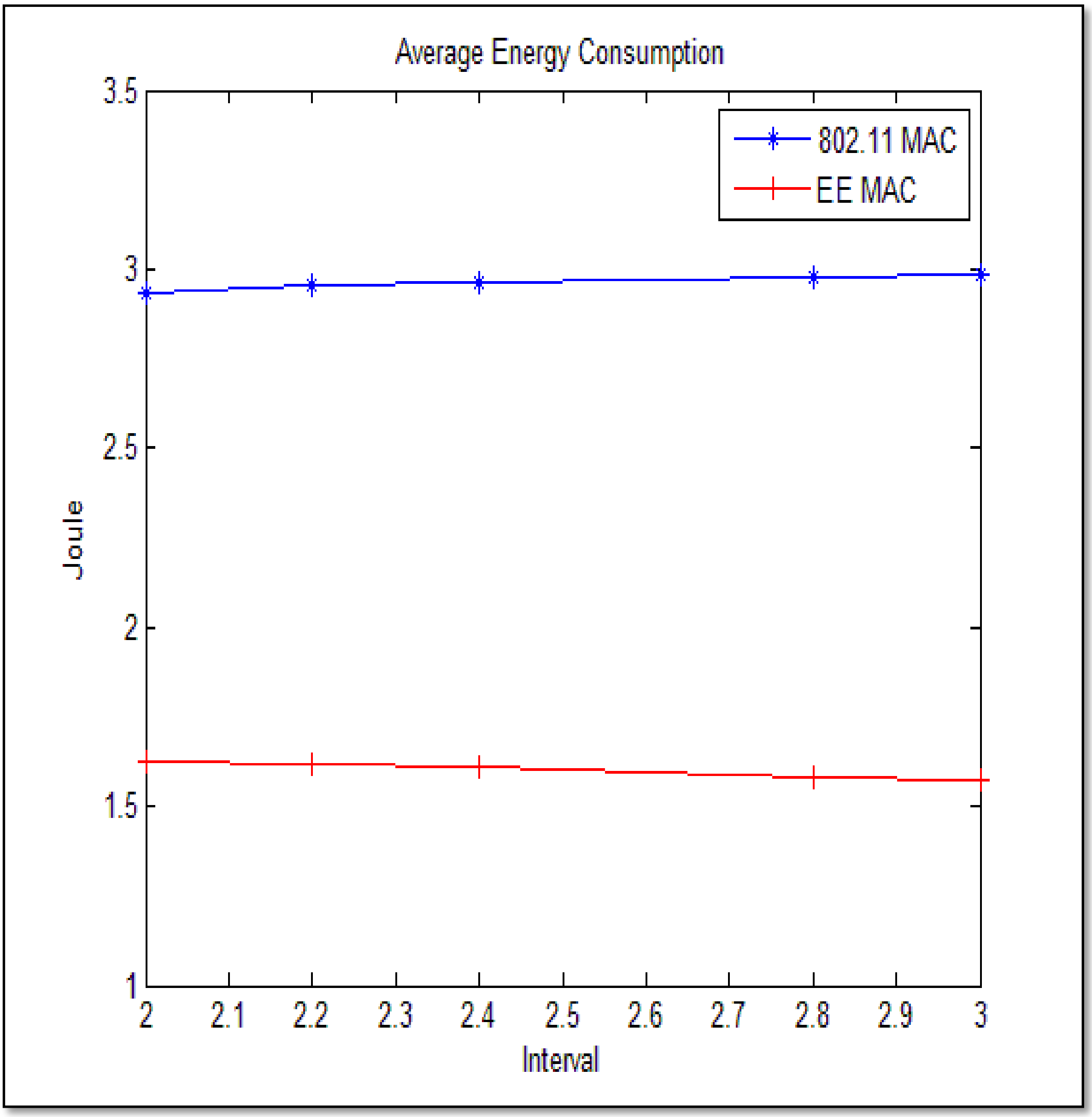

Figure 5.7. Average Energy Consumption for EE-MAC and IEEE 802.11 PSM.

In WSN nodes, overhead is the cost that is incurred when nodes change their location within the network. The routing table need to be updated accordingly which leads to unnecessary routing overhead that lead to increase the energy consumption. The normalized routing overhead is calculated as control overhead delivered to total number of packets received. When the normalized routing overhead is reviewed in case of both the protocols which is shown in Figure 5.8, EE-MAC has significantly better normalized performance because of all nodes in the EE-MAC protocol receive a synchronization message from the sink node so nodes do not change their location within the network.

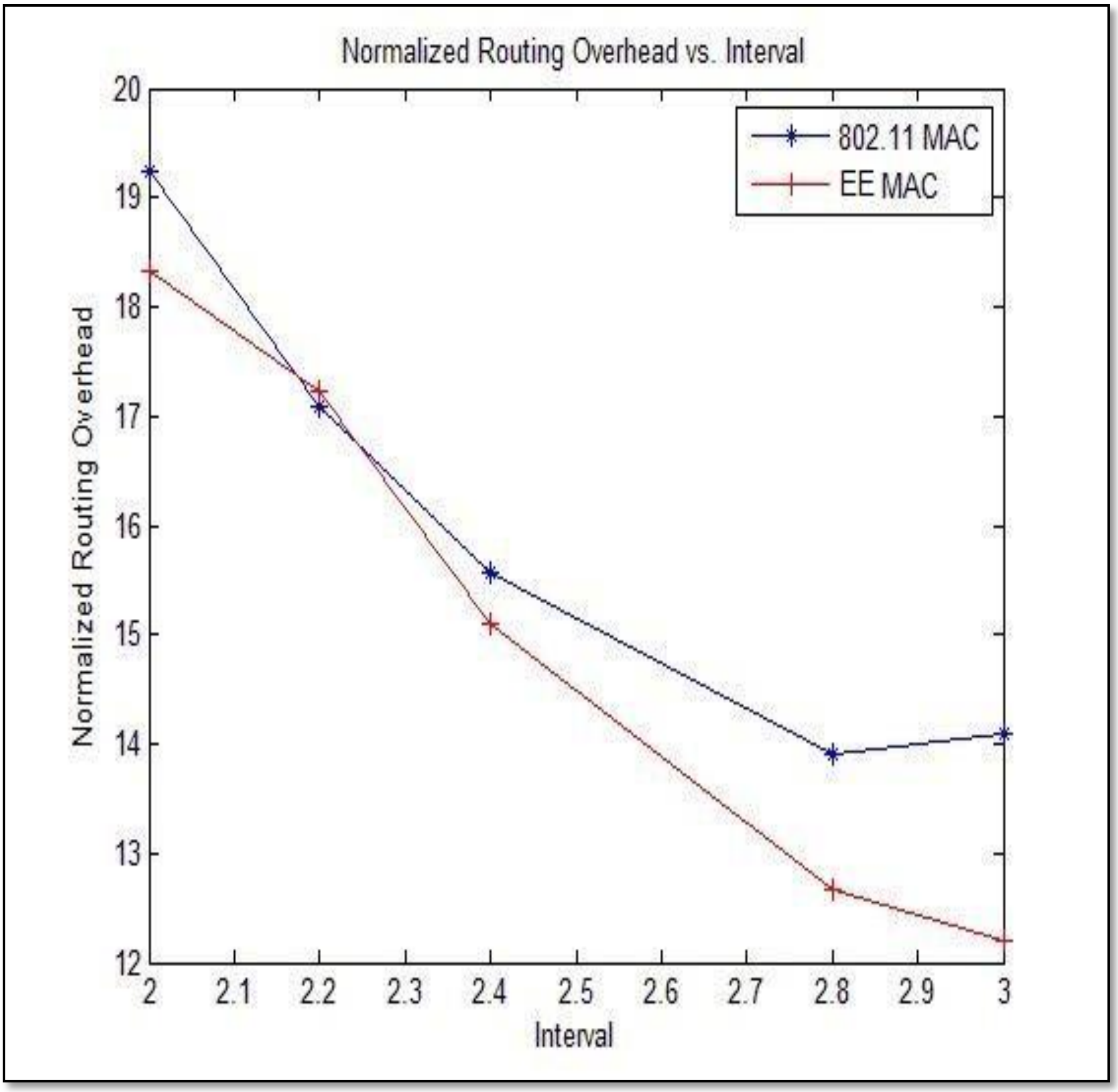

Figure 5.8. Normalized Routing Overheads for EE-MAC and IEEE 802.11 PSM.

5.4 Discussion of Results

The proposed EE-MAC is energy efficient hybrid protocol that is specially designed to support energy efficiency in wireless sensor network nodes. One of the main factors for introducing the EE-MAC protocol is to reduce energy consumption, while handling idle listening and collision. It also shortens the latency while ensuring the reliability in a WSN environment.

The results illustrates that the EE-MAC outperforms to the IEEE 802.11 PSM protocol. It is providing delivery ratio of 99.5% because of the scheduling technique employed by the protocol. EE-MAC has proved lower latency time because it uses a centralized design, whereby nodes are synced by a centralized coordinator. Furthermore, EE-MAC performs localized time slot allocation without changing the time slots of already existing nodes this reduces the latency. The scheduling of EE-MAC has reduced both of the schedule drifts by preventing nodes to use their neighbor time slots and idle listening time by forcing the nodes to go to sleep mode so that the source and destined node get the priority and are only in active mode for data transmission. In addition, EE-MAC protocol procedure avoids the collision between the nodes which results in low packet dropping rate. Of the 3100 packets sent only 15 packets were dropped. EE-MAC also produced a higher throughput and a lower jitter when is compared against the IEEE 802.11 PSM because of the latency is low and the nodes in EE-MAC follow the synchronized schedule that is reason there is no variation (jitter) that causes improvement of throughput. Besides, there is normalized routing overhead is also achieved.

Hence the study can conclude that, performance evaluation of EE-MAC compared against IEEE 802.11 PSM protocol confirm that the EE-MAC protocol decreased the energy consumption to more than 40% in WSN nodes.

CHAPTER SIX

CONCLUSION AND FUTURE WORK

6.0 Conclusion

In this research, EE-MAC, an energy efficient MAC protocol was designed, implemented and analysed using the ns-2 simulator. We have evaluated the performance of the EE-MAC protocol and compared it to the standard IEEE 802.11 PSM. Packets delivery ratio, control overhead, normalized routing overheads, throughput, jitter, dropping ratio, and average energy consumption are tested. In this study, the EE-MAC performs well in reducing the energy consumption, and maintained a high level of throughput, and packet delivery ratio. The energy conservation is due to the efficient scheduling mechanism used for reducing the idle listening times. This also addresses the shortcomings of schedule drifts. The contention-based characteristics on the other hand had resulted in a higher throughput which makes the EE-MAC more reliable. This study also have designed the hybrid EE-MAC protocol because of the prime function of hybrid protocol is to integrate the Carries Sense Multiple Access (CSMA) with Time Division Multiple Access (TDMA) by giving the recognition to their strength and provides the solution to their existing weaknesses and the hybrid protocol allow energy savings provides better scalability and flexibility which is more than contention-based MAC or called TDMA-based MAC.

6.1 Research Contributions

The contributions of this research include the following. Firstly, the procedure is developed to reduce the idle listening time of the WSN nodes so that the energy consumption is optimized which in turn enhances the battery life of nodes. This is one of the prime factors in WSN networks performance. Energy efficiency is attained in most protocols based on the trade-offs between network lifespan and performance. Secondly analysis and simulation reveal that the proposed protocol procedure outperforms IEEE 802.11 PSM protocol with energy conservation and low latency. Thirdly the technique implemented reduces the energy consumption by reducing the Idle listening, schedule drift which are brought out by comparing and analysing with rigorous simulation, which reveal the performance of the our EE-MAC protocol with IEEE 802.11 PSM protocol.

6.2 Future Work

In this study, we have only considered static sensor nodes. In future studies, node mobility will be considered, and we seek to address the energy issues related to mobile WSN that are deployed in many applications today.

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