Jimma University

Jimma Institute of Technology

Faculty of Computing

Computer Networking Stream

Enhanced Sensor Medium Access Control (ESMAC) Protocol for Wireless Sensor Network

By:

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April, 2018

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A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the Requirements for the Degree of Masters of Science in Computer Networking.

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Declaration

I understand, declare that this thesis entitled Enhanced sensor medium access control protocol (ESMAC) is my original work and have not been presented for degree in this or other universities and all sources of reference used for this thesis have been properly acknowledged.

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DEDICATION

I dedicate this thesis for My Mother

Acknowledgment

I would like to thank my God. I also express my gratitude to my principal advisor Mr. Fisaha Bayu for his understanding, patience and support. I would also like to thank my Co-advisor Mr. Shemalis shiferaw. Special gratitude goes to My Mother, brothers, sisters and friends who have been encouraging me through this thesis.

Acronyms	Meaning
ACK	Acknowledgement
ACW	Adaptive contention window
AODV	Adhoc-on-demand
API	Application programming interface
B-MAC	Barkley medium access control
CMAC	Coverage medium access control
CSMA	carrier sense multiple access
CTS	clear-to-send
CW	contention window
DMAC	Dynamic Medium access control
DC-MAC	Dynamic duty-cycle Based Medium access control
DMP	Dynamic multilevel priority
DSR	Dynamic Source Routing
EASPEED	Energy aware SPEED
EDF	Earliest deadline first
ESMAC	Enhanced sensor medium access control
FCFS	First come first served
HMAC	Hybrid medium access control
LEACH	Low energy adaptive cluster hierarchy
MAC	Medium access control
MMSPEED	Multi-path multi-speed SPEED protocol
NAV	Network allocation vector
OS	operating System
PMAC	Pattern Medium access control protocol
P-MAC	Pipeline based medium access control

PA-MAC-- A passive asynchronous MAC protocol

PW-MAC-- Energy efficient predictive wakeup MAC

QOS-- Quality of service

RAP--------------------------Real-Time Communication Architecture for Large-Scale WSN

RASS-- Randomized adaptive sleep scheduling

RI-MAC--- Receiver initiated Medium access control

RTS--- Request-to-send

SCP-MAC--------------------------------------- synchronies contention based MAC protocol

SMAC-- sensor medium access control

SYNC-- synchronization

SJF-- Shortest job first

SPEED---------------Stateless Protocol for Real-Time Communication in Sensor Networks

TDMA--- Time division multiple access

T-MAC-- Time-out-medium access control

THVR-- Two hop velocity based routing protocol

TRAMA-- Traffic adaptive medium access

WISE-MAC------------ An ultra-low power MAC for the downlink of infrastructure WSN

WSN-- wireless sensor networks

X-MAC---------------------------------- A Short Preamble MAC for wireless sensor network

Z-MAC----------------------------------A Hybrid MAC protocol for wireless sensor network

Abstract

Wireless sensor networks have been attracting significant research and commercial interest recently. Since data dissemination is different from traditional ad-hock networks new challenge arises. The challenges are due to resource constraint nature of wireless sensor networks. Wise use of wireless sensor nodes resources such as energy, storage and communication capacity will increase performance of wireless sensor network.

The most effective way of saving sensor node energy in wireless sensor networks is through sleep wakeup scheduling. Existing Medium access control layer contention based scheduling technique such as 802.11 IEEE has short coming for wireless sensor networks. Contention based protocol with features such as idle listening and overhearing waste sensor nodes energy. This thesis discusses best feature of existing Medium access control protocols for wireless sensor networks. We develop network size and remaining energy of sensor nodes based Medium access control protocol for saving sensor node energy while minimizing communication delay between sensor nodes. Enhancement is made to SMAC (Sensor Medium access control) protocol by introducing network size as a configurable parameter to adjust contention window instead of fixed contention window of SMAC (Sensor Medium access control).

To reduce energy consumption of SMAC (Sensor Medium access control) the duty-cycle adjustment based on remaining energy of nodes is proposed. Performance of SMAC (Sensor Medium access control) and ESMAC (Enhanced Sensor Medium access control) is evaluated on Network simulator-2. The combined effect of those two parameters enables as to enhance the performance of SMAC (Sensor Medium access control) in power efficiency, delay and throughput.

Keywords: Wireless sensor network (WSN), Routing Protocols, energy efficiency, Packet Scheduling, Medium Access controls (MAC), Duty-cycle and Contention window

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Chapter one

1. Introduction

1.1 Background

In recent era of networking the existence of low power device with sensing and information delivering abilities becomes common due to their minimum cost and infrastructure-less communications. Those devices are most commonly used in areas which are hard to monitor with other devices. Sensor nodes deployed in such an area forms wireless sensor network in order to deliver the sensed data to be farther processed by the sink node (base station). Wireless Sensor Network (WSN) consists of large numbers of wireless sensor nodes which collect the information from their surrounding environment and send the sensed data to Base Station (BS) or sink node [16][17].

Wireless sensor networks are characterized as tiny, low-powered, energy-constrained sensor nodes with sensing, data processing and wireless communication components. Sensor nodes in WSNs are small battery powered devices with limited energy resources, and wireless sensor nodes battery cannot be recharged once the sensor nodes are deployed.

Therefore, minimizing energy consumption is an important issue in the design of WSNs protocols. Wireless sensor node energy is consumed during data routing and sensing channel. Data routing is communication phase in which sensor node delivers the sensed data to the next-hop and receive packet from the other node. To handle this problem energy aware routing protocols are developed by different authors. The goal of energy aware routing algorithms are to minimize energy consumption of wireless sensor node by considering next-hop residual energy there by extend the network lifetime. Clustering and sleep wakeup scheduling are common methods in energy based routing schemes to save sensor node energy.

However most of the time energy aware routing schemes do not address the in time delivery of data packets with bounded deadline which are so called real time packet. Real-time routing protocols are designed to deliver packets within bounded deadline to meet its requirement. Some of the real-time protocols in wireless sensor network include SPEED, MMSPEED, EASPEED, RAP, PATH, and THVR. Real time delivery of data packets are achieved in this routing protocols either by delivering packets through multiple alternative paths or by using power adaptation module in there routing scheme. Energy consumption is the major drawback of real time routing protocol so that they are used for time critical mission most of the time.

The better way of addressing energy consumption problem in wireless sensor networks is through sleep wakeup scheduling. However, existing MAC protocol use idle listing which consumes comparable energy to energy required for receiving a packet. In addition to idle listing, it also use overhearing which enables sensor nodes in a network to receive packet destined to their neighbor nodes. SMAC is sensor medium access control designed *by wie yie* to achieve energy efficiency in wireless sensor networks. SMAC enable sensor nodes to reduce predominant source of energy wastage called idle listening by letting sensor nodes to turn off their radios and goes to sleep periodically. SMAC is contention based MAC protocol with features such as periodic sleep/wake, message passing, overhearing avoidance and collision avoidance. Contention based MAC protocol use carrier sensing to determine network condition and allow channel access to the nodes [39].

SMAC can be configured in two forms: SMAC with adaptive listening and SMAC without adaptive listening. Duty-cycling is commonly used approach in wireless sensor networks to reduce energy consumption due to idle listening but it introduce additional latency in packet delivery. Duty-cycle allows sensor nodes to periodically sleep and wake up to receive and send packets. In SMAC without adaptive listening the receiving node goes to sleep whenever the sleep time is reached. Turning radio of sensor nodes off while still transmitting or receiving data may result in high packet loss as well as energy wastage due to retransmission of lost packets. Adaptive listening feature of SMAC enables the sensor nodes to receive additional packets while there is transmission from source or other forwarder nodes. However the duty-cycle of S-MAC is fixed and it doesn't consider changes in network. To adopt the duty-cycle of SMAC for light traffic load several schemes has been proposed. In [35] demand wakeup is proposed for high traffic load through on-demand wakeup during sleep period and ensures data transmission do not collided at intended receiver.

On the other hand contention window adjustment is the other challenge in contention based Medium access control protocols. SMAC is one of contention based protocol and decisions made on contention window affect the performance of the protocol. Existing contention based MAC protocol duty-cycle adjustment and contention window adjustment methods doesn't take in to consideration either remaining energy of nodes or network size [39][31]. Contention window is used in computing back-off timer in SMAC so that it can result in delay, loss of packets and energy consumption in varying network size. We perform simulation with varying number of nodes to get the relation between number of nodes and performance parameters such as throughput, delay, power efficiency and energy consumption. Based on those simulation scenarios we put forward more optimal way of adjusting contention window that can maximize performance of SMAC protocol using number of nodes in a network as a configurable parameter.

To adjust duty-cycle of SMAC according to change in remaining energy of nodes, we put threshold of energy and compare the remaining energy of each nodes while deciding the duty-cycle. Adjusting duty-cycle according to remaining energy may result in loss of packet delivery and increase delay due to letting nodes to sleep more time. This thesis mainly concerned with enhancing SMAC protocol contention window adjustment method using network size while adjusting duty-cycle using remaining energy instead of using fixed contention window and fixed duty-cycle of SMAC protocol.

1.2 Statement of problem

Among many network design issues, such as routing protocols and data aggregation, that reduce sensor energy consumption and data transmission delay, MAC scheduling at sensor nodes is highly important since it ensures minimum energy consumption and provides QOS metrics such as throughput, delay in delivering sensed data to the sink node.

Existing contention based MAC layer protocols such as IEEE 802_11 incurs large energy consumption due to their features such as idle listening, overhearing, collision and control packet overhead [39]. To alleviate the mentioned problems SMAC was proposed which uses periodic sleep wake scheduling. SMAC reduces energy consumption of a nodes using fixed periodic sleep wake scheduling which is achieved through setting the duty cycle of a nodes. Duty cycle is the ratio of listening period to cycle time which has the direct proportionality to listening time of a node. i.e duty cycle increase as the listing time of a node increase. SMAC saves node energy when the duty cycle is small but while duty cycle of a node is large SMAC is expected to perform better in delay and throughput. But in either of the above case SMAC loss either saving energy or providing better throughput and minimum delay since the duty cycle of SMAC is fixed.

This thesis focus on solving problem of SMAC protocol related to unbalanced energy consumption among sensor nodes with high and low remaining energy. Since SMAC use fixed dutycycle for all nodes in a network, sensor nodes with low remaining energy deplete their energy prior to nodes with higher remaining energy.

To achieve our goal we use remaining energy of nodes as parameter to set the duty cycle of nodes and network size as a configurable parameter to set contention window size. Contention window in SMAC is fixed which waste slots when number of nodes is too small. Large value of contention window enforces nodes to wait for longer period to transmit. But if the contention window is too small and numbers of nodes in a network are too large, nodes may not get enough slots to transmit their data which may result in packet loss and delay due to intensified competition between nodes.

This study is carried out to answer the following research question:

1) How does setting duty cycle according to remaining energy of nodes achieve better performance in terms of average energy consumption in MAC layer of wireless sensor networks?
2) How can we achieve improved performance in power efficiency, throughput and delay by adjusting contention window according to network size and dutycycle according to remaining energy of sensor nodes?

1.3 Objectives

1.3.1 General objective

The aim of proposed work is to design enhanced version of SMAC (ESMAC) protocol based on contention window adjustment using network size and duty-cycle adjustment based on remaining energy of wireless sensor nodes.

1.3.2 Specific objective

The specific objectives are:

- Reviewing related literatures: extensively reviewing related literatures to analyze working principles of wireless sensor network and to have clear overview about contribution of proposed work.
- Designing algorithm of ESMAC.
- Implementing designed algorithm
- Evaluating performance of ESMAC with SMAC protocol

1.4 Scope and limitation

The scope of this study is delimited to wireless sensor networks to efficiently use scarce resources of wireless sensor node through developing MAC layer protocol that considers network size and remaining energy of nodes in a network. This study exploits the weakness of SMAC scheduling schemes and design proper scheduling algorithm to overcome this weakness.

The limitation of proposed work is:

- ESMAC does not consider factors such as security. Since information delivery through multi-hop network may be lost or tempered by nodes that handover data packets to the next hop node, security is also other challenge.

1.5 Methodology

The purpose of research is to discover answers to questions through the application of specific methodology or procedures. Methodology is a systematic way of solving research problems. The proposed work uses the following methods to achieve a desired goal.

1.5.1 Problem identification phase

The first phase of research process requires reviewing extensive literature and identifying practical relevance of problem that needs to be solved. In line with the concept of problem identification we review related literatures works that have been done on routing and scheduling in wireless sensor network in order to have clear overview of existing problem.

1.5.2 Design phase

The second phase includes designing flowchart of proposed work with its respective algorithm. In this phase the detailed description of proposed work and its algorithm is presented. Design phase consider the problem being identified and provide blueprint for each part of the algorithm that will be implemented in coding part.

1.5.3 Performance evaluation phase

The performance evaluation is the final phase in which the developed algorithm is evaluated against existing algorithm. Performance is evaluated using simulation tools.

1.5.3.1 Simulation tools

We use Network Simulator 2 (NS-2) tool for evaluating the performance of proposed scheme: because of its popularity and applicability for both wired and wireless scenario with fully equipped protocols, models, algorithms and accessory tools, and it is for free. The user describes a network topology by writing OTcl scripts, and then the main NS program simulates that topology with specified parameters. In ns-2, network animator (NAM) is used for the graphical view of the network.

1.5.3.2 Evaluation metrics

The evaluation phase involves identifying how well the proposed algorithm performs against the existing algorithm. To measure the performance of proposed work we evaluate it through the following metrics:

- **Energy consumption:** the performance of proposed work was evaluated with existing MAC layer protocol, specifically with SMAC protocols. Reducing energy consumption of sensor nodes is the foremost factor that needs to be considered while dealing with wireless sensor network protocol design.
- **End-to-end delay:** delay is the other factor that affects performance of wireless sensor network in applications that requires in time delivery of sensed data from the field which is monitored by the wireless sensor nodes. The performance of proposed work was evaluated with SMAC protocol in terms of end-to-end delay to observe the effect of using network size to adjust contention window and remaining energy to adjust duty-cycle.

- **Throughput:** is essential in application such as surveillance, smart home monitoring and patient status monitoring in case of body area network since those data should be delivered to the base station with higher reliability. So the performance of proposed work was evaluated in terms of throughput with SMAC.
- **Power efficiency:** can be described as ratio of Total throughput to the Total consumed energy. So it shows how much the communication between nodes is energy efficient. The larger value of power efficiency shows better performance of the protocol.

1.6 Significance of the Study

Wireless sensor nodes are being used in health monitoring, forest fire detection, surveillance, military, agriculture etc. Since sensor nodes are small in size and able to forward sensed data in multi-hop scenario, communication among sensor nodes should be handled by routing and medium access control protocols. Different application of wireless sensor networks has their own requirement. Application like forest fire detection requires lower energy consumption since most critical event reporting should be done when there is fire detected in the forest. Sensor in such an area should save their energy when there is no fire but they need to deliver data in required speed when fire is detected. Another area of wireless sensor application like health monitoring requires higher throughput, minimum delay and energy efficiency. All status of patient should be delivered to physician with higher accuracy, in-time while still saving sensor nodes energy in health monitoring. We enhance SMAC protocol by adjusting contention window based on network size to increase throughput while reducing delay. Adjusting duty cycle of sensor nodes dynamically based on remaining energy sensor nodes reduce energy consumption of sensor nodes. So ESMAC is better than SMAC for application which requires higher through put and better power efficiency such as health monitoring.

1.7 Thesis Organization

The thesis contains five chapters. Chapter one is all about introduction and problem identification. In Chapter two, we review literatures on wireless sensor networks routing and MAC layer protocols. Chapter three discusses the design of proposed system. In Chapter four, we discuss Performance evaluation of proposed system. Finally in Chapter Five, we discussed Conclusion and future works.

Chapter Two

2. Literature review and related works

2.1 Literature review

2.1.1 Overview of wireless sensor network

In the recent era of network communication, the wireless sensor network due to their unique features and capability can remotely sense the environment very efficiently and effectively. The communications in the WSN has the many-to-one property in that data from many sensor nodes tend to be sent to a few sinks. The wireless sensor network systems are often deployed in areas which are remote or hard to reach. Hence, it is critical that such networks might be unattended for long durations. Extending network lifetime through the efficient use of energy is a key issue in the development of wireless sensor networks [12].

Sensor nodes spend their energy during transmitting the data, receiving and relaying packets. Hence, designing routing algorithms that maximize the life time until the first battery expires is an important consideration designing energy aware algorithms increase the lifetime of sensor nodes [8].

To use limited energy of sensor nodes effectively there are design issues like routing, data aggregation and scheduling in wireless sensor nodes. Energy efficient routing algorithms are aimed reducing energy consumption at sensor nodes Hence increasing node and network life time. Data aggregation and data fusion are a process of combining data from multiple sensor nodes by eliminating redundant information. Aggregation reduces the frequency of transmission or packet size to minimize sensor node energy consumption.

The other way of addressing multiple performance metrics is achieving Quality-of-Service (QoS), which refers to defined measures of performance in networks, including end-to-end latency (or delay) and throughput, jitter (variation in latency) and packet loss (or error rate). The choice of a QoS metric depends on the type of application. Sensor networks performing target detection and tracking will require low end-to-end transmission delays for their time-sensitive sensor data, while data-intensive networks (e.g., multimedia data) may require high throughput.

Scheduling packets received in an efficient manner can reduce waiting time and end-to-end delay. Packet scheduling at sensor nodes ensures delivery of different type of a packet according to their priority and fairness. MAC layer is responsible for medium access control in wireless sensor networks. Wise medium access control strategy improves performance of network since it reduces the chance of collision occurrence, retransmission and energy wastage due to idle listening.

2.1.2 Wireless sensor Node Architecture

Wireless sensor node architecture consists of subsystems which are described with Figure 1:

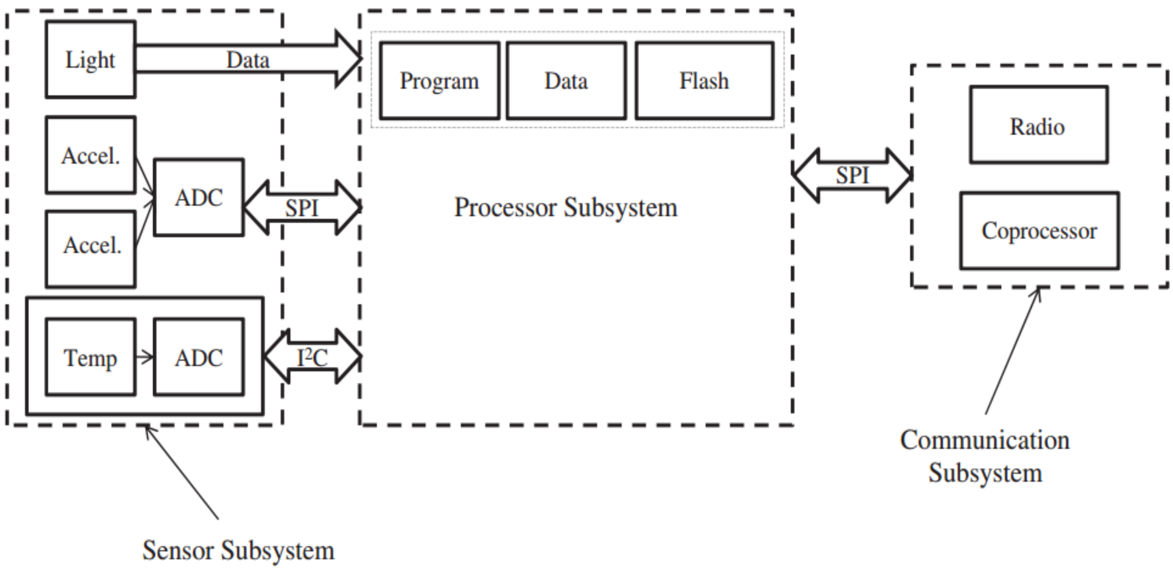


Figure 1:- Wireless sensors Node Architecture [17]

Sensing subsystem: The sensing subsystem integrates one or more physical sensors and provides one or more analog-to-digital converters as well as the multiplexing mechanism to share them.

Processing subsystem: The processor subsystem brings together all the other subsystems and some additional peripherals. Its main purpose is to process (execute) instructions applicable to sensing, communication, and self-organization. It consists of a processor chip, a nonvolatile memory (usually an internal flash memory) for storing program instructions, an active memory for temporarily storing the sensed data, and an internal clock.

Communication subsystem: Fast and energy-efficient data transfer between the subsystems of a wireless sensor node is critical to the overall efficiency of the network. However, the practical size of the node puts a restriction on system buses. Hence the communication scenario on other types of network is not directly applicable to wireless sensor networks.

2.1.3 Wireless sensor network architecture

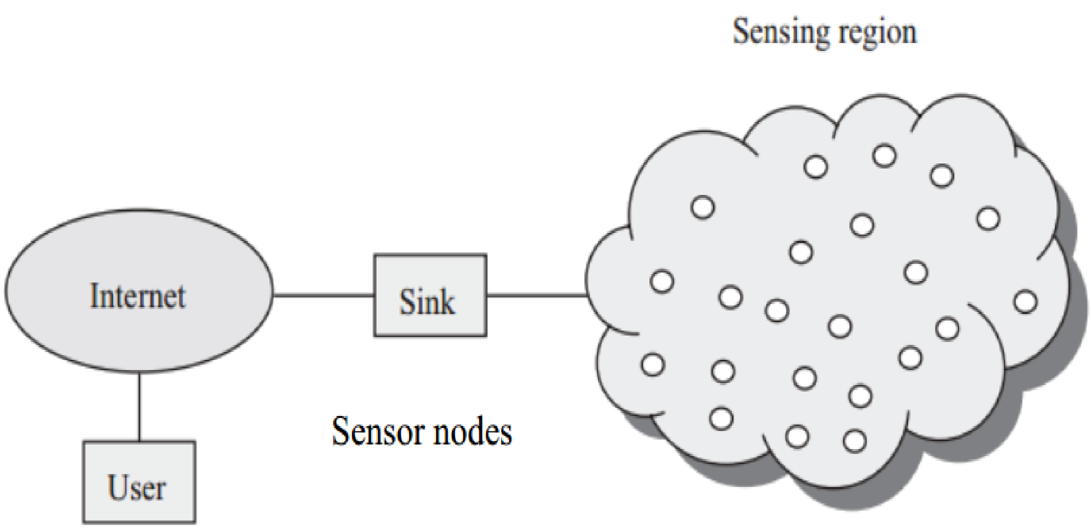


Figure 2: wireless sensor Network architecture [16]

The wireless sensor node deployed in large scale to monitor a given area. While they sense data (event) it will be sent to the sink using routing algorithms. Sensor node sense, store, process the sensed data and deliver it to the sink node according to the routing and other algorithms that are loaded on sensor nodes. Sink node collect the sensor node information and process it to achieve a desired objective of deployed sensor nodes. The processed data will be handed over to the user through the internet. Sink node can be used a gateway that connect sensor nodes with the internet.

The sensor communicates sensed data either in single-hop (sending data directly from source node to the sink) or multi-hop (routing source node data through intermediate nodes) scenario according to application requirement and defined routing algorithm. i.e. Application that requires minimum transmission delay for a sensed data may forward data directly to the sink while application that aims at energy conservation route source data through intermediate nodes.

However, in some application both application requirements are required. In such application both times critical as well as non-time critical data co-exist.

2.1.4 Wireless Sensor Network Characteristics

Wireless sensor networks have the following unique characteristics [16]:

- **Dense sensor node deployment:** Sensor nodes are usually deployed densely to sense the environment or their area of deployment.
- **Battery-powered: -** wireless sensor nodes are battery constrained nodes which are usually powered by battery and deployed in a harsh environment.
- **Severe energy, computation, and storage constraints:** they have highly limited energy, computation, and storage capabilities.
- **Self-configurable:** Sensor nodes are usually randomly deployed and autonomously configure themselves into a communication network. There is high possibility of failure in wireless sensor nodes hence nodes need to reconfigure themselves to change in link quality and instability in the environment.
- **Unreliable**: Sensor, nodes are prone to physical damages or failures due to its deployment in harsh or hostile environment.
- **Data redundancy:** In most sensor network applications, nodes are densely deployed in a region of interest and collaborate to accomplish a common sensing task. Due to dense deployment of sensor node sensing range of wireless sensor nodes overlaps with each other resulting in high correlation in the sensed data.
- **Application specific:** the sensor network is usually designed and deployed for a specific application. The design requirements of a sensor network change with its application.
- **Many-to-one traffic pattern:** In most sensor network applications, the data sensed by sensor nodes flow from multiple source sensor nodes to a sink, exhibiting a many-to-one traffic pattern.
- **Frequent topology change:** the wireless sensor network topology changes frequently due to the node failures, damage, addition, energy depletion, or channel fading. Routing protocols are in charge of providing recovery mechanisms to the failures.

2.1.5 Application of wireless sensor Networks

Wireless sensor network has various application areas. The basic application areas according to [16] are:

- **Monitoring Ambient conditions:** wireless sensor nodes can be used to monitor a wide variety of ambient conditions. The conditions that can be monitored by wireless sensor network are temperature, humidity, vehicular movement, lightning condition, pressure, noise levels.
- **Event Monitoring:** They can be used for continuous sensing, event detection, event ID and location sensing, local control of actuators.
- **Military Applications:** Wireless sensor networks can be used in military applications such as military command, control, communications, computing, intelligence, surveillance etc.
- **Environmental Monitoring:** It also includes environmental applications of sensor networks such as tracking the movements of birds, small animals, insects and monitoring environmental conditions that affect crops.
- **Forest Fire Detection:** It is used for Forest fire detection, the sensor nodes may be randomly, and densely deployed in a forest, they can relay the exact origin of the fire to the end users before the fire is spread uncontrollable.
- **Flood Detection:** Flood detection is also an application of WSN
- **Health Monitoring:** The health applications of sensor networks are providing interfaces for the disabled, integrated patient monitoring, diagnostics, drug administration in hospitals, monitoring the movements and internal processes of insects or other small animals etc. Tracking and monitoring doctors and patients inside a hospital.
- **Drug administration:** The sensor nodes attached to medications minimizes the chance of getting and prescribing the wrong medication to patients which is nothing but drug administration in hospitals.
- **The home applications:** include, Home automation which means the sensor nodes deployed in various devices in the home allow end users to manage home devices locally and remotely.

2.1.6 Wireless sensor nodes operating systems

Wireless sensor network is composed of sensor nodes that are equipped with scarce resources like memory and computational abilities. It is impossible to replace sensor nodes often; therefore, a fundamental objective is to optimize the sensor nodes life time. These characteristics of WSNs impose additional challenges on OS design for WSN, and Hence, OS design for WSN deviates from traditional OS design. The purpose of OS is to manage the allocation of resources to users in an orderly and controlled manner. An OS multiplexes system resources in two ways i.e., in time and in space. Time multiplexing involves different packets transfer tasks taking turn in using the resources. Space multiplexing involves accessing the resource, possibly at the same time.

Major Concerns in Wireless Sensor Networks OS Design

Major issues concerned in WSN OS design according to authors in [17] [43] are:

- **Architecture:** the wireless sensor architecture can be monolithic architecture, Micro-kernel architecture, virtual machine architecture and layered architecture.

  In monolithic architecture service provided by the OS are implemented separately and each service provides an interface for the other service. The module interaction costs are low in monolithic architecture. The drawback of monolithic architecture is the system is hard to understand, modify and maintain.

  A microkernel is the design choice for many embedded OS due to the small kernel size and the number of context switches in a typical WSN application is few.

  The key idea behind Virtual machine architecture is to export virtual machine to user programs this result in better portability feature while reducing system performance.

  The Layered architecture based OS design result in manageability, ease of understanding and reliability while reducing flexibility from OS design perspective.

- **Programming model:** The programming models provided by typical WSN OSs are event driven programming and multithreaded programming. Multithreading is the application development model, but in its true sense it is resource intensive, and so it is not considered applicable for resource constraint devices such as sensor nodes. Event driven programming is considered more useful for computing devices equipped with scarce resource but not considered convenient for traditional application developers.

Therefore, researchers have focused their attention on developing a light-weight multithreading programming model for wireless sensor operating systems.

- **Scheduling:** The main aim of a scheduler is to minimize latency, to maximize throughput and resource utilization, while ensuring fairness. The selection of an appropriate scheduling algorithm for wireless sensor networks depends on the nature of the application. Wireless sensor networks are being used in both real-time and non-real-time applications. Hence WSN OS must provide scheduling algorithms that can accommodate the application requirements. Moreover, an efficient scheduling algorithm should be memory and energy efficient.
- **Memory management and protection:** the memory management refers to strategy used to allocate and de-allocate memory for different processes and threads. There are two memory management techniques: static memory management and dynamic memory management. Static memory management is simple and it is a useful technique when dealing with scarce memory resources. But it results in inflexible systems since there is no run-time memory allocation. Dynamic memory management provides more flexible system because memory can be allocated and de-allocated at run-time.
- **Communication Protocol Support:**
  Wireless sensor network operates in a distributed environment, where sensor nodes communicate with other nodes in the network. All Wireless sensor network operating systems provide an Application Programming Interface (API) that enables application program to communicate.
- **Resource sharing:** The OS must allocate resources and enable resource sharing, which is importance when multiple programs are concurrently executing. The majority of WSNs OSs today provide some sort of multithreading, requiring a resource sharing mechanism.

2.1.7 Wireless Sensor Network OSI layer architecture

Wireless sensor network follows OSI model. But in wireless sensor network there are five basic layers. Those layers include application layer, transport layer, Network layer, Data-link layer and Physical layers.

Application layer is responsible for traffic management and provide software for different application to send quires to obtain certain information.

Transport Layer is responsible for providing reliability and congestion avoidance using techniques such as ACK, NACK and sequence number for loss detection. End-to-end or Hop-by-hop loss recovery techniques are used recover lost packets. Providing Hop-by-hop reliability is more energy efficient than end-to-end reliability. Hence TCP is not suitable for wireless sensor network since it provides end-to-end reliability. UDP has less overhead and requires limited memory.

Network Layer is responsible for routing sensed data to the sink node, as well as delivering updates from sink (base station) to the sensor nodes in the field. In addition to routing, data aggregation and data fusion are performed in network layer. Since wireless sensors are deployed in large number to area that is going to be monitored, sensor nodes are more likely to sense duplicated data. Data aggregation is performed to avoid duplicated data which is received from neighbor nodes or sensed by the node itself. Data fusion refers to performing extra processing on aggregated data. Extra processing on data can be made to produce more accurate output.

Layers above data link layer are called upper layer (Network, transport, application) in this thesis. Since our Major concern is Data link layer the Figure 3 describe sub-layers of data link layer.

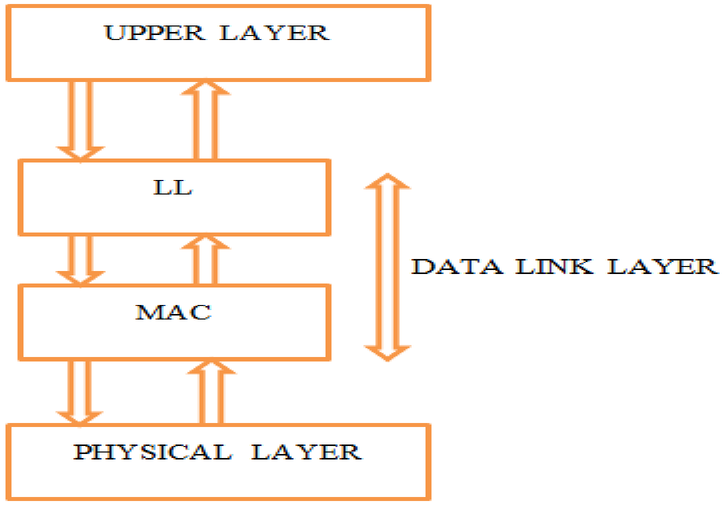


Figure 3: Wireless sensor network OSI layer [44]

Data link layer is responsible for multiplexing data streams, data frame detection, medium access (MAC) and error control. In general term data link layer is responsible for two functions: creating network infrastructure and providing fair, efficient use of communication resources among sensor nodes. Most of existing wireless sensor network MAC protocols takes insuring in time delivery as their primary concern and power saving as their second concern while designing MAC layer protocol. However MAC layer protocol which performs well in saving energy fails to achieve Quality of service parameters less delay, higher throughput.

Since our major concern is enhancing MAC layer protocol physical layer information is obtained to retrieve remaining energy of each node. The channel access and sleep time are adjusted based on remaining energy and network size.

The number and location of wireless sensor networks makes replacing or recharging of battery infeasible. Hence energy consumption is major issue in wireless sensor network design. At physical layer there are some parameters which are kept open for network designer. Those parameters are modulation scheme, transmit power and hop distance. Two main components that contributes for energy loss in wireless transmission are loss due to channel and fixed energy cost to run transmission and reception circuitries. In multi-hop approach the distance between two neighbor nodes determine energy required to transmit packet through the wireless channel to next hop node. Neighbors with short distance require less energy to send and receive through the channel. On the other hand fixed energy required to keep radio on and off consume more energy in network with short distance between neighbor nodes than network with long distance between neighbor nodes. Physical layer takes care of modulation scheme transmit power and hop distance in wireless sensor network.

2.1.8 Wireless sensor network protocols design challenges

Wireless sensor networks are characterized by their resource constraints such as limited power, computing power, memory, limited bandwidth and limited communication capability. Since sensor nodes are deployed in remote location most of the time it is impractical to replace there battery. The better way is to use sensor node energy effectively.

The challenge in wireless sensor networks protocol design includes:

- To design energy efficient protocol that maintains a good network performance. The most common way of conserving energy in wireless sensor network is through the use of clustering and sleep/wakeup scheduling. Sleep wake up scheduling algorithms puts nodes to sleep to save sensor nodes energy. MAC protocols are predominant to save sensor node energy and prolong life time a nodes. However the emergence of time critical application which requires minimum end-to-end delay for packet delivery and other application such smart home surveillance that requires higher throughput; result in change to find an optimal solution that is able to provide both energy efficiency and improving network performance.
- Designing traffic adaptive protocol that is able to learn current channel condition and take an action to reduce transceiver energy consumption. In most sensor network application traffic may start with minimum traffic and it may vary over time. In this type of situation sensor nodes need to go through power saver mode (sleep) when there is minimum or no packet are received or sent to save sensor node energy but they need to sense the channel when there is packet to be sent. A protocol that works well under low contention traffic but unable to adapt to the traffic change may consume higher energy.
- Topology change should be taken in to consideration while designing sensor network protocols. Although in most sensor network applications, nodes are assumed to be stationary those nodes may suffer temporary or permanent damage due to energy depletion or external factor. New node may also add to the network. So the design of

sensor network protocols should take into consideration the dynamic topology change due to the above factors.

2.1.9 Routing Protocols in wireless sensor networks

In [51] LEECH Low energy adaptive clustered hierarchy based routing protocol for wireless sensor network is proposed. LEECH clusters sensor nodes in to multiple clusters. Cluster members send the sensed packets to their corresponding cluster head and cluster heads forward cluster members packets to the base station. Clustering reduce energy consumption of sensor nodes that may result from redundant packet transmission by aggregating sensed data. Cluster head is responsible to manage cluster member transmission and sleep period based on Time division multiple accesses (TDMA). The primary aim of LEACH protocol is to reduce energy wastage of cluster members due to long distance packet transmission. In addition to handing over the cluster members packets to the base station, cluster head perform data aggregation to reduce chance of forwarding redundant packets sensed from different nodes with in the same cluster to the base station. LEACH use probability based cluster head selection method in which each node in a network has probability to be cluster head. Once the node becomes a cluster it will have less probability to be cluster head for the second time before all nodes in networks become cluster head. So in LEACH each node in a network has equal probability to be cluster head.

However LEACH has drawback related to its cluster head selection method and transmission from cluster heads to the base station. The cluster selection method is not aware of remaining energy of each sensor nodes and distance between cluster members as well as cluster member to the base station. The other limitation of LEACH is single hop forwarding method from cluster heads to the base station. To overcome this drawback of leach protocol a number of decent protocols are designed. Multi-hop LEACH is one of protocol used to reduce energy consumption of LEACH due to forwarding packets from cluster heads to base station in a single hop.

Tian He [18] SPEED (stateless protocol for real time communication in wireless sensor network) protocol is one of the well-known real time routing protocols. The protocol consider deadline for each packet which is guaranteed by using an initial velocity to V. The speed V is defined with respect to direct distance from source S until destination T and deadline required for each packet. After this process each node neighbors that guarantees deadline, are selected and delivers the incoming packet to their next hop. If desirable neighbor node is not found, packet will be removed. This protocol ensures a high rate of packet delivery and is scalable as every mechanism works in a localized manner. Every node has only information about its' immediate neighbor (one hop) to select the node as a next hop based on delay estimation process using desired velocity. The performance of proposed SPEED protocol is evaluated against AODV and DSR protocol which shows improved performance both in end-to-end delay and deadline miss ratio. But it doesn't consider energy metric, reliability and it provides only one network-wide level of speed, which is not suitable for differentiating various traffic having different deadlines.

Felemban proposed multi-path and multi-SPEED Routing Protocol (MMSPEED) [19] that meets the requirements timeliness and reliability. MMSEED address the problem of SPEED by assigning deferent level of deadline to the packet unlike SPEED protocol which assign network wide deadline. This protocol works on network layer and MAC layer to offers multiple levels of speed with multiple paths. If intermediate nodes found a packet that delay deadline with current speed, can raise speed level**.** Each node can have multiple copies of packets to achieve the desired level of reliability. If the node can't find the next hop that can meet the required level of velocity, the packet will be dropped to save energy. However, even if MMSPEED address the problem related to timelessness and reliability it doesn't consider remaining energy of next hop while it selects next hop.

In [20] authors point out that MMSpeed does not consider the remaining energy of node and they introduced energy aware routing protocol based MMSpeed (EAMMSpeed). Each node in EAMMSPEED make a routing decision based on Geographical progress towards destination sink, required end-to-end total reaching probability, delay and residual energy at the candidate forwarding node. To achieve timeliness delivery, multiple network-wide packet delivery speed options are provided for different traffic types according to their end-to-end deadlines while reliability is achieved through probabilistic multipath forwarding. Residual energy of neighbor node is introduced during selecting candidate forwarding nodes. Considering node residual energy reduces the workload on nodes with shorter delay path hence balancing energy consumption. The proposed EAMMSPEED is evaluated against MMSPEED in dense network scenarios which show better performance with scaling in number of nodes.

In [21] THVR real time routing protocol for wireless sensor networks is proposed based on the information of two-hop neighbor. Having more information about the one-hop and two-hop neighbor, the system helps to decide routing with more accurate, less energy consumption and packet delay. Two-hop neighborhood information-based geographic routing protocol enhances the service quality of real-time packet delivery for WSN. They adopt the approach of mapping packet deadline to the velocity as SPEED; however, the routing decision is made based on the two-hop velocity integrated with energy balancing mechanism. An energy-efficient packet drop control is incorporated to enhance energy utilization efficiency while keeping low packet deadline miss ratio. THVR use both residual energy and delay at two hop in routing decision to optimize the DMR (deadline miss ratio) and energy consumption during forwarding packet. However, if the node can't find next hop that can meet the required velocity at two hops the packet will be dropped. Another drawback of this protocol is it increases complexity since every node needs to maintain two hop information other than local information.

Roghayeh abbasi [22] develop new routing algorithm using fuzzy technique to improve QOS by reducing energy consumption and end-to-end delay. In wireless sensor network energy utilization is the main issue but in case of real time wireless sensor network timely delivery of data has the same importance as the energy utilization. Each node exchanges information containing position, delay and residual energy of nodes. While selecting next hope sensor nodes compute the fuzzy controller based on this metrics. Delay is computed using time when the packet is sent by the source and received by the node. Position is used to compute the distance between the nodes while residual energy stands for remaining energy of a node. The developed fuzzy model has five input variables: node residual energy, distance to sink node, delay between two nodes, factor confidence and deadline of a packet and one output variable called priority which gives a node to be selected as a next hope. The protocol is compared against SPEED and THVR protocol which shows improved performance in deadline miss ratio and reduced energy consumption.

In RAP [23] provides convenient, high-level query and event services for distributed micro-sensing applications. It suggests Velocity Monotonic Scheduling (VMS) policy suitable for packet scheduling in sensor networks. RAP is designed for large scale wireless sensor networks. It is based on a different concept of packet requested velocity. It is expected that each packet meets its end-to-end deadline if it can move toward the destination at its requested velocity, which reflects its local urgency. RAP provides convenient, high-level event services for distributed micro-sensing applications. RAP implements static velocity monotonic scheduling and dynamic velocity monotonic schedule to determine packet to be delivered first based on urgency. In static velocity monotonic scheduling packet with higher velocity will be sent before packet with less required velocity without considering remaining distance to arrive at sink node. Dynamic velocity monotonic scheduling takes into consideration remaining distance to arrive at sink in addition to required velocity. The performance of RAP is evaluated against SPEED routing protocols. RAP improves real-time delivery than SPEED protocol since it schedule packets with their required velocity.

In [24] RACE protocol which is called real-time scheduling policy for large scale wireless sensor network is proposed. RACE Support a soft real-time communication service through the path with minimum delay is the main goal of RACE algorithm. Thus, the end-to-end delay in the sensor network becomes comparative to congestion of nodes between source and destination. To find the path with minimum traffic load between source and destination is the role of bellman ford algorithm. Weight of algorithm is the sum of propagation delay, queuing delay and contention delay. Earliest Deadline First (EDF) Packet scheduling algorithm is used in each node to send the packet with earliest deadline before other packets. RACE reduces average end-to-end delay and deadline miss ratio as compared to SPEED and RAP protocols.

All real-time routing protocols which are discussed in this section either support only real-time traffic or use classifier to differentiate real time traffic from non-real-time traffic. However, using this method will either starve non-real-time data while there is continues arrival of real time data. To come up with the solution to this problem researchers develop dynamic multilevel packet priority scheduling which serve the packets according to their level priority.

Table 1: Comparison between wireless sensor network routing protocols

Protocol	**Energy based**	**QOS based**	**Real time delivery**
LEECH	Clustering is used to save sensor nodes energy	Leach does not consider parameters of QOS.	It is designed for energy efficiency only so it is not applied in time sensitive applications.
SPEED	Is not aware of energy efficacy	Better QOS than classical wireless sensor network routing protocols	Primary purpose is achieving real-time delivery through routing packets with higher required speed priority to be forwarded first
THVR	Energy efficient	Achieve improved quality of service than SPEED protocol	Two hop information about the route is considered to make decision of route
RAP	Not energy efficient	Deliver packets based on required velocity	Deadline based packet delivery since packet with higher required velocity is sent first using novel velocity monotonic scheduling.
RACE	Not aware of nodes energy	Race is modified version of RAP protocol	Improved in time delivery
MMSPEED	No energy awareness	Use multi path to enhance QOS of SPEED protocol	Improve in time delivery through multipath routing of SPEED protocol.
EMMSPEED	Energy efficient protocol.	QOS aware routing protocol	Enhanced deadline aware packet delivery

2.1.10 Packet scheduling in wireless sensor networks

Packet priority scheduling is the process of prioritizing packets in their desired order of priority. The priority of packets can be assigned either according to deadline of a packet, type of data, and number of queue. Prioritizing packets will reduce delay for time critical application while providing required level of delivery for non-time critical application.

Scheduling packet at the sensor is important for prioritizing application in wireless sensor network. Packet scheduling schemes can be assigned either by data delivery deadline, packet priority (preemptive, non-preemptive), packet type (real time, non-real time) and number of queue (single queue and multi-queue).

In fact, whereas the objective of the low delay sensor network is to minimize the average response time of a given set of tasks, the objective of real-time sensor network is to meet the individual timing requirement of each task. Real-time system provides some important features in the critical applications, including Timeliness, Design for peak load, Predictability, Fault tolerance, Maintainability.

Most of packet scheduling schemes uses FCFS packet priority scheduling which assign packet priority based on the arrival time of the packet. However in case of application in which both time critical packets and periodical packet co-exist, FCFS scheme results in long waiting time for real time packet since it needs to wait non-real time packets that are arrived before the real time packet to be processed and delivered to the next-hop. This will result in high end-to-end delay as the real time packet Travers through the network to the destination node. The better way to resolve this issue is to use separate priority level for different type of packets which is so called multilevel packet scheduling. In multilevel packet scheduling schemes real time packets are assigned the higher priority while lower priority are assigned to packets with tolerant to a longer delay (periodical data).

As we discus in the previous section packet scheduling at sensor nodes is highly important since it ensures delivery of different types of data packets based on their priority and fairness with a minimum latency. To achieve these objectives researchers made the following attempts:

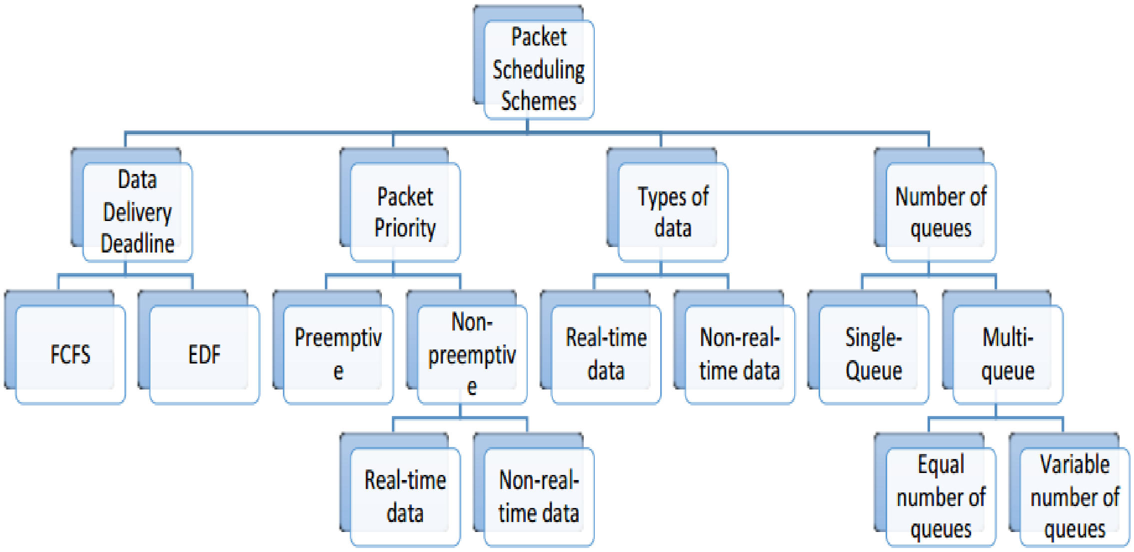


Figure 4: Classification of packet Priority scheduling in wireless sensor network [3]

1.1.10.1. Data Delivery Deadline based scheduling

- **Fist come first serve scheduler:** packets are processed according to their arrival time. So that packets from distant nodes need more waiting time than packet from local node. Packets from neighbor node need less time to be processed. Real time packets have the same priority with non-real time which will result higher delay for real time data. The advantage of FCFS is simple to implement and it is fairness.
- **Earliest Deadline First:** Packet need to arrive at destination with in the given deadline. The disadvantage of this scheduling algorithm is if a new packet arrives with shortest deadline, it will be allowed to be processed first hence starvation of processes with a higher burst time and larger end-to-end delay.

1.1.10.2 Packet priority based scheduling

- **Packet priority based scheduling:** In packet priority based scheduling algorithm each packet that enters a reedy queue is assigned priority. The packet with highest priority will be executed first and then lower priority packet and so on.

  Priority based scheduling include preemptive or non-preemptive. In preemptive priority packet scheduling higher priority packet can preempt the execution of lower priority packet by saving the state of lower priority. This scheme results in starvation of lower priority data packet if there is continues arrival of higher priority packet. In non-preemptive arrival of higher priority packet do not interrupt the execution of current lower priority packet. The disadvantage of non-preemptive priority packet scheduling higher end-to-end delay for real-time and emergency messages since it has to wait until completion of currently executing non-real-time packet.

1.1.10.3. Type of data based scheduling

- **Real-time:** Real-time data need to be delivered with minimum end-to-end delay. Hence real-time packets will be given higher priority than non-real-time data packets.
- **Non-Real time:** Non-real-time packets will be processed if there are no real-time packets in a queue. FCFS or SJF schemes are common scheduling techniques for non-real-time packets.

1.1.10.4. Scheduling based on number queue

- **Single Queue:** In single queue scheduling each sensor nodes have a single ready queue. All types of data packets enter the ready queue and are scheduled based on different criteria: type, priority, size, etc. Single queue scheduling has a high starvation rate.
- **Multi-queue:** The data packets are placed into two or more queues according to their priority and type. In multilevel queue scheduling has two phases allocating task among different queues and scheduling packets in each queue. Ready queue is partitioned in to three queues with different priority according to the application requirement. Real time data goes to queue pr1 (highest priority queue) and processed in their arrival time (FCFS). Non-real time remote packets go to queue pr2 (less priority than queue pr1) and processed in either FCFS or SJF. Non-real time local data that are generated by the sensor node itself goes to pr3 (the lower priority queue). This scheme performs better in terms of end-to-end delay and average task waiting time. Dynamic multilevel scheduling schemes are developed taking deferent techniques like distance traversed packet, remaining deadline of a packet and fuzzy logic into consideration [1]-[8].

Table 2: Comparison of packet scheduling schemes in wireless sensor networks

Scheduling scheme	Preemptive/non-preemptive	Strategy	Queuing strategy
FCFS	Non-preemptive	Packet coming into queue are schedule in order of arrival	Single level queue
SJF	preemptive	Queued packets are scheduled based on completion time	Single level queue
EDF	preemptive	Packet with earliest deadline will be scheduled first	Single level queue with high priority to packet with earliest deadline
MP	Non-preemptive	Incoming packets are queued into multiple level of queue	Multiple level queue with varying priority
DMP	Preemptive when real-time packets arrive while non-real time packets are being executed	Dynamic packet queue allocation method based on their importance	Three level of queue with highest priority to real-time packets

2.2 Medium Access Control protocols for wireless sensor Networks

MAC protocols in wireless sensor networks can be classified based on two brood categories as the contention based and contention free protocols. However there are some protocols which have both contention based and contention free features which are called hybrid protocols.

MAC protocols

Contention based	Reservation based	Hybrid
IEEE MAC 802_11	BMA-MAC	Z-MAC
SMAC	FLAME	IEEE 802.15.4
DC-SMAC	PA-MAC	
DW-MAC	TRAMA	
TMAC	P-MAC	
SCP-MAC	PMAC	
WISE-MAC	RASS	
B-MAC		
X-MAC		
ACW-MAC		
D-MAC		
RI-MAC		

2.2.1 Contention Free and Hybrid Medium Access Control Protocol

In [25] Randomized adaptive sleep scheduling protocol is proposed. The philosophy RASS is based on clustering and adjusting the sleep scheduling based on the data rate of a node. At the beginning node in a network become clustered based on clustering algorithm. Each clusters contains one cluster head and one or more cluster members. Cluster head polls the cluster members to send the sensed data packet by broadcasting request. The cluster members start to send sensed data upon reception of the request. Then cluster head calculate the sending rate of each node and sort them based on the initial threshold of data sending rate. Nodes with minimum data sending rate are supposed to be slow senders. Slow senders become in sleep mode by turning of their radios to avoid sensing and processing in the current time slot to save energy. But nodes with higher data rate are considered as faster senders and they become active nodes. Cluster head generate the schedule based on the data sending rate of each node while they send their data packet. After the schedule is generated, cluster head is responsible to broadcast the schedule information to all clusters.

The scheduling is performed by following two steps:

In the first step nodes in each cluster with minimum data sending rate are randomly set to sleep mode in each slot. Also, the work schedule is generated based on the following two cases. If, some 'k' nodes in the cluster have data sending rate lower than minimum threshold rate, then 'n' nodes are set to sleep mode. If, all 'k' nodes in the cluster have data sending rate greater than minimum threshold rate, then 'n/2' nodes are set to sleep mode randomly.

The second step is In case of minimum data sending rate of all the nodes in the cluster, at the particular time slot, the time slot is divided into tiny slots that are equal in size. Then round robin scheduling is used to set at-least one node in active mode in order to avoid the absence of the cluster. RASS becomes energy efficient since it puts some nodes to sleep to reduce energy wastage.

In [42] authors propose Pipeline based medium access control protocol for wireless sensor networks. P-MAC divides the network around the sink node by using Grade Division and Scheduling Assignment (GDSA). Each node sets up its schedule according to the grade it belongs to. Nodes that are located in the same grade will maintain the same scheduling time. This schedule is staggered with lower and upper grades. P-MAC use pipelining to forwards packets from upper to lower grade to reduce the network latency. RTS in P-MAC contain grade information, thus only nodes from lower grade can respond with CTS. Grade is assigned beginning from sink node to the leaf nodes. Sink node will be assigned 0 grade and the neighbor nodes receiving broadcast message called GRADE update Gm field of grade message by incrementing it according to their location. P-MAC has period known as SEND DATA and RECEIVE DATA. Sender node which will be most likely to be located at i^{th} position transmit data to the receiver node located at i-1 position, sender should be in the period of SEND DATA while receiver is expected to be at the RECEIVE DATA period. Time of SEND/RECEIVE DATA is computed as:

$$\boldsymbol{TSorTR = 2CW + 2DIFS + 2SIFS + durRTS + durCTS + durDATA + durACK}$$

Where durRTS, durCTS, durDATA, durACK stands for transmission duration of RTS, CTS, DATA and ACK respectively.

Nodes with the same grades keep the same schedule according to grade information during grade division process. To make delivery latency acceptable frames can be forwarded continuously in pipeline way from higher grade nodes to the lower grade nodes. The adjacent nodes within the same grade contend with each other for shared medium while those nodes in different grades co-operate with each other for data transmission. The performance of P-MAC is evaluated against RMAC in-terms of average power consumption and throughput with varying simulation time and traffic interval. P-MAC performs better in both average power consumption and throughput.

In [27] TRAMA is design to enhance the classical TDMA based algorithm in an energy efficient manner. One transmitter is selected with in two hop neighborhood using distributed slot selection algorithm. All nodes within one-hop neighborhood transmit and receive data without any collision through this approach which in-turn minimize the occurrence of hidden terminal problem. Time is divided as random access and schedule access (transmission) periods. In case of contention based channel access two-hop topology information is established through random access period. *Schedule_ interval* is transmission duration needed which is assumed to be calculated at MAC layer by the information delivered from application layer.

Every node announce their neighboring nodes about slots it is going to use and slots for which the node has highest priority but not being used currently. This announcement is delivered to the neighboring nodes through schedule packet. The intended receiver of schedule packet is indicated using bitmap whose length is almost equal to the number of neighboring nodes. The technique of indicating intended receiver using bitmap reduces number of multicast and broadcast communication among nodes operating under TRAMA. In comparison with CSMA based protocols TRAMA achieve higher percentage of sleep time and less collision probability. In TRAMA all nodes are defined to be either in transmit or receive state during random access period for schedule exchange.

In [28] Hybrid medium access control protocol, Z-MAC is designed for wireless sensor network. Z-MAC protocol is hybrid MAC protocol, which alternate between conventional CSMA and TDMA. The choice to alternate between CSMA and TDMA is made based on network contention. Hybrid protocols overcome most limitations of single scheme protocols. In low network contention CSMA is an ideal solution but it can result in low throughput under high traffic condition. In the other hand in case of high network contention TDMA can efficiently schedule nodes and maintain high channel utilization but slots are wasted in low traffic condition. ZMAC use CSMA in low channel contention and switch to TDMA when there is high channel contention.

ZMAC works in two modes:

- Setup mode: each node assigned a time slot and represented as owner and non-owner to indicate whether the current slot is assigned to the node. ZMAC does not assign the same slot to nodes in two hop neighbor.
- Transmission mode: time is divided in to slot in transmission phase.

In Z-MAC unlike TDMA nodes can transmit at any time if the channel is free but if the channel is not free the priority is given to “owner node”. The priority is implemented through adjusting contention window size in the way that allows the owner node to have the higher priority. However Z-MAC has limitation related to initial slot assignment, hidden terminal problem and time synchronization.

In [26] Pattern based Medium access control protocol is designed to overcome frequent sleep wakeup of SMAC and T-MAC at the beginning of each cycle whether there is traffic or not. This frequent sleep wake up consumes energy since they need to turn on and off their radio in-order to sleep or wakeup. To overcome this problem PMAC propose pattern generation scheme based on nodes own traffic and neighbor nodes traffic. The pattern of nodes determines when to sleep and wakeup. For instance the pattern of 001 indicates the sensor node tentatively plan to sleep for two consecutive time slot and stay awake in third slot. New pattern generated for subsequent period are broadcasted by node at the end of current period. To achieve the exchange of pattern time is divided into supper time frames (STF) which has two sub-frames. STF has two sub-frames pattern repeat time frame (PRTF) and pattern exchange time frame (PETF). The pattern repeat time frame is (PRTF) is time in which each node repeats its current pattern. PRTF has a period in which all nodes stay awake and listen to the channel. If node receives any packet during this period from downstream node it will set its pattern to 1. This enables node to wake up quickly next time since it is more likely to receive packet. Generated pattern is exchanged during pattern exchange time frame (PETF). The pattern generated for the last time during PRTF decides the schedule for the next packet repeat time frame. Performance of PMAC is evaluated against SMAC protocol in-terms total energy consumption, total throughput and power efficiency.

In [13] authors propose end-to-end delay optimization while saving sensor node energy through sleep wakeup scheduling an opportunistically forwarding packet. Sensor node forward packets to the next hop node that wakes up among available next-hop nodes in parent set. The life time of event driven sensor network is viewed in two phases: configuration phases and operation phase. In confirmation phase nodes are deployed and optimize the control parameters of the proposed forwarding policy and their wake-up rates. In the operation phase, each node alternates between two phases, i.e., the sleeping phase and the event reporting phase. The scheme significantly reduces end-to-end delay since node doesn't need to wait for the next hop to wake up.

In [14] Novel Sleep/wakeup Scheduling Method for Wireless Sensor Networks Based on Data Fusion which increase the sleeping time of cluster head is proposed. The scheme adopts data fusion window and adjust sleeping time periodically. Data fusion window original value is the product of the number of child nodes in the cluster at first and the transmission time as well as the sensing delay. The head periodically counts the number of children in the node tree and then compares with the number of children previously stored in the head. If the children are fewer than before, then the data fusion window will shrink, and the shrunk size is the product of the number of child nodes in the cluster currently and the transmission time as well as the sensing delay. The sleep time is adjusted if there is any node in the cluster which is dead the next fusion window will be updated. Hence the cluster head sleep time will be adjusted according to the next fusion. This scheme reduces energy wastage of cluster head using adoptive data fusion window.

Table 3: Comparison of contention free MAC protocols

Parameters / Protocol	**Working principle (strategy)**	**Advantage**	**Disadvantage**
RASS	Cluster head polls cluster members and adjust sleep schedule based on data sending rate nodes.	It is energy efficient since sensor nodes with low sending rate become sleep.	It does not consider priority of received data since node with low sending rate may have more important data.
TRAMA	Use Distributed slot selection algorithm to select one transmitter in two hop neighbor. Bitmap is used to specify intended receiver of the schedule.	Save energy since nodes which are not transmitting and receiving goes to sleep. Throughput is better compared to contention based protocols.	High delay since it increases percentage sleep time. It is suitable for non-time critical application which requires energy efficiency and higher throughput.
P-MAC	Grade division scheduling algorithm is used to divide network around the sink. Pipelining is used to reduce network latency.	Better throughput and average power saving due to implementation of pipeline concept	Exchanging grade information among nodes creates additional overhead.
ZMAC	Hybrid MAC protocol which alternate between CSMA and TDMA scheme based on network contention. In low contention CSMA is used while TDMA is used for high network contention.	Hybrid protocols overcome most of the problem of single scheme based protocol. Perform well both in low and high traffic condition	Switching from CDMA based scheme to TDMA based scheme result in overhead of slot assignment and clock synchronization
PMAC	Pattern generation scheme is used to generate pattern that determine when to sleep and wakeup. Supper time frame has two periods: Pattern generation period and pattern repeat period.	When traffic load is light nodes spent most of their time in sleeping to save energy.	It needs strict synchronization and knowledge of network topology. More collision occur during exchange of pattern

2.2.2 Contention based MAC protocols in wireless sensor networks

Contention based protocol in wireless sensor networks is described as a communication protocol which allow multiple sensor nodes to use the same radio channel without prior co-ordination (without prior channel reservation). There are a number contention based protocols in wireless sensor networks but the common feature which is shared by all those protocols is the channel access policy is based on competition. Whenever the node needs to send a packet; it tries to get access to the channel. The most common problem of this type of protocols providing quality of service QOS, since access to the channel is not guaranteed beforehand.

The following are Contention Based MAC Protocols for wireless sensor network:

In [29] Authors evaluate performance of CSMA and IEEE 802.11. CSMA is one of contention based commercial wireless local area network protocol. CSMA follows RTS/CTS/ACK method in which each sensor nodes sense the medium whenever it needs to send a packet. Initially each sensor nodes listen to the medium for the time interval of DIFS (distributed inter-frame spacing). If the medium is detected to idle after sensing for DIFS time interval, the node begins to sense the medium for random back-off time. Transmission of RTS/CTS began after detecting the idle channel. Source node send RTS packet after back-off timer is declined to zero. Receiver node delays transmission of CTS packet for SIFS (short inter-frame spacing) period of time. After SIFS period of time, receiver replies with CTS packet. If CTS is not received by the source node (the node which sends the RTS packet), source node waits for CTS time-out period and retransmit RTS packet. CSMA use four way handshaking mechanisms through RTS/CTS/ACK and data. Four way handshaking mechanisms has advantages in avoiding hidden terminal problem and saving energy required to retransmit actual data. Since the size of control packets (RTS/CTS/ACK) are basically smaller than actual data size, energy required to retransmit control packets are smaller than energy required for retransmission of actual data packets. CSMA implement virtual carrier sensing mechanism through NAV (network allocation vector). It is implemented through adding the amount of time required for completion current in header of each packet. Neighbor nodes of a receiver and sender extend their back-off timer for the duration of time in NAV. The common problem in CSMA is hidden terminal problem and it does not use periodic sleep/wake scheduling scheme. Due to long idle listening period CSMA consume more energy and it is not suitable for energy constraint wireless sensor nodes.

The IEEE 802.11 is contention based MAC protocol. In contention-based protocols, nodes wait for a random time within a contention interval after detecting a collision. Usually, a back-off scheme is used: the contention interval increases when traffic is higher, because the back-off scheme reduces the probability of collisions when the load is high.

IEEE 802.11 MAC protocol is standard for wireless local area networks (LANs), and has also been implemented in many network simulation packages for wireless multi-hop ad hoc networks.

The best feature of MAC 802_11 protocol over previous CSMA is the avoidance of hidden terminal using RTS and CTS. In CSMA hidden terminal is the common problem which occurs when nodes try to communicate with each other. Suppose there are three nodes A, B, C in which both A and C tries to communicate with node B but both A and C doesn't share their transmission range (i.e C is out of transmission range of node A and A is out of transmission range of node C) while both nodes try to send the packet to node B at the same time collision will happen at node B such a problem is described as hidden terminal problem which degrade the network performance. However MAC 802_11 result in memory overflow compared to CSMA since it uses additional control packets such as RTS, CTS and ACK packets.

In performance of MAC 802_11 is compered against CSMA in terms of packet loss, end-to-end delay and throughput. According to their study MAC 802_11 performs better in detecting hidden terminal problem but as the network load increase the performance is degraded due to extra control packet overhead introduced by MAC 802_11. MAC 802_11 handles the problem of hidden terminal in most of the situation but in some circumstance it fails to avoid hidden terminal problem.

Another problem with IEEE 802_11 is in order to perform effective carrier sensing against collision that may happen, it makes nodes to listen to the channel when the channel is idle. However radio will consume almost the same energy as in receiving state while it listens to the idle channel. Idle listening consume considerable amount of energy when traffic load is small.

To overcome energy wastage in IEEE MAC 802_11 due to idle listening and to enhance this protocol by including features that are suitable for wireless sensor networks a number of protocols are developed.

In [34] authors propose communication protocol based on converge cast. The most observed communication pattern within sensor networks is Converge-cast. Data gathering trees can be described as unidirectional paths from possible sources to the sink. The aim of DMAC is achieving very low latency while being energy efficient. DMAC could be described as an improved Slotted Aloha algorithm where slots are allocated to the sets of nodes based on data gathering tree. So during receive period of a node, all of its child nodes have transmission and contention periods. Low latency is achieved by allocating subsequent slots to the nodes that are successive in the data transmission path. Through implementing this technique DMAC achieves minimum latency compared to other sleep/listen period allocation methods. In some scenarios the latency of the network becomes crucial; DMAC could be a strong candidate in such a cases.

The drawback of DMAC is it doesn't consider collision avoidance methods that may occur when a number of nodes which has the same schedule try to send to the same node. This scenario may happen in event-triggered sensor networks. Besides, the data transmission paths may not be known in advance, which may prevents the formation of the data gathering tree.

In [35] demand wake-up medium access control (DW-MAC) is proposed. In wireless sensor network most of the time Duty cycle is used to reduce energy consumption due to idle listening, however duty cycle also introduces additional latency in packet delivery. Several schemes have been proposed to overcome this latency, but those techniques mainly work for light traffic load. WSN could often experience high traffic loads, either due to broadcast or converge-cast traffic. Authors present a new MAC protocol, called Demand Wakeup MAC (DW-MAC) that introduces a new low-overhead scheduling algorithm that allows nodes to wake up on demand during the Sleep period of an operational cycle and ensures that data transmissions do not collide at their intended receivers. This demand wakeup adaptively increases effective channel capacity during an operational cycle as traffic load increases, allowing DW-MAC to achieve low delivery latency under a wide range of traffic loads including both unicast and broadcast traffic. The authors compare DW-MAC with S-MAC and RMAC using ns-2. The result of simulation shows that, DW-MAC outperforms these protocols, with increasing benefits as traffic load increases.

In [36] Wise-MAC which operates by sending preamble is proposed. In Wise-MAC a sender starts the preamble before the receiver is expected to wake up rather than selecting a random time. Preamble precedes each data packet for alerting the receiving node. If a node finds the medium busy after it wakes up and samples the medium, it continues to listen until it receives a data packet or the medium becomes idle again. The initial size of the preamble is set to be equal to the sampling period. The nodes exchange their sleep scheduling by using acknowledgement message to make their neighbor node aware of their sleep schedule. Every node record neighbor sleep schedule and decides own schedule according to their neighbor schedule. The random wake-up preamble is adopted in-order to decrease the possibility of collisions caused by the specific start time of a wake-up preamble. The wake up preamble length can be affected by clock drifts between the source and the destination. It performs better than S-MAC in varying traffic load. The protocol definition, which mitigates the external time synchronization requirement, handles the clock drifts. The drawback of WISE-MAC is decentralized sleep–listen scheduling which results in different sleep and wake-up times for each neighbor of a node. Buffering packets for neighbor which is in sleep mode and delivering those packets as each neighbor wakes up result in higher latency and power consumption in broadcast-type communication. It may result collision due to hidden terminal problem occurs at beginning transition a node.

Berkeley MAC or B-MAC [37] is an asynchronous duty cycle MAC protocol. In B-MAC, each node has its independent duty cycle scheduling. Node can transmit by sending a preamble along with the data packet, which must be longer than the receiver's sleeping time, to make sure that the receiver will be in wake up mode. If a node is in a wake cycle, it samples the medium only when a preamble has been detected. Power consumption, throughput and latency are improved in B-MAC; however, overhearing and the long preamble are major drawbacks.

To achieve low power consumption BMAC combines CSMA and low power listening features to sense medium access. In BMAC reliability of channel assessment is achieved through a filter mechanism. It provides a flexibility interface which allows the sensor node to change any operating variables in the protocol, such as delay and back off values. BMAC employs an adaptive preamble sampling scheme to reduce duty cycle and minimize idle listening. BMAC does not have synchronization RTS/CTS. As a result of enhanced feature of B-MAC idle Listening is reduced to a minimum and it has a better overall performance than S-MAC.

When network is idle B-MAC results in Low overhead and it is simple to implement. However, the drawback of this protocol is Overhearing problem is not solved. Power consumption of all nodes in the sender's transmission coverage increased while there is of Long preamble. BMAC has lower duty cycle hence leads to higher cost to overhear and hence more contention.

In [37] X-MAC was proposed to overcome the drawbacks of B-MAC. It uses short preambles to avoid the overhearing problem. The preamble contains the target address to help untargeted nodes to sleep and allow the targeted node to send early ACK. This not only avoids overhearing but also reduces the latency by half. The lack of flexibility is the main drawback of this protocol as it is very hard to reconfigure it after deployment. Another problem with this approach is that it fails to take the traffic caused by the preamble transmissions into account. The power efficiency of XMAC becomes degraded as wireless medium is occupied by the preamble transmissions. XMAC builds upon the foundation provided by asynchronous duty-cycled MAC protocols. XMAC protocol improves the problems of low power listening, overhearing, and excessive preamble. Asynchronous protocols like BMAC and Wise-MAC, rely on LPL (low power listening) also called preamble sampling. XMAC uses short preamble which allows interruption and wake up faster. XMAC take the advantages of low power listening, namely low power communication, simplicity, decoupling of transmitter and receiver sleep schedules through the usage of short preamble embedded with address information of the target. Due to avoidance of synchronization XMAC protocol has low overhead, less complex, low latency and it is energy-efficient. The drawback of XMAC is related to the process of "avoiding overhearing" by embedding the target receiver node ID which makes multicasting/broadcasting difficult. As a result X-MAC is Unable to schedule small listening periods.

In [38] receiver initiated medium access control protocol is proposed. RI-MAC uses the receiver initiated mechanism to achieve lower power consumption, higher throughput and packet delivery ratio. Similar to B-MAC, each node has its independent duty cycle scheduling. The key difference compared to B-MAC and X-MAC is that the sender in RI-MAC stays in active mode until the targeted receiver is ready and the message start to be delivered. Receiver will inform the sender by sending beacon frame.

Whenever receiver node wakeup it broadcast the beacon to notify neighboring node data transmission. Upon reception of beacon neighbor node which has data to transmit will send data since the receiver is awake. Beacons in RI-MAC are used for two purpose one for initiation of the connection and the other for continuation of the current connection. After receiving the current transmission data successfully the data packet receiver node again broadcast a beacon, which is used for two purposes: as an acknowledgment to currently received data and to announce continuation of connection to the sender. The beacon frame format of RI-MAC contains hardware preamble, FCF (frame control field), FCS (frame check sequence), Src (source address), BW (back-off window), Ds (Destination address). The back-off window and destination address is the optional field in beacon frame field. The size of a beacon stores beacon frame length. Any node transmitting the beacon adds its address as a source address to enable the receiving node in identifying the sender of beacon.

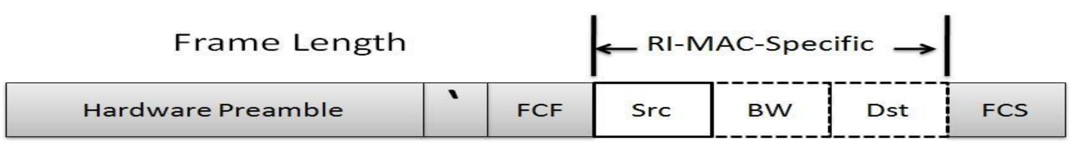


Figure 5: Beacon frame format of RI-MAC [38]

RI-MAC reduces the data period in duty-cycle as a result it is able to reduce energy consumption of nodes since the receiver node will not listen to the idle channel while there is no transmission. In addition to increase lifetime of nodes RI-MAC use receiver initiated transmission which reduces collision that may happen due to transmission of packets from different source sensor nodes at the same time.

The remaining part of our theses discus Contention based MAC protocols that are designed for wireless sensor network to enhance energy efficiency, delay and throughput.

2.3 Related Works

In [39] Sensor Medium access control protocol for wireless sensor network was proposed. The best feature that SMAC introduce is periodic sleep wake up. The basic idea behind periodic sleep listen is to let node to sleep during their sleep time while listening to the channel and transmission will be performed during the listen time. Using periodic sleep listen SMAC is able to reduce energy spent for idle listening which is predominant energy consuming factor in wireless sensor network especially when network load is light. During the sleep period node turns off its radio to save energy. SMAC follows duty cycle to put the nodes to sleep as well as listen phase. Duty cycle is defined as the ratio of listen period to cycle time. SMAC defines complete synchronization mechanism through broadcasting SYNC, periodic neighbor discovery and neighbor list maintenance.

Duty cycle can be adjusted by the user according to the application requirement. Duty cycle can be described as ratio of listen period to frame length. Frame length (cycle period) is fixed for all nodes in a network while listen period may vary. Listen period consist of two parts SYC period and DATA period. SYC period is the moment in which broadcast packets will be transmitted to solve synchronization problem among neighboring nodes. DATA period is the designed for transmitting data packets. Each schedule followed by SMAC nodes is controlled by schedule timer which can reschedule when the current schedule expires. Nodes are expected to have at list one schedule to follow. Each frame in SMAC has expiration period which is called checking point. At each checking point SMAC will decide what to do for next period. There are other features of SMAC like overhearing avoidance and message passing. Overhearing occurs when nodes overhear the packets which are not destined to them. To avoid overhearing SMAC leads nodes of both sender and receiver neighbor to sleep. Message can be sent as fragment and single packet. SMAC fragment long message into small fragments and transmit it in burst, but only one RTS/CTS packet is used to send those fragments. But ACK packets should be sent by the receiver each time it receives those fragments. If there is packet lose sender extends its transmission time.

The low duty cycle reduce sensor nodes energy consumption but increase latency. Whenever node receives a data packet from its downstream hop it will not send that packet until the next listening period of next hop nodes. This incurs large delay when there is multi hop communication network. Other drawback of SMAC is fixed duty cycle which is followed by each node in a network. When network load is light minimum duty cycle performs better in saving sensor nodes energy while during high traffic load maximum duty cycle performs better. However in wireless sensor network it is not real to find fixed traffic type since traffic load may change over time. To come up with the solution to this problem, researchers made an attempt by adapting the duty cycle to network load.

SMAC has the following features:

- **Periodic sleep listen**

The well-known feature of SMAC is periodic sleep listen. It includes SYNC time, data time and sleep time. Sync time is short period that allows the synchronization between nodes. Data time is period in which the actual data is sent or received and it is almost two times larger than the sync time. During sleep time nodes go to sleep to save energy consumption that may happen during idle listening. The duration of sleep period is higher that data period and sync period. In data period nodes become ready to send and receive the data after they send RTS and receive CTS packets.

SMAC tries to reduce energy consumption and avoid collision by applying scheduling and contention scheme.

To reduce time spent on listening to the idle channel, during listen period node wake up for listening to the channel and communicate with other nodes that needs to send or receive packets. But during the sleep period node will go to sleep by turning of their radio.

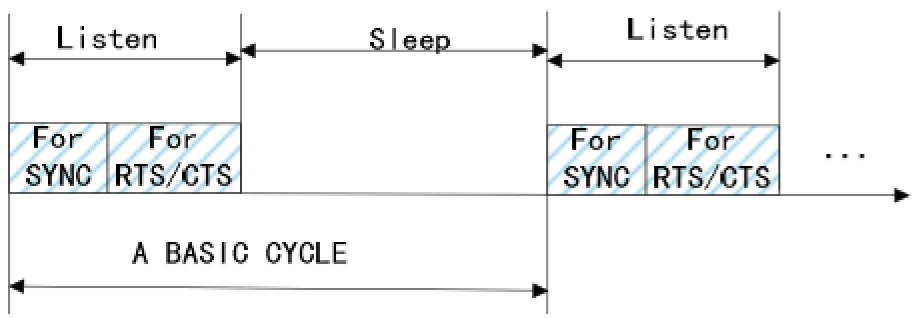


Figure 6: periodic sleep-listen [31]

So using sleep listen feature SMAC reduce unnecessary energy wasted during idle listening which is more effective when traffic load is light.

- **Duty cycle**

Duty cycle is defined as ratio of listen period to complete sleep listen period which is known as frame length.

$$\text{Duty cycle} = \frac{\textit{listen period}}{\textit{frame length}} \quad \text{……………………………………………………… eq. 2.1}$$

Duty cycle can be adjusted from 10% to 100% to control the length of sleep period. Listen period contains two parts: SYNC period and DATA period.

SYNC period is the period in which SYNC packets are broadcasted. SYNC packets are broadcast packet that can solve the synchronization problem among the sensor nodes. DATA period is the period in which data packets including control packets such as RTS and CTS are sent or received among communicating nodes.

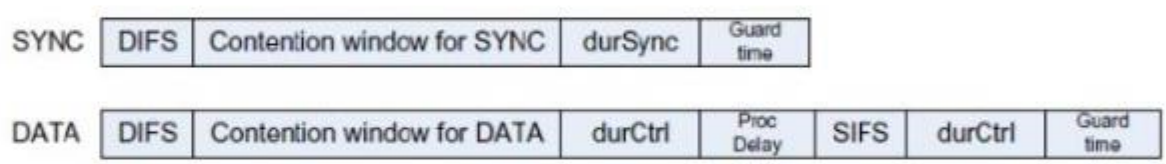


Figure 7: SMAC frame format [30]

Table 4: SMAC SYC and DATA packet frame format with description

Fields	**Description**
DIFS	DIFS (DCF inter-frame space) is a minimum idle time of the medium that is used for contention based MAC protocols. In DCF node that needs to transmit the data frames supervise the channel activity until DIFS. After sensing an idle DIFS, the node still waits for a random back-off interval before each transmitting.
DATA CW	Contention window for DATA packets which is used for transmission of data packet.
SYNC CW	Contention window for SYNC packet which is used for the purpose of synchronization among nodes.

SIFS	Short interface space in ms. it is used before sending a CTS or ACK packet. It takes care of the processing delay of each pkt.
Guard time	Guard time at the end of each listen interval, in ms.

- **Synchronization**

SYNC packet

Neighbor nodes in SMAC exchange their schedule through broadcasting SYNC packets. SYNC packets are broadcasted during SYNC period.

Table 5: SYNC frame format

Fields	**Description**
type	Flag indicating this is a sync packet
Length	Fixed size with 9 bytes
srcAddr	ID of the sender
syncNode	ID of sender's synchronization node
sleepTime	Sender's next sleep time from now
state	Indicate whether the node change schedule recently
crc	Cyclic redundancy check

Every SMAC nodes maintain at least one schedule table to store its own schedule and neighbor schedule. Schedule that is generated by the node it-self is called a primary schedule and other schedules in a table are called secondary schedule.

If its entire neighbor follows the same schedule, node may not have secondary schedule.

Table 6: Field definition of schedule table

Fields	Description
txSync	Flag indicating need to send SYNC
txData	Flag indicating need to send data
numPeriods	Counter for sending sync period
numNodes	Number of nodes on this schedule
syncNode	The node which initialize this schedule
chkSched	Flag indicating need to check numNodes

- **Neighbor List**

Each node which uses SMAC records neighbor information in a neighbor list. The maximum number of neighbors in a neighbor list can be adjusted using user adjustable SMAC parameter.

Neighbor list is established through SYNC packet exchange. Transmission of unicast data takes place after checking existence of destination node in a neighbor list.

Table 7: Neighbor list field description

Fields	Description
nodeID	ID of this node
schedID	ID of schedule that is followed by this node
active	Flag indicating this node is active recently
state	Flag indicating this node has changed the schedule

- **Carrier Sense**

S-MAC achieves carrier sensing through both physical and virtual mechanisms. The medium is said to be free if both virtual and physical carrier sensing determines that medium is free. Each time radio starts or stop receiving or transmitting physical layer perform physical carrier sensing to check the current radio state and physical layer informs the MAC layer.

- **Collision avoidance**

S-MAC use RTS/CTS mechanism as defined in DCF which can reduce the duration of collision and solve the so-called hidden terminal problem. Before actual DATA packet, the sender and receiver should exchange RTS / CTS packets. There are two types of packets in S-MAC: Broadcast packets and unicast packets. Broadcast packets are sent without using RTS/CTS prior to transmission. Unicast packet follows RTS/ CTS /DATA /ACK sequence to send data. After carrier sensing a node cannot start transmission of data immediately, since it has to wait for some time known as DIFS time. DIFS is the minimum idle time of a medium used for contention based MAC protocol. According to [31], to avoid collision a node compute random back-off time with eq. 2.2

Back-off = Random (0,CW) + slotTime …………………………………………………… eq. 2.2

Transmission and reception of DATA is performed at DATA period. Data period is fixed according to some physical and MAC layer parameters such as radio bandwidth and contention window size.

Collision may occur either during transmission of RTS/CTS/DATA/ACK packets. For instance if collision happen while two neighbor nodes transmit RTS packets at the same time, SMAC performs retransmission of RTS packet again after some random back-off time. Those neighboring nodes become aware of the collision after waiting for CTS expire time in which the sender should receive CTS after transmission of RTS packet.

- **Overhearing Avoidance**

Overhearing is major source of energy wastage in contention based wireless sensor MAC protocols. It occurs when node receives packets destined for the other node. The best way to achieve overhearing is to let each node to listen transmission of all its neighbors. This feature is good for high network traffic scenario but result in energy wastage when network traffic is light.

To avoid overhearing S-MAC nodes goes to sleep whenever they receive CTS or RTS packets destined to the other nodes. In a general word in S-MAC both the neighbors of Sender and receiver goes to sleep. This feature of S-MAC enables it to save more energy since the primary goal of S-MAC is saving energy.

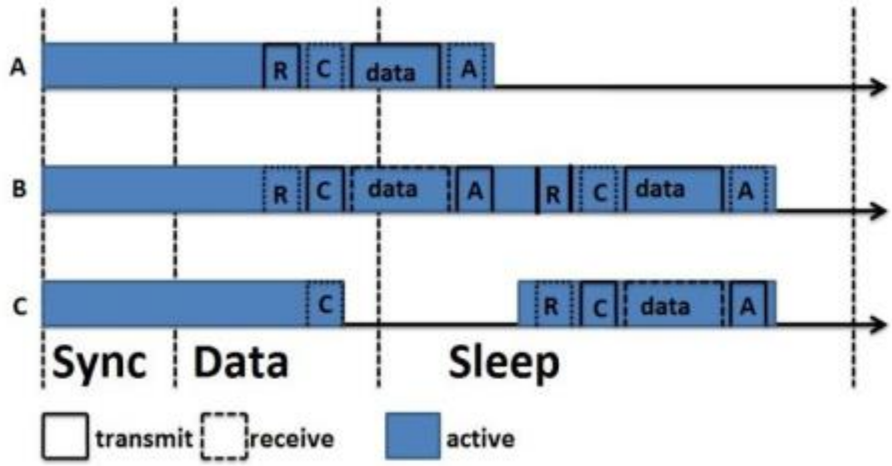


Figure 8: overview of SMAC protocol

Suppose in figure 8. there are three nodes A, B and C. whenever node A wants to send data to node B it will send RTS packet prior to the actual data transmission and the receiving node (let say node B) replies with CTS packet. However during this communication there will be a neighbor node of node B which is able to hear the communication of node A and B. let say this neighbor node which overhear this communication is node C. since the transmission of both RTS and CTS packets are in broadcast mode, node C will receive CTS packet broadcasted from node B. Upon reception of CTS packet node C will go to sleep until the communication between those two neighboring node is completed. So by putting nodes which are neighbors of both senders and receivers to sleep, SMAC is able to achieve energy efficiency than conventional IEEE 802_11 protocol in case of sensor networks.

- **Message Passing**

Other feature of SMAC is message passing technique in which long message if fragmented in small pieces of messages (fragments) and sent to the receiver. For all fragment SMAC sends only one RTS and CTS packets but the sender expects ACK packet for each fragment that are sent.

- **Adaptive Listening**

Adaptive listening is proposed to reduce latency of scheduling sleep/wakeup in SMAC. Sleep/wakeup scheduling of SMAC reduce the energy consumption but it results in high latency in transmission of data packets in multi-hop scenario. The basic idea behind adaptive listening is to let each node to transmit additional data packet after the current transmission is completed. This feature enables SMAC to give each node additional data period for transmission or reception of data packet.

In [32] authors Propose adaptive duty cycle mechanism by replacing fixed duty cycle of SMAC with priority discriminant function. Hence, nodes with more packets get access to channel prior to the nodes with fewer packets. The basic idea behind dynamic duty cycle is when network traffic is relatively large the duty cycle is doubled which enables nodes to listen more time so that loss of packet will be minimized but when the network traffic is relatively small the duty cycle will be reduced by half of the original. Authors prove the proportionality between duty cycle and frame length through the mathematical model. Frame length is the sum of listen period and sleep period. Duty cycle and T_{frame} has inverse proportionality in which minimizing the duty cycle increase the T_{frame} value which in turn incurs additional delay. Duty cycle is given by the eq. 2.1 as a follow:

$$\text{Duty cycle} = \frac{T\ listen}{T\ frame}$$

The authors point out that SMAC uses fixed sleep scheduling mechanism without considering traffic load in a network. In case of wireless sensor network most of the time network traffic change drastically which may cause problems such as collision and packet loss. DC-SMAC can predict network traffic to dynamically adjust network duty cycle. DC-SMAC adjusts the duty cycle based on number of packets in a queue and transmission time required to send each packets. The assumption behind DC-SMAC is the minimum transmission interval is 3d where d is the sum of time required for carrier sensing and time required for transmitting the packet ($d = t_{cs} + t_{ts}$).

With this assumption DC-SMAC adjust the duty cycle in three cases based on average transmission delay which is computed as sum of transmission delay of each packet in a queue divided by total number of packets:

Case 1: If average transmission delay is less than 3d the duty cycle is adjusted to half of the original assuming that the traffic load is small.

Case 2: If the average transmission delay is in between 3d and T_{frame} the initial duty cycle is used assuming that the traffic load is moderate.

Case 3: If average transmission delay is greater than T_{frame} the duty cycle will be doubled by assuming that there is high network traffic.

Through the use of average transmission delay DC-SMAC is able to evaluate the network load in order to decide better duty cycle which considers current network condition. DC-SMAC is evaluated in star topology containing four nodes. As per the author result it performs better in energy consumption, throughput and end-to-end delay.

In [33] T-MAC is proposed to overcome the short coming of S-MAC under variable traffic load. A node following T-MAC ends their listen period when no activation event occurs among neighbor nodes within time threshold TA. So the variable load in the network is considered in T-MAC. The activation events are periodic frame timer, reception of any data on the radio, the end of transmission of its own data packet or acknowledgment, overhearing of CTS or RTS. TA describes minimal amount of idle listening per frame. In T-MAC node will not go to sleep while its neighbors are communicated since it may be the receiver of subsequent messages. Every node transmit their queued message in burst when the sending node doesn't receive any answer in the interval TA, it will go to sleep. This situation may happen since the first frame transmission which may reduce the throughput. If the node does not receive the any answer it should re-send the RTS and it will go to sleep after waiting for two subsequent trails. The value of TA is greater than sum of contention interval, length of RTS packet, short time between ending of RTS packet and beginning of CTS packet (turnaround time). The main aim of TMAC design is to reduce the time of idle listening in which node may listen to the channel where there are no packets that are being transmitted. In addition to idle listening there are other factors that have been taken into consideration while designing TMAC, those factors includes:

- Collision: during transmission of packets from communicating nodes at the same time those packets may be collide with each other and the energy to transmit them will be wasted.

- Protocol overhead: since control packets exchanged in most of the protocols doesn't contain any application data T-MAC considers the energy to send and receive those control messages as overhead.
- Overhearing: the communication through the air takes place in shared medium. So through this communication node may receive packets that are not destined to it. Avoiding overhearing reduces the energy wasted to receive packets that are not destined to the current node.

However the predominant waste of energy occurs during the idle listening than other factors that has been stated above. TMAC reduce the energy required for idle listening by introducing the activation factor TA.

The shortcoming of TMAC is it suffers from early sleeping problem. The early sleeping problem of T-MAC makes it vulnerable for lower throughput of the protocol than earlier SMAC protocol.

In [31] authors propose contention window adaptive Medium access control protocol. Contention window adjustment determine performance of network since it will be used for determining when and how long to transmit packets. During light traffic load, a high contention window may cause an unnecessary wait, and then make energy efficiency descend. On the other hand, if there is heavy traffic, a smaller one may lead to intensifying competition. SMAC protocol can't adapt to dynamic network traffic, and may result in serious delay, and even high power consumption.

Considering the deficiency of SMAC back-off mechanism ACW-MAC modifies RTS frame as well as contention window. ACW-MAC propose back-off algorithm which uses adjust stable contention window instead of constant contention window.

In SMAC node calculate random back-off time before transmission and set back-off timer. Node starts to transmit when timer is declined to 0. Random back of time is important for collision avoidance. ACW-MAC introduce two parameters known as CW_{init} and CW_{basic} . CW_{init} is initial contention window which is obtained by dividing the sum of minimum contention window and maximum contention window by two. Then the value of initial contention window will assigned to CW.

$$CW_{init} = \frac{CWmin + CWmax}{2} \quad \text{……… eq. 2.3}$$

Contention window basic is obtained by dividing contention window into two intervals.

ACW-MAC also introduces other parameter called ACCESS which will be set to 1 if the node access the channel and transmit packet successfully last time. If node fails to transmit packet successfully last time ACCESS will be set to 0. Current network traffic load is determined by comparing current contention window with contention window basic. Then current contention situation is announced to neighbor nodes through newly added RTS packet field called CONTENT. Authors evaluate performance of SMAC and ACW-MAC through five node star topology. As routing protocol AODV is used to evaluate performance. As per the result of performance evaluation ACW-MAC performs better in-terms of average end-to-end delay, throughput and average energy efficiency by varying CBR interval.

The fixed contention window of SMAC cannot achieve better performance as traffic load changes since it requires either waiting more time to transmit packets or intensify the competition for the channel under varying network traffic. As we try to discuss existing literatures related to our work none of existing literatures in contention based protocol specifically none of SMAC modification takes into consideration network size while adjusting contention window and remaining energy while adjusting duty-cycle. We enhance the performance of SMAC protocol by considering those two parameters. We also illustrate the effect of number of nodes in network on the performance of SMAC while traffic interval kept constant increase in number of nodes in network degrades the performance of the protocol. As a solution for this problem our thesis adjust contention window based on network size instead of fixed CW.

Table 8: Comparison of some contention based MAC protocols

Protocols / Parameters	SMAC	T-MAC	DC-MAC	ACW-MAC
Working principle	Adaptive listening, Static sleep schedule	Active time out, Dynamic sleep schedule	Dynamic duty-cycle based on packet in a queue and transmission time required to deliver the packet.	Adaptive contention window based on traffic load.
Collision	Reduced by overhearing avoidance	Reduced by adaptive timeout	Use random back-off scheme as in SMAC	Use additional access field on the control packets.
Energy consumption	Low energy consumption	Low energy consumption	Low energy consumption than SMAC in heavy traffic.	Consume less average energy than SMAC.
Advantage	Minimize energy consumption	Achieve optimal active period	Reduce end to end delay and increase throughput.	Reduce delay and increase throughput,
Dis-advantage	RTS-CTS increase energy, Fixed CW and Fixed duty-cycle	Early sleeping problem. Reduced throughput than SMAC.	Only feasible for heavy traffic.	Adding additional field increase bandwidth and energy consumption

To achieve less energy consumption and better network performance in wireless sensor network, efforts have been made both in MAC and routing layers. This thesis work mainly deals with MAC protocols for wireless sensor network and we made an effort to enhance energy efficiency of SMAC protocol.

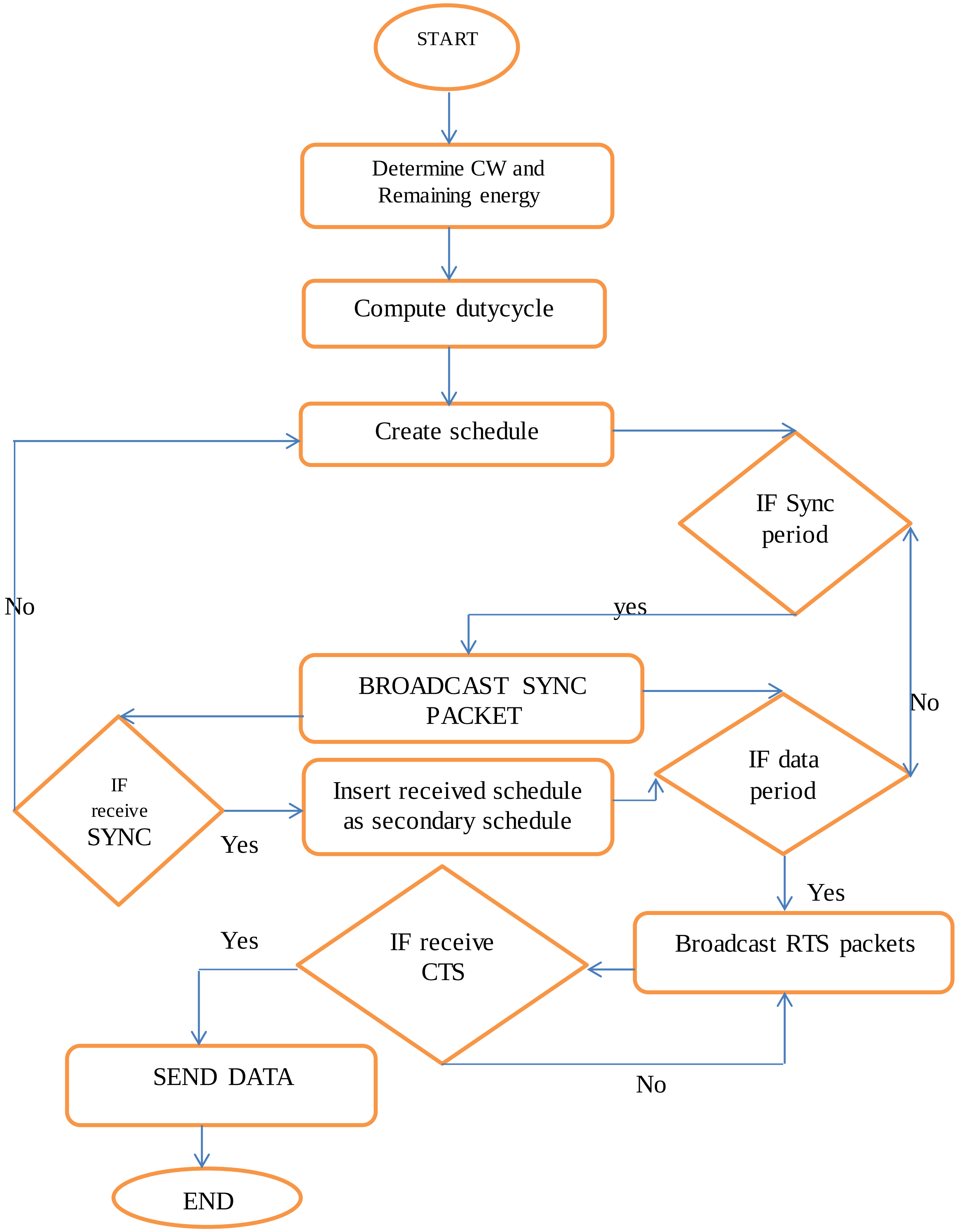
CHAPTER THREE

3. PROPOSED SYSETEM DESIGN

In this study an attempt is made to enhance sensor medium access control protocol for wireless sensor network. The design of Medium access control protocol is supposed to include the important features such as ensuring energy efficiency, less delay, higher throughput and being adaptive to topology change. Based on the reviewed literatures and some design factors that we have discussed earlier, we propose an improvement to the SMAC (sensor medium access control) protocol. SMAC protocol has one most visible drawback related to static duty cycle. This feature of SMAC makes it fixed and unable to adapt to change in the network, which can result in higher end-to-end delay and energy consumption due to retransmission of lost packet. Even if SMAC is synchronization based MAC protocol, practically it is impossible to have full time synchronization among wireless sensor nodes. To overcome the problem related to fixed contention window size and fixed dutycycle of SMAC, we developed an algorithm that utilize network size and remaining energy of a node to adjust contention window size and duty cycle of SMAC protocol. Since contention window contains time slot which is required to wait by each node before transmitting or receiving SYNC packet and DATA packets including control packets, the larger value of contention window for small number of nodes results in long idle listening to a channel while small value of contention window for large of nodes results in intense computation among sensor nodes which results in loss of packet. To prove our thought we perform simulation by varying number of nodes and duty cycle. Then we measure the sensor nodes remaining energy and perform simulation to know how well our proposed work performs through dynamic change in nodes remaining energy. The combination of these two factors is able to improve performance of sensor medium access control protocol in throughput, delay and power efficiency.

3.1 High Level Design of Proposed work

Proposed work mainly deals with designing MAC protocol that maximizes the throughput while still being energy efficient based on SMAC protocol. High level design for the proposed work is designed based on features of SMAC protocol and additional features that we propose as an improvement to the SMAC protocol for wireless sensor network.


START
Determine CW and
Remaining energy
Compute dutycycle
Create schedule
IF Sync
period
yes
No
BROADCAST SYNC
PACKET
No
IF
receive
SYNC
Yes
Insert received schedule
as secondary schedule
IF data
period
Yes
Broadcast RTS packets
Yes
IF receive
CTS
No
SEND DATA
END

3.1.1 Description of the Flow chart

ESMAC is proposed as a modification of SMAC protocol. So features of SMAC are kept the same in ESMAC but some additional features are introduced using adjustable contention window and remaining energy of each nodes in the network to adjust the sleeping time of sensor nodes.

The phases of ESMAC are:

3.1.1.1 Determining contention window

In the initial phase each nodes in the network determine their contention window based on number of nodes in the network. We perform various simulations under varying number of nodes to determine the contention window that maximize throughput of wireless sensor network which operate under sensor MAC protocol (SMAC protocol). The simulation result of varying number of node enable as to determine the relationship between contention window and number of nodes in the network. Based on the simulations in almost all cases SMAC performs better in throughput and delay, when contention window becomes comparable to number of nodes in a network. In ESMAC contention window is determined using:

SYNC_CW= N -- eq. 3.1.

DATA_CW= N -- eq. 3.2.

Where CW stands for contention window, N is number of nodes in a network. Every node in the network computes their contention window using the above equation. By using simulation experiment on ns-2 we are able to get the optimal contention window that increase throughput and minimize end-to-end delay. We achieve the improvement of those parameter by adjusting contention window for SYNC and DATA to eq(3.1) , eq(3.2) respectively.

Where N is configurable parameter number of nodes (Network size) and CW is contention window. The value of computed CW is used to set value of SYNC and DATA contention window.

3.1.1.2 Determining remaining energy of nodes

Nodes in a network evaluate their remaining energy against specified thresholds. When the energy of sensor nodes drops below the specified thresholds, sensor nodes re-adjust their duty-cycles. Sensor node become active for less time when their energy becomes less than certain specified threshold. By reducing duty-cycle the sleep time of sensor node become larger and sensor nodes save more energy.

In contention based MAC protocols which operate using dutycycle, Energy conservation is based on sleep time length:

$$\text{Ec} = \frac{Tsleep}{Tframe} \quad \ldots\ldots\ldots\text{eq. 3.3}$$

Frame length (Tframe) is complete sleep listen cycle

$$Tframe = Tsleep + Tlisten \quad \ldots\ldots\ldots\text{eq. 3.4}$$

Sleep Time (Tsleep) can be computed from eq. 3.4 as a follow:

$$Tsleep = Tframe - Tlisten \quad \ldots\ldots\ldots\text{eq. 3.5}$$

Substituting eq.3.5 in eq.3.3:

$$Ec = \frac{Tframe - Tlisten}{Tframe}$$

Simplifying the above equation:

$$Ec = \frac{Tframe}{Tframe} - \frac{Tlisten}{Tframe} = 1 - \frac{Tlisten}{Tframe} \quad \ldots\ldots\ldots\text{eq. 3.6}$$

Dutycycle is computed as a follow:

$$dutycycle = \frac{Tlisten}{Tframe} \quad \ldots\ldots\ldots\text{eq. 3.7}$$

Substituting eq.3.7 in eq. 3.6, Energy conservation (saving) of a node is related to:

$$Ec = 1 - dutycycle \ldots\ldots\ldots\text{eq. 3.8}$$

From eq. 3.8 we can conclude that energy conservation or energy saving of sensor nodes increase with reduction in dutycycle of a node.

The reason for saving more energy with reduction in dutycycle is due to increasing sleep time of sensor nodes. Based on the eq.3.8 we propose the adaptive dutycycle which takes in to consideration remaining energy of sensor nodes.

After their deployment sensor nodes loss their energy due to different factors such as: idle listening, overhearing, collision, data routing and etc. Those factors results in unbalanced energy consumption among sensors with less remaining energy and high remaining energy. To reduce occurrence of this situation proposed ESMAC protocol adapts the dutycycle using ***Algorithm 2.***

Frame length is fixed according to the some physical layer parameters in SMAC. So for a given dutycycle the listen time can be determined as:

$$Listen_{time} = dutycycle * \ framelength$$

Sleep time will be determined using the following equation:

$$Sleep_{time} = cycle_{time} - listen_{time}$$

Let consider the case with 30% dutycycle. Lets' say the frame length is 50 second. Listen period can be computed as:

$Listen_{time}$ = 30/100 * 50 = 1500/100 = 15 second

$Sleep_{time}$ = 50.00 – 15.00 = 35 second

In our scheme if the remaining energy of sensor node drops below 0.75 of initial energy, duty-cycle becomes 0.75 times its initial duty-cycle. In case of the above example duty-cycle becomes: 0.75 * 30 = 22.5 %

$Listen_{time}$ = 22.5/100 * 50 = 1125/100 = 11.25 second

$Sleep_{time}$ = 50.00 – 11.25 = 38.75 second

From the above example in the proposed scheme there will be more sleep time than SMAC protocol. By sleeping nodes for longer time when sensor nodes energy drops below specified thresholds (i.e 0.75, 0.5, 0.25) of its initial energy, ESMAC is able to save wireless sensor nodes energy.

3.1.1.3 Creating schedule based on contention window and dutycycle of nodes

Based on CW and remaining energy, each node will determine its own sleep/listen schedule. The prepared schedule will be broadcasted to the neighbor nodes using SYNC packet. SYNC packet is a synchronization packet which is used to synchronize sleep/wakeup schedule among neighbor nodes. Neighbor nodes receiving the schedule will try to match the received schedule with its own schedule. If the schedule matches it will acknowledge the sender and if it doesn't match it will add the received schedule as secondary schedule in its schedule table. Listen time has duration in which sensor node needs sense carrier before sending or receiving packets. This period is used for both SYNC and DATA packets. In ESMAC contention window is determined according to the number of nodes in a network which will be smaller for small number of nodes but larger for large number of nodes in a network.

3.1.1.4 Broadcasting RTS/CTS packets

The broadcast of RTS and CTS packets are used for same purpose as in SMAC protocol. SMAC protocol broadcast RTS (request to send) to send data from source to the destination. Whenever the node receives RTS it will check for the neighbor nodes which are sending to or receiving from the current node and if there is no neighbor node performing this activity the node will send CTS (clear to send) broadcast packets to the sender node. Every neighbor nodes which receive CTS broadcast packets will go to sleep to prevent collision during transmission of data. But sender of RTS broadcast packet will not go to sleep. After receiving CTS packet, sender waits for some back-off time and sends the actual packet.

3.1.1.5 Sending Actual Packet

In this phase the actual data will be sent among neighbor nodes which operate under ESMAC protocol. This phase works as data sending phase of SMAC protocol which uses message passing technique to send actual data among nodes. In message passing technique of SMAC the actual data is fragmented into small fragments and those fragments will be sent as burst. SMAC send only one RTS and receive only one CTS for the whole fragments of the same data packets but each fragments need to be acknowledge by the receiver.

3.2 The Algorithm of proposed ESMAC protocol

Algorithm 1:

1. *Determine the remaining energy of node*
2. *Compute duty_cycle using **Algorithm 2.***
3. *Determine CW that fits to current network size*
4. *Generate primary schedule*
5. *Create SYNC packet*
6. ***If** SYNC period t**hen***
7. *Broadcast SYNC packet*
8. ***If** receive SYNC packet **then***
9. *Check the schedule against primary schedule*
10. ***If** schedule match **then***
11. *Follow the current schedule*
12. ***else***
13. *Insert current schedule as secondary schedule*
14. ***Else If** Data period **then***
15. *Send RTS*
16. ***If** receive CTS **then***
17. *Send data*
18. ***else***
19. *Rebroadcast RTS*
20. ***Else***
21. *Go to sleep*

Algorithm for adjusting duty-cycle according to predefined energy threshold

Algorithm 2:

1. *Get initial value of dutycycle*
2. *Get remaining energy of sensor node*
3. ***If** remaining energy > 0.75 * initial energy **then***
4. *Dutycycle = dutycycle*
5. ***Else if** ((remaining energy <= 0.75 * initial energy) && (remaining energy > 0.5 * initial energy)) **then***
6. *Dutycycle = dutycycle * 0.75*
7. ***Else if** ((remaining energy <= 0.5 * initial energy) &&(remaining energy > 0.25 * initial energy)) **then***
8. *Dutycycle = dutycycle * 0.5*
9. ***Else***
10. *Dutycycle = 0.25 * dutycycle*

Contention window in our scheme is determined with the following equation

DATA_CW = (number of nodes in network)………………………………….. eq(3.1).

SYNC_CW = (number of nodes in network) ----------------------------- eq (3.2).

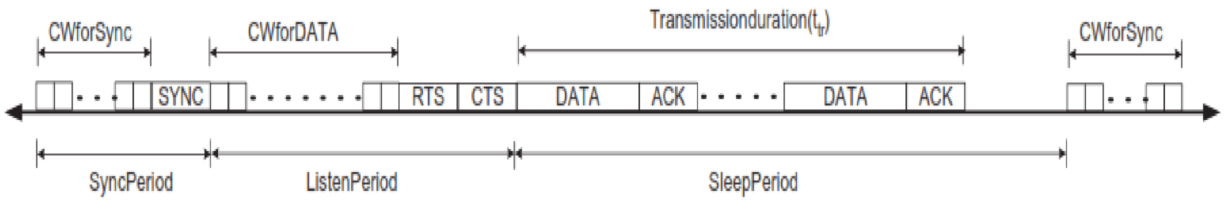


Figure 9: Frame Structure of SMAC [55]

Every node in network competes for SYNC_CW time slot before sending SYNC packet to their neighbor nodes. After winning the channel access nodes begin to send their SYNC packet. DATA_CW has time slot that nodes need to sense channel before transmitting DATA packets. If the node wins the channel after performing carrier sense for DATA_CW time slots, it begins to send DATA packet. Minimum contention window for sending both synchronization packets and DATA packets results in intense competition between sensor nodes which result in higher packet loss. Maximum contention window size results in higher waiting time since node need to sense channel for time duration of DATA_CW or SYNC_CW before sending packet. SMAC use fixed contention window size for both SYNC and DATA.

Hence proper adjustment of contention window can affect the value of those periods in SMAC. In this thesis using network size as a parameter to adjust contention window size for both data packets and SYNC packet, we are able to improve the performance of SMAC protocol with respect to Power efficiency, average energy consumption, average delay and throughput. The reason for this achievement is increase in CW size of both SYNC and DATA packets as number of nodes in network increases but it will keep minimum CW size while number of sensor nodes in network is small. Our method reduces wasted slots when sensor nodes in network are small while still keeping competition among sensor nodes from becoming intense when sensor nodes in network increase.

CHAPTER FOUR

4.1 IMPLEMENTATION

In chapter three we propose the architecture and algorithm for enhanced version of SMAC (sensor medium access control) protocol.

4.2 Simulation Tools for wireless sensor network

Wireless sensor network are designed for the use of applications such as: temperature, gas, ambient conditions, humidity etc. Despite their wide application resource constraint nature of wireless sensor nodes pose additional requirement in optimizing the use of limited resource of wireless sensor network. The area of wireless sensor network is still under investigation by various researchers across the world to develop new algorithm, protocol and technique to make wireless sensor network more efficient. Implementing each algorithm on sensor network is not feasible, so using simulation tools to implement and evaluate algorithms and techniques become an optimal solution. Wireless sensor network simulator consists: Event, medium, environment, node, transmitter, physical, MAC, Routing and application layers.

There is a number of simulation tools used in wireless sensor network, some of them are discussed in this section:

- **Network simulator two (NS-2)**

According to authors in [52][55] Ns-2 is object oriented simulator consisting of C++ and object oriented command language (OTCL). C++ is used to implement varies protocols and extending simulator while OTCL is used for creating network topology, configuring simulator and setting network topology. It can run on varies operating system such as: Linux, mac OS, Solaris and windows. It support dual output test based and graphical based. Graphical simulation is performed using Network animator (NAM). The results of simulation drown from trace file using XGRAPH. NS-2 provides support for different protocols including MAC layer protocols such as 802.11, 802.15.4, 802.16, SMAC etc.

- **Network simulator three (NS-3)**

According to authors in [52] NS-3 not supports any application programming interface belonging to NS-2. Therefore, NS-3 is not recognized as extension of NS-2. In NS-3 all programs are written in pure C++ with optional python bending. There is no graphical tool in ns-3 but result can be plotted by using other open source software such as NetAnim.

- **OMNET ++**

According to authors in [52][56] OMNET ++ is discrete object oriented network simulator. OMNET++ is basically not a simulator but it provides framework and tools to write simulation scenario. OMNET++ is free for the use of education and research purpose. It has basic elements called modules which can be categorized in to three types. Those modules include: simple module, compound module and network module. To debug modules and C++ program OMNET++ contains Eclipse IDE.

- **Quality Networking (QUALNET)**

According to authors in [52] Qualnet is commercial network simulation software. It supports variety functionalities including GUI design and Visualization. Qualnet has packet tracer to keep track of network information and to make visualization representation of packet trace file. Command line interface and file editor are also available in Qualnet.

- **Global Mobile Information System Simulator (GloMoSim)**

According to authors in [52][56] Glomosim use layered approach to make a simulation among different layers. At data link layer CSMA, MICA, MICAW, FAMA and 802.11 are supported. At network layer GLOMOSIM support sensor protocols such as AODV and DSR. But current version of GLOMOSIM does not support any sensor network features.

- **MATLAB**

According to authors in [52] Matrix laboratory support easy programming capability and provide easy platform for users to develop custom functions. MATLAB consists of varies tool boxes such as: Aerospace, Fuzzy Logic, Control System Design, Symbolic Computations, Communication and Statistics. It is supported by SIMULINK at the backend. MATLAB has built in IEEE 802.15.4 communication and various parameters like SNR (Signal to Noise Ratio, Attenuation and Interference) are available.

We implement the design of proposed enhancement to SMAC on network simulator NS-2.34. Network simulator-2 is open source simulator tool which implement various protocols. Network Simulator (NS) is a discrete event simulator targeted at networking research that provides substantial support for simulation of various networks. It contains C++ code and Tool command language (TCL). We evaluate the performance of proposed work by change in number of nodes and with change in duty cycle. The design of power efficient medium access protocol can prolong the lifetime of network. In addition to energy efficient design latency and throughput are also important features that need to be taken into consideration for wireless sensor networks.

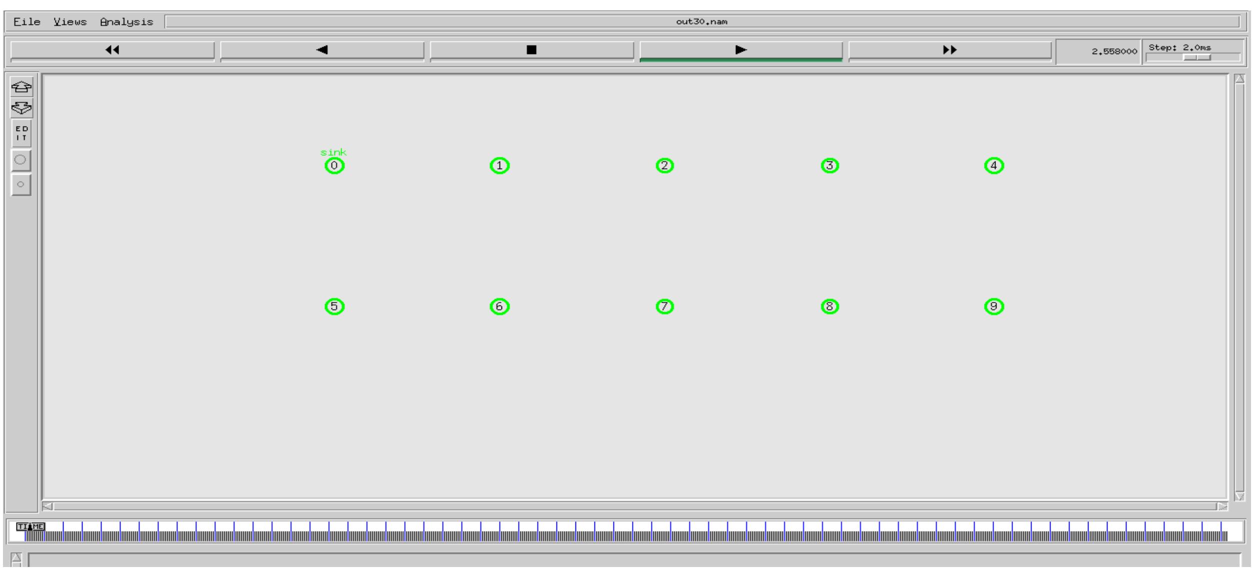
4.3 simulation setup

- Grid Topology is used to evaluate performance of proposed work to existing SMAC protocol.
- The evaluation was made in two simulation scenario: The first scenario is changing dutycycle from 10 to 100 for ten nodes in a network. The second scenario is changing number of nodes from 6 to 30. In both cases we evaluate performance of proposed work (ESMAC) with SMAC in terms of power efficiency, average throughput and average delay.
- The simulation parameters are taken from article stated in [30].

Table 9: parameters of evaluation in change in number of nodes

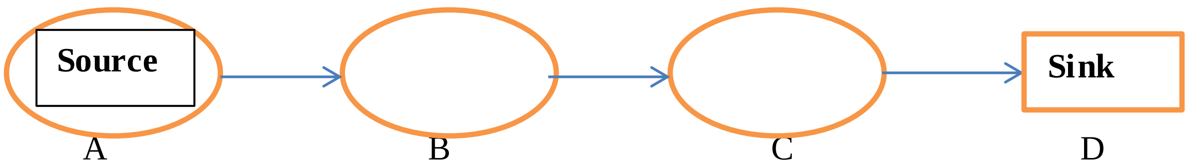
Parameters	Description (value)
MAC protocol	**ESMAC/SMAC**
Routing protocol	**AODV**
Number of nodes	**6,10,12,14,16,18,25,30**
Initial energy	**1000J**
Idle power	**1.0 watts**
txpower	**1.0 watts**
rxpower	**1.0 watts**
Sleep power	**0.001 watts**
Transition power	**0.2 watts**
Transition time	**0.005 watts**
Interface queue length	**50**
Simulation time	**100 s**

Sample grid topology of 10 nodes



Node 0 is considered as sink node which receives packet sent from source nodes and expected to process it.

Contention window adjustment based on network size increase the throughput.



S-MAC can deliver a packet up to 2 hops per operational cycle but generally cannot go beyond that within the cycle since the next hop after C (such as some node D) is unlikely to have been awake to overhear the communication from B to C; node C will transmit an RTS to D but will go back to sleep itself when it fails to receive a CTS in reply from D. The use of adaptive listening can also cause a significant increase in energy consumption, since many neighboring nodes may overhear the RTS or CTS and wake up, whereas only one of them is the next-hop node. Moreover, since a node does not wake up until an overheard communication ends, this node then may not have complete knowledge of the busy state of the wireless medium. For example, the node might have missed hearing an RTS or CTS of another data transmission in the neighborhood; if the node in this case starts transmitting any packet, the packet may cause collisions at other nodes. Based on this information, we try to simulate SMAC with enabled synchronization flag in multi-hop scenario.

We varied the duty-cycle from 10 to 100 and compare the performance of ESMAC with SMAC protocol. In all most all simulation scenarios, ESMAC outperform SMAC in Average throughput, power efficiency and Average delay.

Table 10: parameters of evaluation in change in duty-cycle

Parameters	Description (value)
MAC protocol	ESMAC/SMAC
Topology configuration mode	Grid
Traffic	CBR
Agent	UDP
Routing protocol	AODV
Initial energy	1000J
Network area	801x500
Number of nodes	10
Duty cycle	10,20,30,40,50,60,70,80.90,100
Idle power	1.0 watts
txpower	1.0 watts
rxpower	1.0 watts
Sleep power	0.001 watts
Transmission power	0.2 watts
Interface queue length	50
Simulation time	500 s

Performance of ESMAC and SMAC with change in duty cycle based on adjusting duty-cycle of SMAC according to remaining energy of sensor nodes only:

Figure 10: Average energy consumption

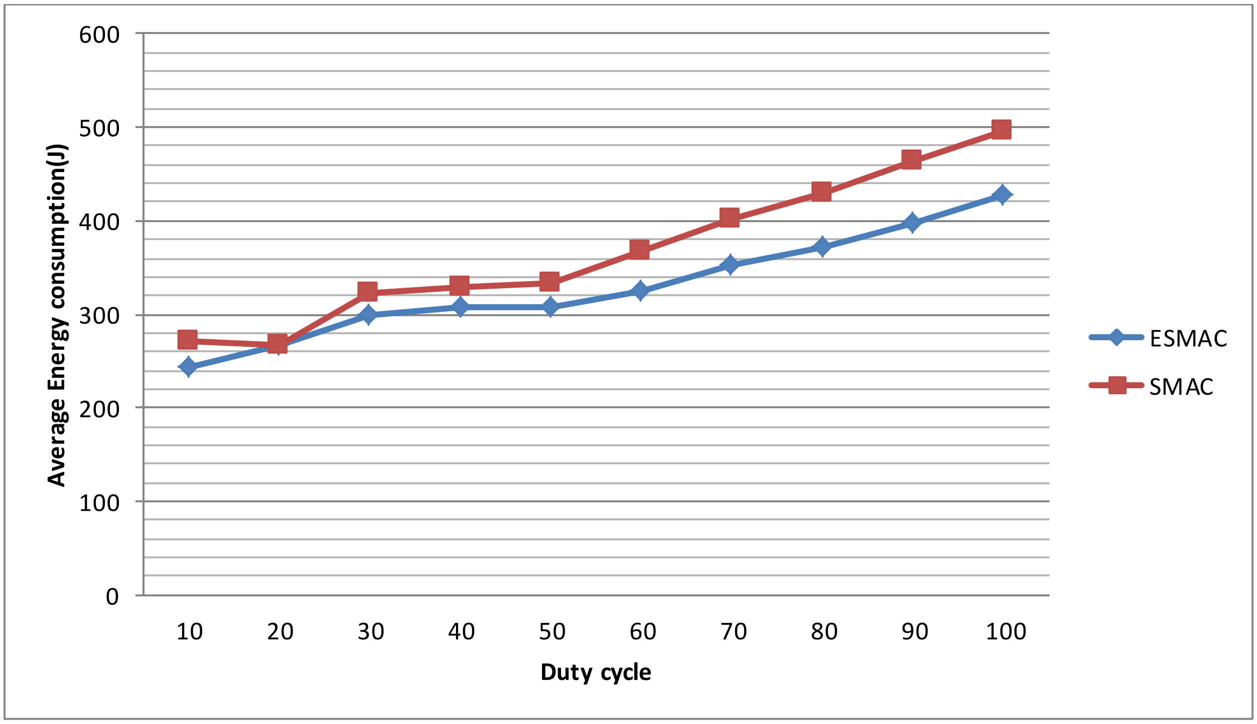
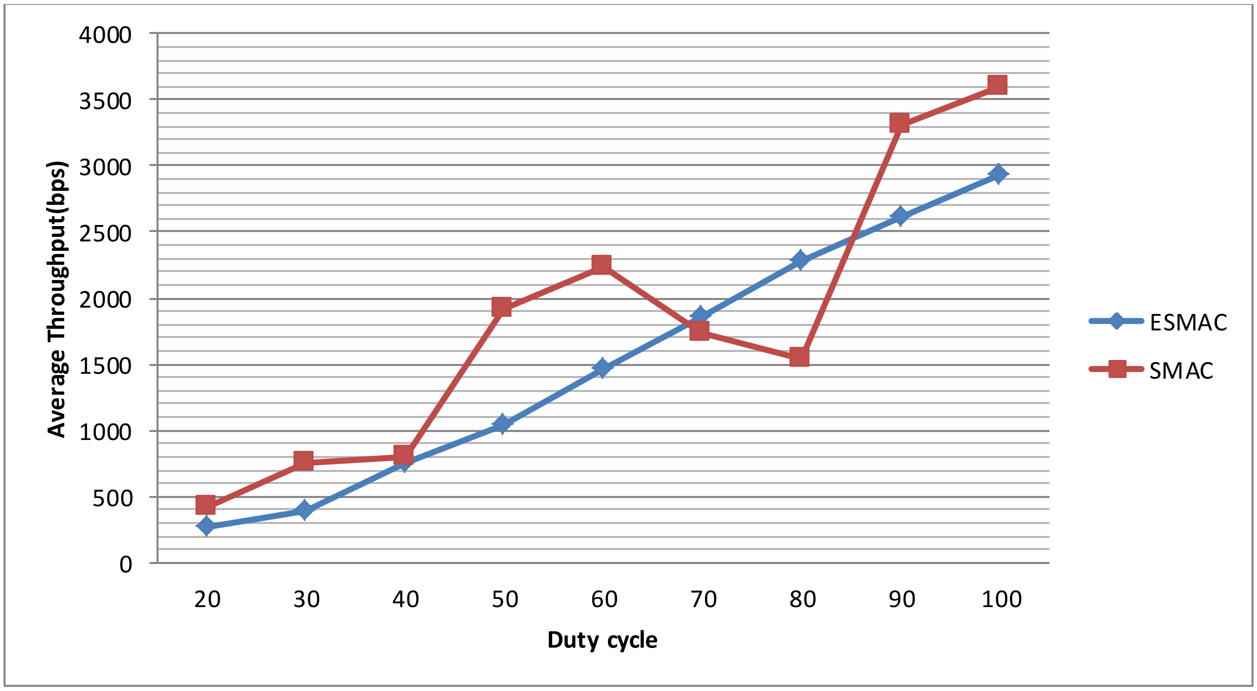


Figure 11: Average throughput



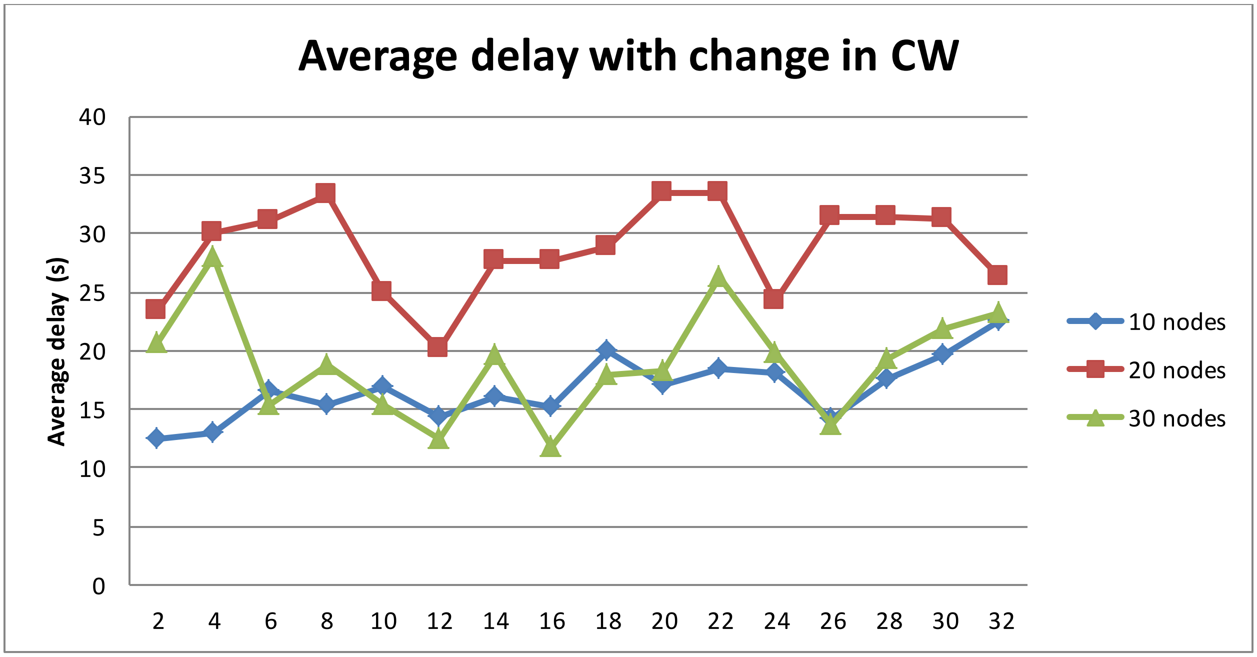
Since ESMAC let nodes with low remaining energy to be active for less period of time by reducing the duty-cycle, it is able to save more energy than SMAC. From the result of Average energy consumption in figure 10, we are able to observe that ESMAC performs batter in energy saving than SMAC. However, letting nodes to be active for less time reduce throughput of network. As figure 11 shows, the throughput of ESMAC is less in almost all cases than SMAC protocol.

The scenario of adjusting dutycycle of sensor nodes dynamically based on remaining energy is suitable for application requiring saving sensor nodes energy with acceptable reduction in throughput.

However, some applications requires high throughput while still saving sensor nodes energy. For such application we add additional feature on ESMAC to make contention window adaptive to change in number of nodes in a network (network size). Network size is proposed to be a configurable parameter.

The rest of this Chapter discus performance evaluation of proposed ESMAC with combined features of adaptive dutycycle to remaining energy and adaptive contention window to network size.

Figure 12: Simulation performed to find optimal contention window size



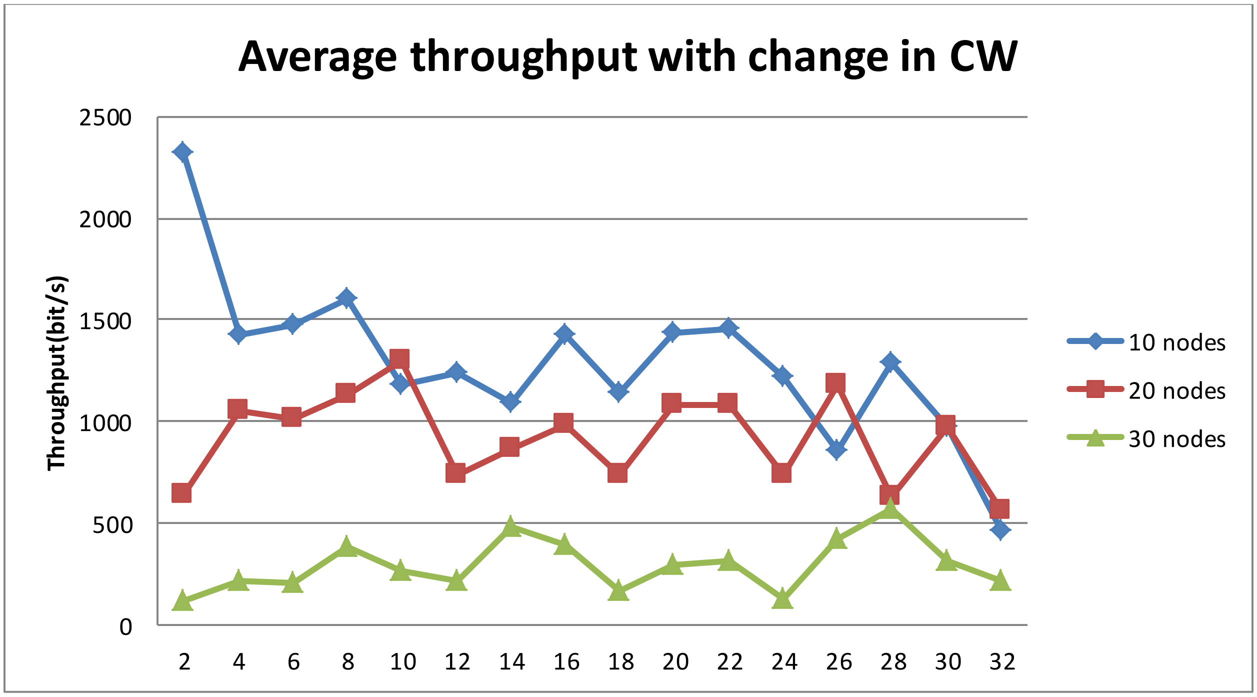


Table 11: simulation result of the change in contention window

Cw Size	Throughput	Delay
2	116.20	20.60
4	221.89	28.06
6	205.02	15.44
8	386.82	18.75
10	262.46	15.43
12	221.38	12.45
14	483.43	19.66
16	389.63	11.85
18	171.14	17.88
20	299.97	18.23
22	318.15	26.31
24	129.01	19.79
26	425.99	13.69
28	572.95	19.22
30	316.96	21.85
32	221.41	23.26

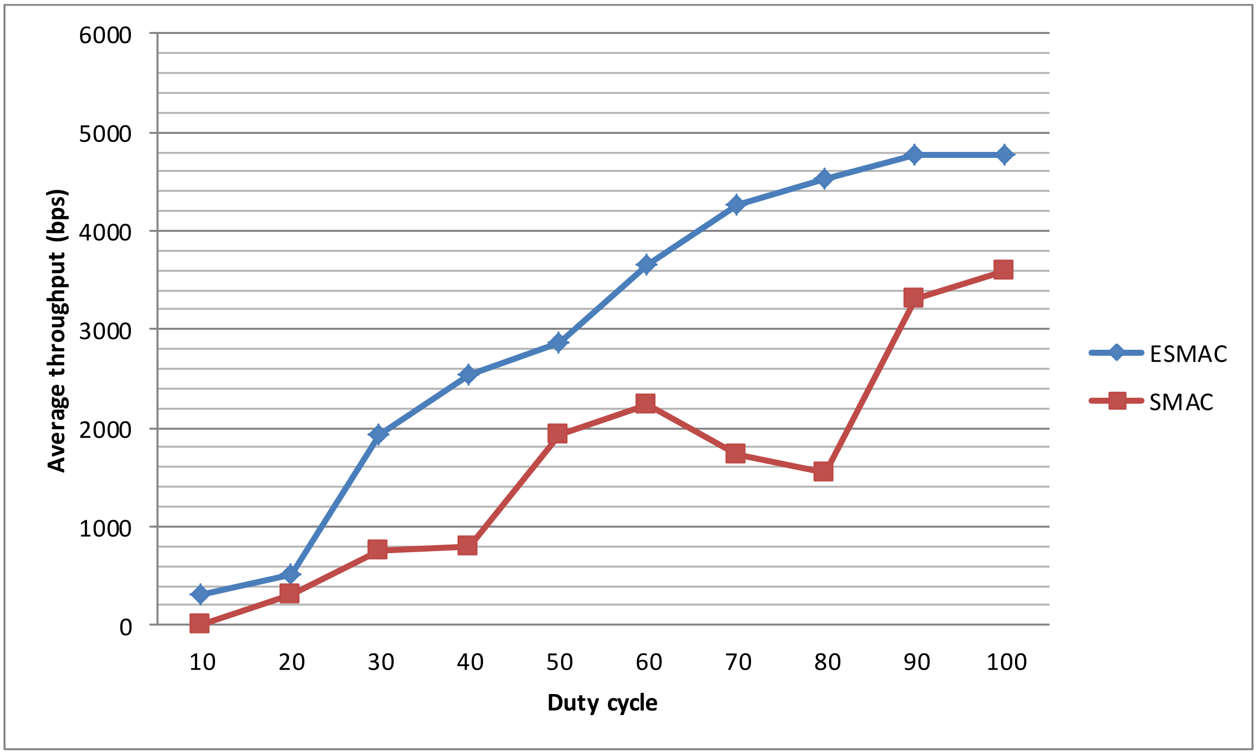
As Table 11 results suggest contention window size comparable network size increase throughput while still results in lower delay. So we propose configurable contention window size based on number of nodes in a network. The result of simulation is made for constant traffic condition type. Traffic interval and other configuration parameters used in all simulation scenarios are the same.

Based on simulation result since result of throughput increase as contention window size becomes comparable with network size, we prefer adjusting contention window size according to network size instead of fixed contention window size of SMAC protocol.

Grid Topology used for evaluating performance of ESMAC and SMAC with change in duty-cycle

Grid topology is used with 10 nodes. This scenario is used to evaluate ESMAC with change in duty-cycle. ESMAC throughput increases with increase in duty_cycle.

Figure 13: Average throughput with change in duty-cycle



As the Figure 13 show, at duty-cycle 10 SMAC throughput is zero but ESMAC throughput is higher. As duty-cycle increase throughput of ESMAC becomes larger than SMAC throughput. Increasing duty-cycle means increasing listen period of sensor nodes. In both cases while duty-cycle increase throughput increases significantly. Since ESMAC use contention window size which is determined based on network size, CW used to evaluate average throughput with change in duty-cycle is the same for equal number of nodes. Since contention window size in the 10 nodes scenario becomes 10 in ESMAC while it is 63 in SMAC. So in ESMAC nodes listen to channel for shorter period of time than SMAC. Too small contention window size results in intense competition among sensor node. Due to intense competition sensor node data will be lost which increase chance collision occurrence and reduce throughput of the network. Too large contention window size results in wastage of slots which reduce throughput of the network.

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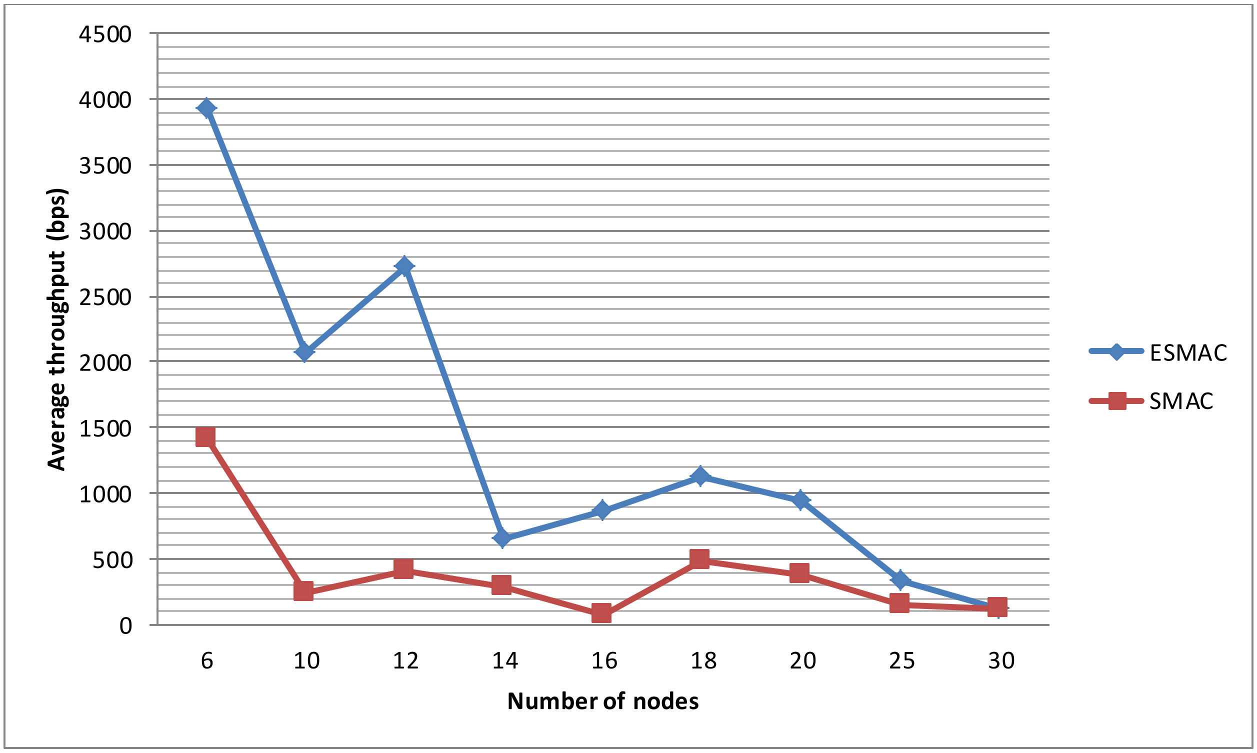
Figure 14: Average throughput with change in number of nodes



In Figure 14, average throughput of ESMAC is evaluated against SMAC with change in number of nodes. With smaller number of nodes ESMAC throughput is higher than SMAC but as number of nodes exceed 30 both protocols result in equal performance. At 40 numbers of nodes SMAC throughput becomes zero. The reason is with increase in number of nodes communication becomes multi-hop which will increase complexity of synchronization among neighbor nodes. Since SMAC is contention based protocol which compete sensor nodes for accessing the shared channel, each node does not have their own transmission and reception slot duration. While one node is sending data to its next hop, the next hop node may be not in a receiving state. This situation result in drop of data packets.

Average end-to-end delay comparison of ESMAC and SMAC:

End to end delay is improved in ESMAC since contention window size for small number of node becomes smaller for small number of sensor nodes. In multi-hop scenario since sensor nodes deliver data through multiple hops, the time used to listen for the channel before transmission at each hop becomes larger. This scenario increase delay significantly. Since there is no packet received during initial duty-cycle (10% dutycycle) the end-to-end delay for SMAC cannot be evaluated. We evaluate end-to-end delay in both change in number of nodes and change in dutycycle.

Figure 15: Average end-to-end delay with change in duty-cycle

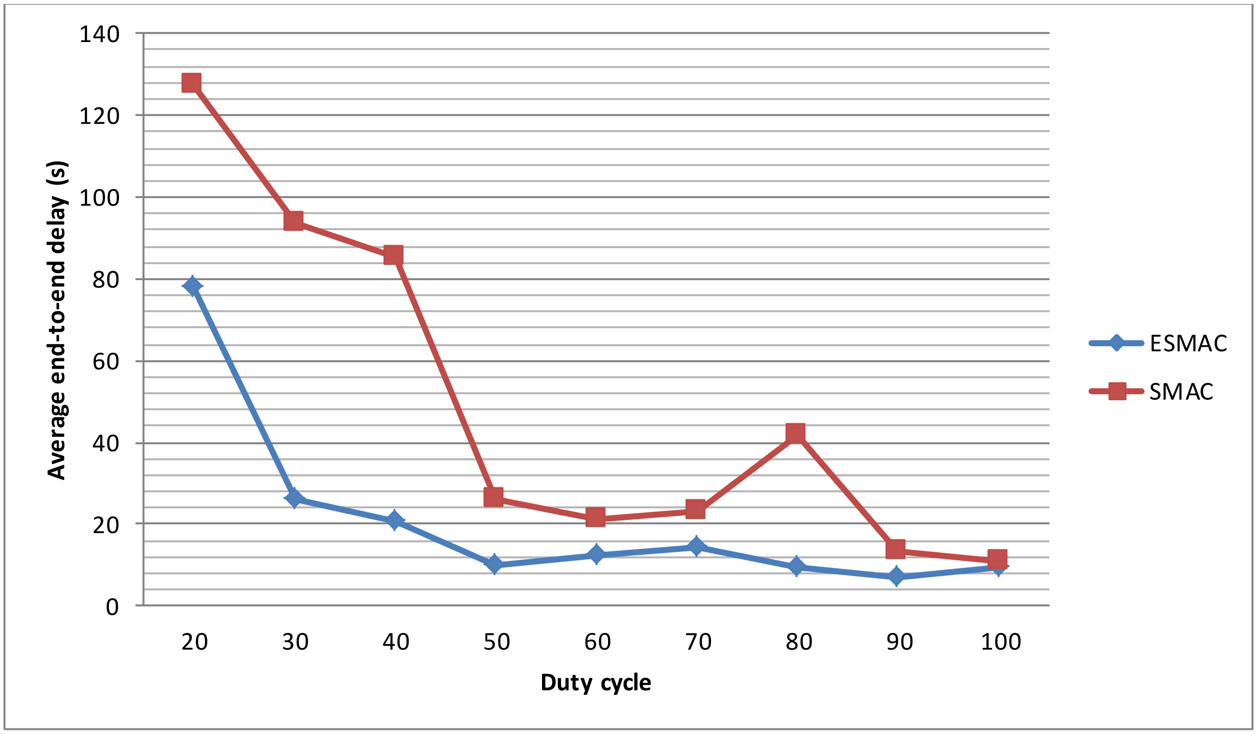


Figure 16: Average end-to-end delay with change in number of nodes

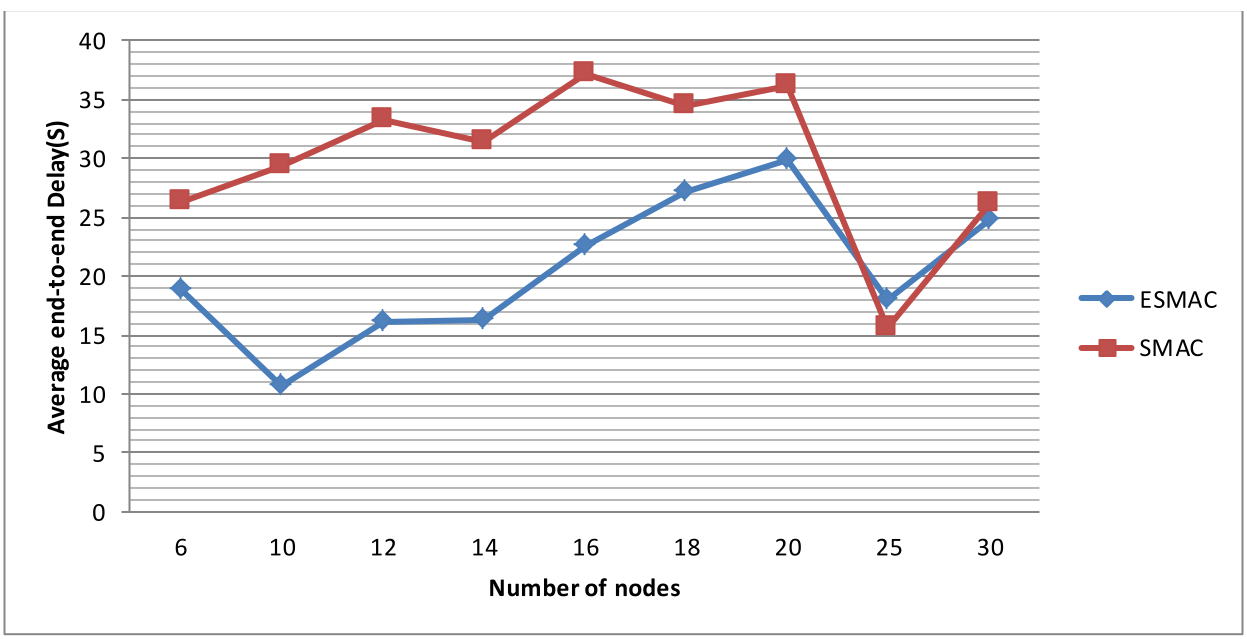


Figure 17: Power efficiency with change in dutycycle

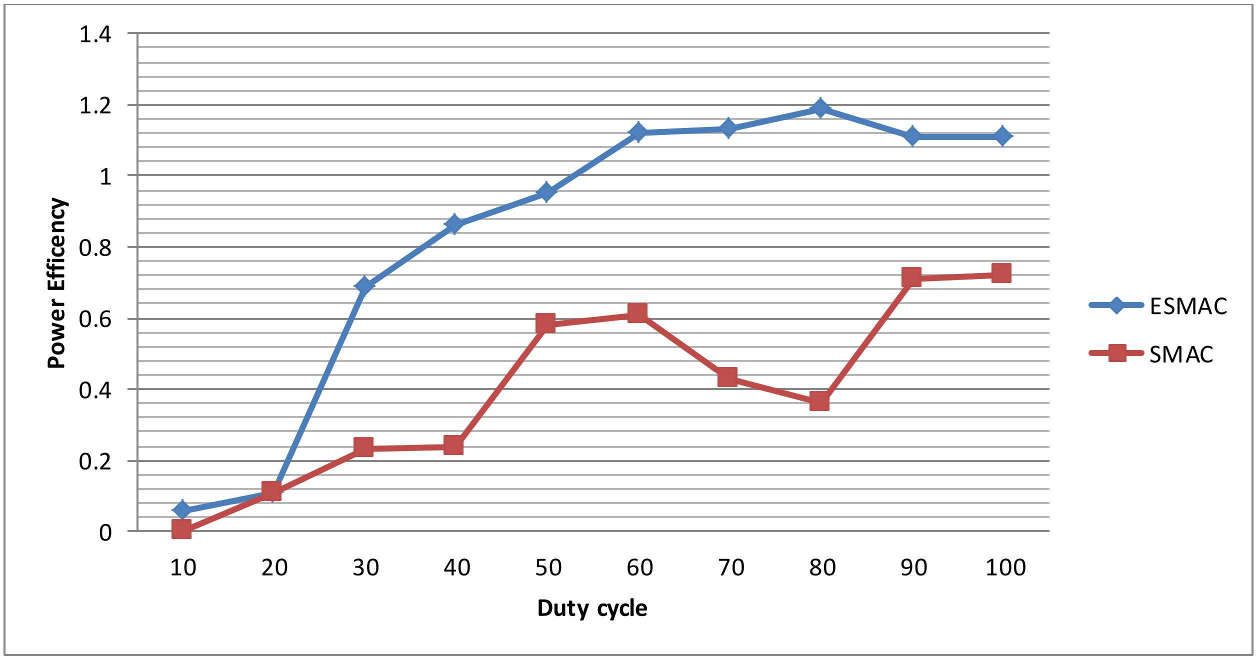


Figure 18: Power efficiency with change in number of Nodes

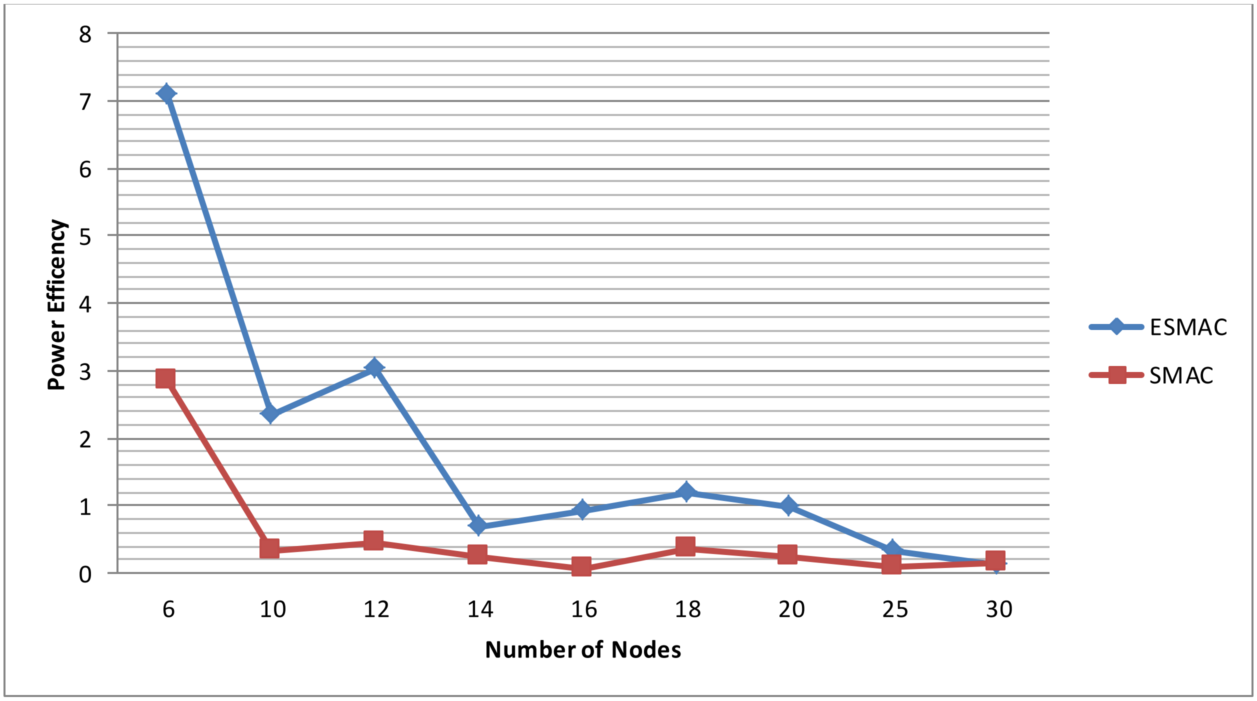


Table 12: Simulation result of ESMAC with change in dutycycle and contention window

Change in dutycycle for ESMAC			
Dutycycle	**Average Throughput**	**Average delay**	**Power efficiency**
20	505.88	78.86	0.11
30	1936.65	26.06	0.69
40	2549.38	20.52	0.86
50	2870.77	9.9	0.95
60	3662.4	12.28	1.12
70	4267.18	14.28	1.13
80	4518.46	9.58	1.19
90	4778.95	6.81	1.11
100	4773.12	9.38	1.11
Change in number of nodes for ESMAC			
Number of nodes	**Average throughput**	**Average delay**	**Power efficiency**
6	3925.47	18.78	7.08
10	2073.32	10.75	2.34
12	2730.47	16.03	3.02
14	658.72	16.23	0.68
16	869.61	22.56	0.91
18	1128.16	27.2	1.19
20	945.76	29.78	0.97
25	326.96	18	0.34
30	114.52	24.84	0.13

Table 13: Simulation result of SMAC with change in dutycycle and contention window

Change in dutycycle for SMAC			
Dutycycle	**Average Throughput**	**Average delay**	**Power efficiency**
20	319.77	127.49	0.11
30	746.57	93.77	0.23
40	796.39	85.18	0.24
50	1922.67	26.11	0.58
60	2232.09	21.34	0.61
70	1732.35	23.12	0.43
80	1541.07	41.79	0.36
90	3307.35	13.2	0.71
100	3594.27	10.94	0.72
Change in number of nodes for SMAC			
Number of nodes	**Average throughput**	**Average delay**	**Power efficiency**
6	1414.5	26.25	2.78
10	240.46	29.35	0.34
12	412.22	33.19	0.44
14	285.62	31.31	0.25
16	80.34	37.19	0.06
18	491.58	34.43	0.36
20	382.21	36.2	0.25
25	150.11	15.56	0.09
30	114.7	26.13	0.15

As Figure 17 and Figure 18 result show, ESMAC is power efficient than SMAC with almost all duty cycle that are used to evaluate the performance of both protocols. As duty cycle increase the power efficiency of ESMAC become higher.

In performance evaluation of ESMAC and SMAC with lower duty cycle we are able to observe that SMAC doesn't receive any packet and its throughput becomes zero. But ESMAC receives higher number of packets. We use *bits/second* as a unit to compute throughput in this scenario.

As duty-cycle increase there will be more energy consumption since node listen time increase with duty-cycle. However, in ESMAC the listen time of sensor nodes is determined based on remaining energy of sensor nodes. As sensor node energy decrease the sleep time increase in ESMAC.

In wireless sensor network design achieving energy efficiency while delivering sensed data with small delay and higher throughput is foremost design challenge.

In comparison with SMAC, ESMAC average energy consumption is reduced as increase in duty-cycle due to adjustment of duty-cycle based on remaining energy of node. As remaining energy of node drops below 0.75, 0.5 and 0.25 of initial energy ESMAC adjust the duty cycle to 0.75, 0.5 and 0.25 of initial duty-cycle. Since duty-cycle is the ratio of listen time to frame length when duty-cycle is minimized nodes will get more time to sleep.

The duty-cycle adjustment and contention window adjustment method that are used in ESMAC enables as to enhance the performance of SMAC protocol.

CHAPTER FIVE

5. Conclusion and Future Work

5.1 Conclusion

Wireless sensor networks are recently being used in a number of applications ranging from home monitoring to environmental monitoring by deploying them to a specific application. However wireless sensor nodes are resource constraints nodes which need wise use of limited resources. Major approach to enable wise use of limited sensor node resources is the Medium access control mechanism. There are three general categories of MAC protocols in wireless sensor networks. Those are contention based, contention free and hybrid protocols. In this thesis we point out weakness of well-known Contention based SMAC protocol and propose the ESMAC protocol to overcome shortcoming of SMAC protocol related to energy and other parameters (throughput, delay). Generally by adjusting contention window based on network size and by adjusting duty-cycle based on remaining energy of nodes, we are able to achieve better performance in-terms of throughput, average end-to-end delay and power efficiency than SMAC protocol.

5.2 Contribution of the study

- Adjusting Duty-cycle according to remaining energy of sensor nodes:

This study is able to find out that allowing sensor nodes with small remaining energy to sleep more time can reduce energy consumption of sensor nodes. This is achieved by reducing duty_cycle of sensor nodes with lower remaining energy. The remaining energy of sensor nodes is evaluated against specified hard thresholds and if the remaining energy of sensor nodes drops below that threshold, sensor node adjusts its duty_cycle to be lower than the current duty_cycle.

- Adapting duty_cycle based on remaining energy of nodes and adapting Contention window according to network size:

Finding optimal contention window size for contention based MAC protocol can improve performance of the protocol. As per finding of this paper, adjusting contention window according to the size of the network can improve performance of contention based protocol (specifically SMAC protocol).

The combined parameter of dutycycle adjustment based on remaining energy of sensor nodes and contention window adjustment using network size improve performance of contention based SMAC protocol in terms of Average energy consumption, Average throughput, Average delay, Power efficiency.

5.3 Future works

Wireless sensor networks that used for application such as target tracking, patient health monitoring and surveillance purpose requires minimum delay with higher delivery accuracy of event reporting. Routing layer is responsible to determine the optimal path to forward the sensed packets to the destination node. As our future research direction we aimed at:

- Introducing the concept of opportunistic forwarding scheme which fit with proposed ESMAC by setting number of forwarder set of nodes instead of single forwarding node. So that node doesn't need to wait for next hop to wake up rather it will forward the event to any node which wakes-up from the set of forwarding node. This method can reduce the delay of delivering packet and improve the throughput. Apart from TDMA schemes contention based schemes has challenge in achieving in time delivery of packets as well as achieving better result in throughput. As our future research direction we put forward implementing set of forwarding node and forwarding packet in an opportunistic manner.

- Packet priority also needs to be considered while there are packets with different urgency requirement. We also need to consider packet priority to use ESMAC for application that requires mixed data types. So the node with more urgent packets will get higher priority of accessing the channel than nodes with less urgent packet. In order to achieve this objective sensor which generate those packets should mark each and every packet according to their urgency requirement. So any intermediate sensor nodes which receive the forwarded packet can recognize the urgency level of a packet. We aimed at adding additional field in RTS packet which holds the number of urgent packet in queue of the sender. So receiver node reply with CTS to the sensor node with higher number of urgent packet. This scheme can reduce end-to-end delay of urgent packets.

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Appendix:

Appendix A: Simulation parameters (tcl script)

```
#====================================
#    Simulation parameters setup
#====================================
set val(chan)   Channel/WirelessChannel    ;# channel type
set val(prop)   Propagation/TwoRayGround   ;# radio-propagation model
set val(netif)  Phy/WirelessPhy            ;# network interface type
set val(mac)    Mac/ESMAC                  ;# MAC type
set val(ifq)    Queue/DropTail/PriQueue    ;# interface queue type
set val(ll)     LL                         ;# link layer type
set val(ant)    Antenna/OmniAntenna        ;# antenna model
set val(ifqlen) 50                         ;# max packet in ifq
set val(nn)     10                         ;# number of mobilenodes
set val(rp)     AODV                       ;# routing protocol
set val(x)      1072                       ;# X dimension of topography
set val(y)      544                        ;# Y dimension of topography
set val(energymodel)      EnergyModel ;# Energy model
set val(initialenergy)    initialEnergy ;# Initial energy in Joules
set val(stop)   500.0                      ;# time of simulation end
#====================================
#       Initialization
#====================================
set val(initialenergy) 1000 ;# Initial energy in Joules
Mac/ESMAC set syncFlag_ 1
Mac/ESMAC set dutyCycle_ 30
```

```
Mac/ESMAC set initialenergy 1000
Mac/ESMAC set nn_ $val(nn)
#====================================
#    Mobile node parameter setup
#====================================
$ns node-config -adhocRouting  $val(rp) \
            -llType        $val(ll) \
            -macType       $val(mac) \
            -ifqType       $val(ifq) \
            -ifqLen        $val(ifqlen) \
            -antType       $val(ant) \
            -propType      $val(prop) \
            -phyType       $val(netif) \
            -channel       $chan \
            -topoInstance  $topo \
            -agentTrace    ON \
            -routerTrace   ON \
            -macTrace      ON \
            -movementTrace  ON \
                -energyModel $val(energymodel) \
                -idlePower 1.0 \
                -txPower 1.0 \
                -rxPower 1.0 \
                -sleepPower 0.001 \
                -transitionPower 0.2 \
                -transitionTime 0.005 \
                -initialEnergy $val(initialenergy)
```

Appendix B: Running simulation and computing result using awk script