QoS-supported Energy-efficient MAC Protocol based on IEEE 802.11e (QEMAC) for Wireless Multimedia Sensor Networks

Author

Adeel Shahzad
MS-07 (Software Engineering)

Supervisor

Dr. Ghalib AsadUllah Shah
Assistant Professor

DEPARTMENT OF COMPUTER ENGINEERING
COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND ECHNOLOGY
ISLAMABAD.

September, 2010

QoS-supported Energy-efficient MAC Protocol based on IEEE 802.11e (QEMAC) for Wireless Multimedia Sensor Networks

Author

Adeel Shahzad

MS-07 (Computer Software Engineering)

A thesis submitted in partial fulfillment of the requirements for the degree of

MS (Computer Software Engineering)

Thesis Supervisor:

Dr. Ghalib AsadUllah Shah

Assistant Professor,

Department of Computer Engineering.

Thesis Supervisor Signature: ____

DEPARTMENT OF COMPUTER ENGINEERING

COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

September, 2010

ABSTRACT

The handiness of low-cost modest imaging sensors fostered the emergence of Wireless Multimedia Sensor Network (WMSN) applications i.e. traffic congestion avoidance, video surveillance, localization, telemedicine, and industrial process control systems. The above applications require not only guaranteed-support of QoS but also the energy efficient multimedia processing in the WMSN, which necessitates appropriate sensor MAC protocol. Since the need to minimize the energy consumption has driven most of the research in sensor networks so far, mechanisms to efficiently deliver application-level QoS, and to map these requirements to network-layer metrics such as latency and jitter, have not been primary concerns in mainstream research on sensor networks. In this thesis work, we propose an energy-efficient MAC protocol (QEMAC) that caters the Quality of Services for the multimedia heterogeneous environment with fairness feature. QEMAC is based on the latest IEEE 802.11e standard and enhances it for energy-conservation and fairness without violating QoS constraints to the wireless multimedia sensor networks. Simulation results reveal that QEMAC provide fairness and suffers low delay and jitter with efficient energy consumption as compared to the other QoS-aware sensory MAC protocols

UNDERTAKING

I certify that research work titled **"QoS-supported Energy-efficient MAC Protocol based on IEEE 802.11e for Wireless Multimedia Sensor Networks"** is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Adeel Shahzad

REG NO: 2007-NUST-MS PhD-CSE (E)-15

ACKNOWLEDGEMENTS

First of all Thanks to Allah who enabled me to present this thesis. After that my thanks go directly to my parents. They always worried about creating the necessary conditions for me to carry out my studies successfully. I deeply thank them for their love and patience for putting up with me all these years.

I would like to say bundle of thanks to my supervisor Dr. Ghalib A. Shah for his guidance, availability and also for giving me room for my imagination during the thesis work. I think without His support after the blessing of Majesty God I could not be able to complete my thesis.

I would also like to say thanks to one of my best friends and a class fellow Asif Usman who helped me out thoroughly in my thesis work. Finally I am grateful to all those who helped, encouraged, and guided me during my thesis work.

DEDICATION

This thesis is dedicated to my parents, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also and very specially dedicated to my respectable teacher and supervisor ***Dr. Ghalib Asadullah Shah****, who taught me that even the largest task can be accomplished if it is done one step at a time.*

"The task of the excellent teacher is to stimulate 'apparently ordinary' people to unusual effort. The tough problem is not in identifying winners: it is in making winners out of ordinary people."

K. Patricia Cross

TABLE OF CONTENTS

Abstract .... ………...ii

Acknowledgement iv

List of Figures viii

List of Tables...ix

List of Abbreviations x

Chapter I: Introduction...1

1.1Wireless Sensor Networks...1

1.2 Introduction to Wireless Multimedia Sensor Networks 2

1.3 MAC Layer in Wireless Multimedia Sensor Networks 4

1.4 Motivation ………………………………………….………………...5

1.5 Statement of the Problem 6

1.6 Objectives 8

1.7 Thesis Organization...8

Chapter II: Literature Survey………………………………….. 9

2.1 Introduction to MAC Protocol for WMSNs ……………… ………....9

2.2 Sensor-MAC(S-MAC)..9

2.3 WISE-MAC 10

2.4 SIFT..11

2.5 T-MAC/DS-MAC...12

2.6 Adaptive FEC Code Control Algorithm (AFECCCA).........................13

2.7 DMAC...14

2.8 MAC 802.11e..15

Chapter III: Proposed Approach 17
3.1 Introduction to Proposed Approach 17
3.2 IEEE MAC 802.11E 17
3.3 Design of QEMAC 20
3.3.1 Quality of Service with Fairness in EDCA 20
3.3.2 No Internal Collision 21
3.3.3 Dynamic Duty Cycling 21
Chapter IV: Experimental Results 24
4.1 Simulation Parameters and Results 24
4.2 Future Work 30
Chapter V: Methodology 32
5.1 Introduction 32
5.2 Script 32
5.3 Network Simulator-2(NS-2) 34
5.4 Trace File(.tr) 35
5.5 Matlab for Plotting Graph 35
5.6 Extending MAC 802.11b to 802.11e 36
6 References 39

LIST OF FIGURES

Number *Page*

Fig 01 Research Challenges in WMSNs..03

Fig 02 Traffic Differentiation and Priority Queueing in WMSNs 05

Fig 03 802.11e EDCA Multiple back-off for different Access Catogories 07

Fig 04 S-MAC Messaging Scenario 09

Fig 05 Wise-MAC Concept 10

Fig 06 DSMAC duty cycle doubling...13

Fig 06(b) A data gathering tree and its DMAC implementation....................15

Fig 07 EDCF proposed by 802.11e...17

Fig 08 TxOP depicting Contention Free Bursting …………………………....18

Fig 09 Comp. between Legacy and QEMAC EDCA Virtual

Access Mechanisms 21

Fig 10 Sleep\Awake Mechanism in QEMAC...23

Fig 11 Avg. Throughput Comp. between 11e, 11b and QEMAC Protocols .26

Fig 12 Avg. Delay Comp. between 11e, 11b and QEMAC Protocols...........27

Fig 13 Delay Comp. between 11e and QEMAC intra nodes (ACs) 28

Fig 14 Delay Comp. between 11e(M) & QEMAC(Q) intra nodes(ACs) 29

Fig 15 Borrowing Procedure in QEDCA...30

Fig 16 Process Block Diagram 32

LIST OF TABLES

Number *Page*

Table 01 CW and TxOP Time Limits according to AC type in FSA 20

Table 02 Simulation parts with Otcl scripts, topologies and Results...................................24

Table 03 Simulation Parameters 25

LIST OF ABBREVIATIONS

ACK	Acknowledgment
AIFS	Arbitration Interframe Spaces
CW	Contention Window
DCF	Distributed Coordination Function
DIFS	DCF Interframe Spaces
EDCF	Enhanced DCF
ITU-T	International Telecommunication Union – Telecommunication
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
MAC	Medium Access Control
PHY	Physical Layer
WLAN	Wireless Local Area Network
QoS	Quality of Service
RTS/CTS	Request to Send/Clear to Send
TXOP	Transmission Opportunity
NAV	Network Allocation Vector
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
ACs	Access Categories

BEB	Binary Exponential Backoff
QEMAC	QoS-supported Energy-conservation MAC

CHAPTER 1

INTRODUCTION

1.1 Wireless Sensor Networks (WSNs)

Emergence of Wireless Sensor Networks is fascinating the network research community and devising itself as a magnetic orbit of pursuit. Due to the advancement of Micro Electro Mechanical System (MEMS), the era of WSNs are turning to more and more lower-cost, multi-functional, lower-power, feasible, maturation and highly integrated digital electronics of wireless communications [1]. WSNs distinctively comprises of an enormous amount of sensors powered with batteries with the abilities of communication, sensing, and processing [2]. These electronic equipments consist of a system of circuits that appraises the ambient stipulates, like environmental surroundings e.g. light, humidity, temperature, etc. Processing on such output signals exposes the properties about objects location and/or the events befalling in the sensor's vicinity. The collected data is then sent by the sensors, normally through radio transmitters to a centralized station called sink, either directly or via multiple wireless hops [1, 3, 4]. The network of wireless sensors can be deployed over a battle field for military surveillance and reconnaissance, on a global scale for environmental monitoring and habitat study, in emergent environments for search and rescue, tracking of real time objects, infrastructure for health monitoring, smart homes to realization, or even in human bodies for patient monitoring etc. [1].

The superiority of the above adverted features also impose a bundle of limitations on the WSNs design such as scalability, production costs, fault tolerance, network topology, power consumption, operating environment etc. And these limitations have led to an intensifier research in the past few years that accosts the potency collaboration among the sensors in gathering and processing data. Deployment area has no existing infrastructure for either communication or energy in the most applications. Thence, a canonic requirement for sensor nodes is to survive with a throttled source of energy as a small but very smart form of battery [5]. This results in the sensors to remain active and alive for long duration of time period from several weeks to years. Nonetheless, the robust progress and development of embedded computing, sensors, MEMS and availability of cheap Complementary Metal Oxide Semiconductor (CMOS) microphones and cameras twined with the substantial progress in multimedia source coding techniques and distributed signal processing, allowed for the egression of so called Wireless Multimedia Sensor Networks (WMSNs).

1.2 Introduction to Wireless Multimedia Sensor Networks (WMSNs)

The amazedness of Wireless Multimedia Sensor Network (WMSN) [6] is a meshing of complected sensor nodes wirelessly which are equipped with multimedia devices, such as microphones and cameras, and having the ability to capture video and record the audio streams, images, and also the scalar sensor data. The promising WMSN comprises both type of applications i.e. military and civilians which require visual and audio information such as traffic control systems, Industrial process control and the disaster management systems like surveillance, law-enforcement reports, advanced health care delivery, etc. In such applications multimedia support has the potency of enhancing the collected information, enabling multi-resolution views, and enlarging the coverage range [24] i.e. the measurements of scalar data comparison.

In addition to the challenges faced by WSNs, WMSNs have also unique challenges which are mainly due to the characteristics multimedia data communication such as tolerable end-to-end delay, high bandwidth demand, real-time delivery, and proper frame loss rate and jitter. Moreover, unlike the nature of the multimedia applications that are typically producing a huge amount of data, there are many resource constraints in WMSNs that includes limited bandwidth, energy, memory, and processing capability because of the physically smaller size of the sensors. Hence, to use the network scarce resources in an efficient and fair manner and also to meet the QoS requirements, these research issues along with other attributes of WMSNs such as security and coverage become an interesting, and it should be considered at the communication protocol stack's different layers. In addition WMSNs have additional requirements such as in-node multimedia processing techniques (e.g., distributed multimedia data compression and source coding), and application-specific QoS requirements.

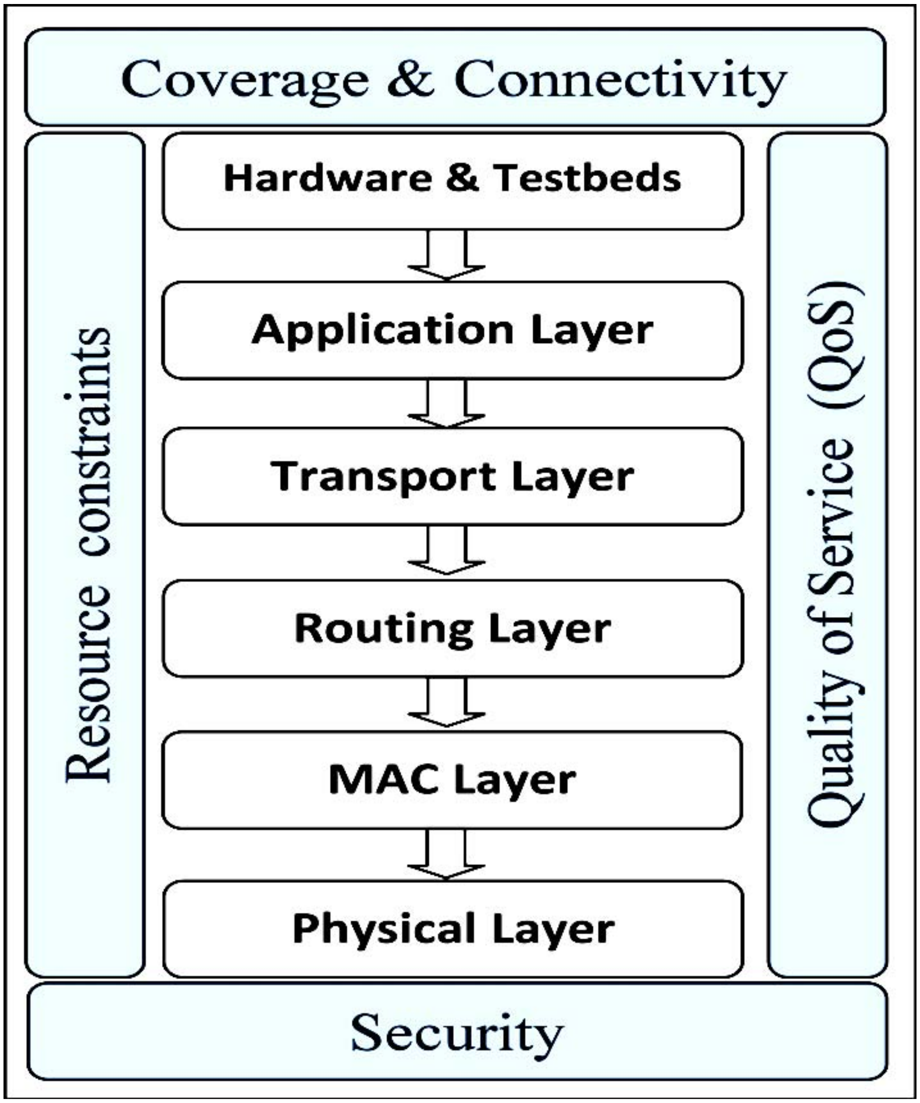


Figure 1. Protocol stack in WMSNs.

The above adverted challenges, characteristics, and WMSNs designing requirements open many future research directions to develop protocols, research issues and architectures, tested, devices, and algorithms to maximize the lifetime of the network while satisfying the various applications QoS-requirements.

In this research work, I developed a Quality-of-Service supported Energy-conservation MAC protocol based on 802.11e with fairness feature for WMSNs. Therefore in the next section I concisely elaborate the MAC layer in WMSN.

1.3 MAC Layer in WMSN

The vital role to play in wireless sensor networks is to design the highly reliable and efficient Medium Access Control (MAC) protocols. Schematically, with the minimal energy cost under a moderate network load condition the goal is to cater adequate transmission capacity. Survey in [8] exposes the eye catcher overview of the existing WSNs MAC protocols, unwrapping the application-specific diverse requirements and lack of standardization has divested wireless sensor networks from an existent medium access control protocol.

Now if we talk about WMSNs, MAC is an essential part to coordinate the channel access within the mesh of competing devices. It is worthy to achieve valuable QoS support ((i.e., transmission rate, fairness, bit error rate, delay, etc.) with efficient resource utilization that the MAC layer caters error-free, reliable data transfer with minimal retransmissions. By enforcing scheduling policies (Figure 2), error control, channel access, MAC layer attempts to accost these consequences. Hence, a proposal of MAC layer protocol for multimedia sensor networks should gratify the following features:

- Energy-efficient
- Transmission reliability,
- Minimal control overhead,
- Maximal network throughput,
- And more importantly, guarantee to a certain level of QoS support.
-

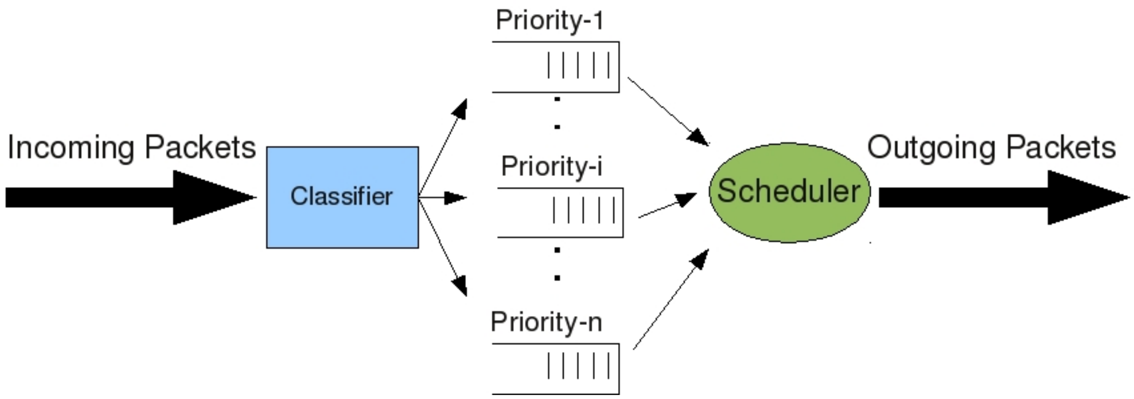


Figure 2. Priority Queuing and Traffic Differentiation in WMSNs.

1.4 Motivation

It is stated earlier, due to the small form factor of the sensor nodes they have limited power and need to be highly efficient to cater QoS support. To achieve that goal in the WMSNs, the MAC protocols should be scalable and robust to be highly energy efficient and QoS supportive.

Eventually, it is generally hard (or impractical) to charge/replace the exhausted battery, which gives way to the primary objective of maximizing node/network lifetime, leaving the other performance metrics as secondary objectives. Therefore, the medium access decision within a dense network composed of nodes with low duty-cycles is a hard problem that must be solved in an energy-efficient manner. Thus, the design of communication protocols, particularly MAC and routing protocols, are mainly charmed by the nodes energy conservation to achieve the long-lasting life of the sensory meshing environment [9], [10].

Although QoS-enabled MAC mechanism suitable to multimedia applications have been defined by the 802.11e standard but it is not specifically designed for the WMSN. Unlike other wireless networks, the size and cost of the sensor nodes are the primal design goals that limit the node resources such as processing power, memory, energy, transmission range and bandwidth. Therefore, the medium access decision within an obtuse mesh composed of nodes with low duty-cycles is a hard problem that must be solved in sufficient and energy-efficient way.

In IEEE 802.11e standard, EDCF is well defined for the QoS support but it is not concerned with the energy saving issue and fairness feature, since it is not specifically designed for the Sensors environment. Therefore the question, how to get an energy-efficient MAC protocol caters fairness at the same time with the capability of QoS support for the WMSN, still needs to be answered.

The work reported in this thesis aims at designing a QoS-supported Energy-efficient MAC protocol (QEMAC) which not only caters the QoS on the basis of 802.11e MAC protocol as well as provides the fairness feature in which not only higher priority data traffic is considered but also lower level i.e. which does not include voice or video traffic take part step by step. The fairness feature is provided in the QEMAC by enhancing the 802.11e MAC protocol.

1.5 Statement of the Problem

To provide an energy-efficient MAC Protocol with the ability of QoS support to the Multimedia Wireless Sensor Network based on IEEE 802.11e standard with the fairness feature. Since, in the legacy IEEE 802.11 standard, QoS support to the wireless networks was not provided well as the DCF used in it, takes every node in the network with equal priority. The QoS support was provided by enhancing the DCF, in which the stations are categorized with their priorities assigned to them according to their work loads. The technique implies that a station has to wait for accessing the channel according to its priority like it is not of fixed time length as in the old IEEE 802.11 standard, i.e every station in the IEEE 802.11 wait for DCF time before starting to communicate with the other station. Whereas in the latest IEEE 802.11e standard a station waits for SIFS (Short Inter Frame Space) time with the highest priority and then for AIFS (Arbitrary Inter Frame Space) time which could be extended step by step according to the priority of the stations as shown in the figure 3.

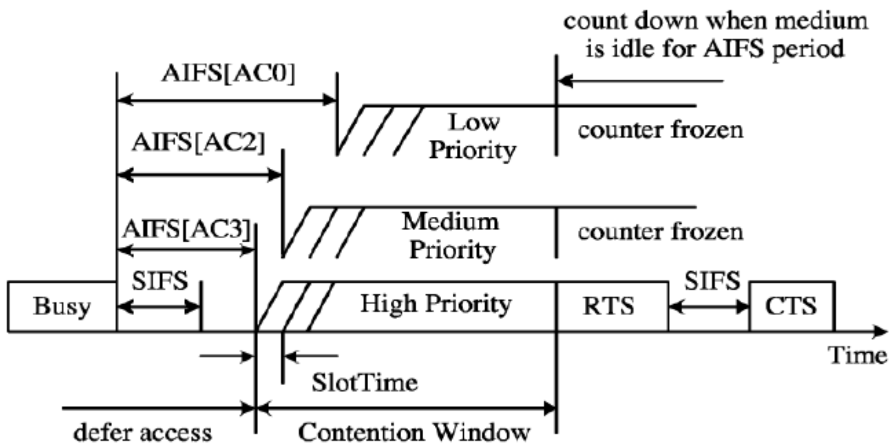


Figure 3: 802.11e EDCA Multiple back-off for different Access Categories

The AIFS is used only in the EDCA (Enhance Distributed Channel Access) which has the time length greater than or equal to the legacy DCF time length. By using this type of variable length waiting time, QoS like greater throughput, less jitteriness, low latency and collision avoidance could be achieved enormously which are most important requirements for the finer performance of multimedia applications. It is also a good tactic to achieve the QoS support in the wireless sensor network but the problem occur when we talk about the energy saving which is the most important requirement for the sensor networks, because of sleep/awake mechanism is not available in the IEEE 802.11e standard.

We propose a **QoS Energy-Efficient MAC Protocol based on IEEE 802.11e for WMSN(QEMAC)**, in which we will modify the IEEE 802.11e standard by merging the sleep/awake mechanism in the EDCA as well as fairness feature. By which we will not only save the energy consumption of the sensors and the great support of QoS for the WMSN but by featuring the fairness in QEMAC, lower priority data traffic also get the channel access periodically and does not stuck at all as the higher priorities always or most of the time get the channel access in the 802.11e MAC protocol.

1.6 Objectives

- To provide an energy efficient MAC protocol to achieve reliability
- To provide QoS support for the WMSN's voice and video type data traffics.
- To provide fairness by which each type of data traffic could get accessibility of the channel periodically on the basis of their priorities assigned to them.

1.7 Thesis Organization

This thesis is organized in 5 chapters and references. The first chapter consists of introduction to WSNs and WMSNs and then discusses the problem statement and solution to QoS, energy-conservation and fairness related protocol issues and objectives and motivation to the proposed work. The second chapter consists of literature survey on some of the past work on MAC protocols for WMSNs. In the third chapter I elaborate my proposed approach that how it achieve QoS support with fairness feature in the WMSNs. In the fourth chapter I discuss the experimental results of the proposed approach and comparisons with legacy MAC and 802.11e MAC protocols, and then conclusion and future work in this area. And in the last chapter I give the short detail about the methodology used to evaluate my results of my research work. References section is written in the end of this thesis.

Chapter 2

LITERATURE SURVEY

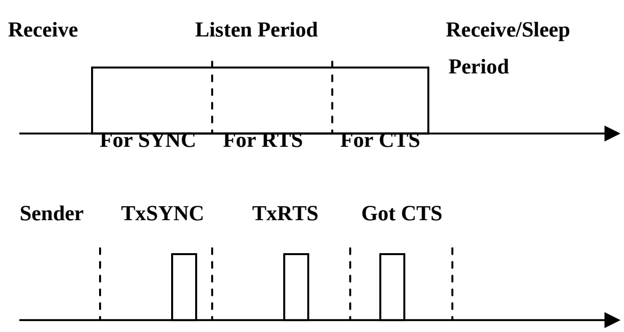
2.1 Introduction to MAC Protocols

In this section we will discus the related work of energy-efficient MAC Protocols, some of which are also provided QoS support to the Wireless Sensor Networks but there is not a single MAC protocol which provide the QoS with fairness at the same time as QEMAC just combined both of these necessary features for WMSNs. Sensor MAC (S-MAC), Wise MAC, SIFT, and Timeout-MAC (T-MAC)/ Dynamic Sensor-MAC (DSMAC) are some of the related MAC protocols defined for sensor networks; here we will discuss them in detail.

2.2 Sensor-MAC (S-MAC)

The basal figment behind the S-MAC [13] is to manage the synchronizations locally and based on these synchronizations schedule the periodic sleep/listen mechanism. Virtual constellation is formed by the Neighboring nodes to set up a common sleep schedule. When two neighboring nodes reside in two different virtual clusters wake up at listen periods of both clusters, contravene the scheduling of their own cluster.

SYNC packet is broadcasted to the neighboring nodes to accomplish the exchanges of schedule. Figure 4 depicts a sample *sender-receiver* communication. RTS/CTS packet exchanges are used for unicast type data packets. Collision avoidance (CS in the fig) is achieved by carrier sense.



CS CS Send data

Figure 4: Messaging Scenario of Sensor-MAC

Advantages [20] of S-MAC are the energy wasting problem caused by idle listening is reduced by sleep schedules, since it was not available in the legacy IEEE 802.11. Furthermore, with sleep schedule announcements time synchronization overhead may be prevented

And the *Disadvantages* [20] are Broadcast data packets do not use RTS/CTS which increases collision probability. Adaptive listening incurs overhearing or idle listening if the packet is not destined to the listening node. Under the variable traffic load the efficiency of the algorithm decreases due to the fixed time length of Sleep/Listen periods.

2.3 Wise-MAC

Wise MAC [15] was the first protocol requires only a single-channel for both data and control packets to decrease idle listening by using non-persistent CSMA (np-CSMA) with preamble sampling [14]. A preamble predates each data packet for alarming the receiving node in the preamble sampling technique. Wise MAC introduces a method to determine the length of the preamble dynamically, to reduce the power consumption incurred by the predetermined fixed-length preamble. Figure 5 depicts the concept of Wise MAC.

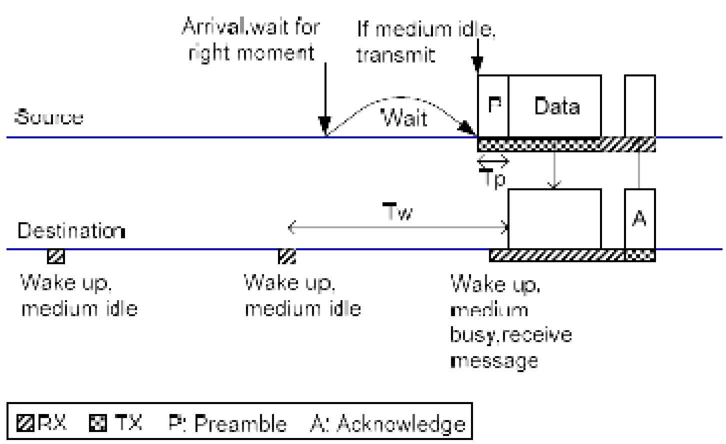


Figure 5: Wise MAC Concept

Advantages [20] Wise MAC executes better results as compare to the above described Sensor-MAC editions [15]. And under variable traffic circumstances, its dynamic preamble length adaptation results in better performance. Furthermore, clock drifts are dealt in the protocol definition to extenuate the external time synchronization requirement.

Disadvantages [20] are the different sleep and a wake-up time for each neighbor of a node because of sleep/listen scheduling is not centralized. Since in the sleep mode broadcasted packet will be buffered for neighbors and delivered many times as each neighbor wakes up, therefore this problem proves more crucial for the broadcasting type communication. And due to this redundant transmission, power consumption and higher latency will occur, which campaigns the serious drawbacks for the multimedia applications. In Wise MAC, hidden terminal problem occur due to the non-persistent CSMA, which causes the collisions when one node transmits the preamble to a node that is already receiving data from another node. It happens because the preamble sender is not come within the range of the already communicating nodes.

2.4 SIFT

It is a MAC protocol [16] proposed for event-driven sensor network environments. In SIFT the 1st report *R* of node *N* will be transmitted with low latency, when an event is sensed on the channel. In SIFT the time is divided into CW contention slots immediately after any transmission, whose duration is usually several orders of magnitude smaller than the time it takes to send a data packet. Immediately after any collision or transmission, each station picks a random contention slot. Collision will occur if two nodes relay at the same time, when they both pick the same slot. When a collision occurs, most CSMA protocols specify that the colliding nodes double their value of CW, known as binary exponential backoff (BEB). Comparing with legacy 802.11 MAC protocol [16] it is proved that Sift decreases latency substantially when a report is being tried to be sent by many nodes. Sift is a method proposed for contention slot assignment algorithm based on CSMA/p* [17] (where p* is non-uniform probability to minimize latency optimally) to be exist with other MAC protocols like WISE MAC or Sensor MAC.

Advantages [20] by using many traffic sources, very abject latency is attained in SIFT. Slightly consumption of energy to get lower latency is a compromise factor in the WMSNs, if latency is an important parameter. It could be tuned to incur less energy consumption. The high energy consumption is a result of the arguments indicated below.
Disadvantages [20] are increased idle listening caused by listening to all slots before sending and increased overhearing. When there is an ongoing transmission, nodes must listen till the end in order to contend for the next transmission which causes overhearing. Besides, system-wide time synchronization is needed for slotted contention windows. That is why; the implementation complexity of Sift would be increased for the protocols not utilizing time synchronization.

2.5 T-MAC/DSMAC

Static sleep-listen periods of S-MAC result in high latency and lower throughput as indicated earlier. Timeout-MAC (T-MAC) [18] is proposed to enhance the poor results of S-MAC protocol under variable traffic load. In T-MAC, *listen* period ends when no activation event has occurred for a time threshold *TA*. The decision for *TA* is presented along with some solutions to the *early sleeping* problem defined in [18]. Variable load in sensor networks are expected, since the nodes that are closer to the sink must relay more traffic. Although T-MAC gives better results under these variable loads, the synchronization of the listen periods within virtual clusters is broken. This is one of the reasons for the *early sleeping* problem.

Dynamic Sensor-MAC (DSMAC) [19] adds dynamic duty cycle feature to S-MAC. The aim is to decrease the latency for delay-sensitive applications. Within the SYNC period, all nodes share their one-hop latency values (time between the reception of a packet into the queue and its transmission). All nodes start with the same duty cycle. Figure 6 conceptually depicts DSMAC duty cycle doubling. When a receiver node notices that average one-hop latency value is high, it decides to shorten its sleep time and announces it within SYNC period. Accordingly, after a sender node receives this sleep period decrement signal, it checks its queue for packets destined to that receiver node. If there is one, it decides to double its duty cycle when its battery level is above a specified threshold.

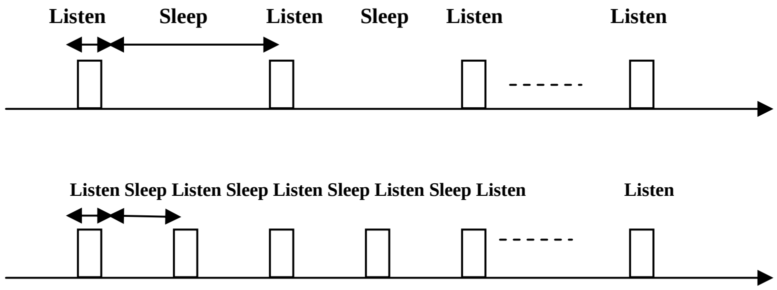


Figure 6: DSMAC duty cycle doubling

The duty cycle is doubled so that the schedules of the neighbors will not be affected. The latency observed with DSMAC is better than the one observed with S-MAC. Moreover, it is also shown to have better average power consumption per packet.

2.6 Adaptive FEC Code Control Algorithm (AFECCCA) [21]

Even thou, by the cause of mobility contraption and the betterment of the relay speed the popularity of wireless network is dispersed rapidly. But the wired networks are far away better than the wireless networks in the transmission efficiency because of the habitual propagation errors, namely high bit error rate (BER) of the wireless networks. The BER is also be reckoned by the great vacillation due to the little movements of the transmitters, receivers, and the other obstructions in the wireless networks. In order to protest against this high and widely vacillation error rate, wireless networks use both prevention (by choosing an error resistant with low-speed modulation method) and correction (by employing forward error correction (FEC) on top of ARQ to dilute the number of retransmissions) techniques in their physical and data link layers respectively. However, the wireless networks should dynamically adjust the amount of FEC codes when the BER channel deviates widely for getting more performance improvement. Because the amount of BER channel does not remain constant therefore the deterministic selection of pertinent FEC code size disgraces the performance of the network.

And this problem is nicely overwhelmed by introducing Adaptive FEC code control (AFECCC) algorithm [21]. AFECCC algorithm improve the performance by dynamically adapts the amount of FEC codes when the BER channel deviates widely.

FEC code size is adjusted according to the channel status which is implicitly indicated by acknowledgment packets arrival. When a packet is lost, it ascends to the higher FEC level otherwise descends to the lower FEC level in a multiplicative increase additive decrease (MIAD) way. Before dropping to the lower one, the stay time on each level is dynamically decided to maintain the balancing among the previous success rate. The more frequently AFECCC adopts a level, the longer it stays at this level. Thus, instead of retransmitting the whole packet it is better to transmit the additional FEC code which is a lot smaller than the original packet size. The simulation practices with the various theoretical channel models and also experiments over sensor networks shows that AFECCCA provide much better performance not only than any of the previous static FEC algorithms but also give the better results over some conventional dynamic FEC algorithms. So QoS support somehow is provided terrifically by this algorithm. Since we know that the Energy efficiency is the most important requirement of the sensor network which is not concerned in this algorithm.

2.7 DMAC

In WSNs Converge cast is the highly ascertained communication pattern. The single directional paths to the sink node from the possible sources are normally represented by data gathering trees. Attaining very low latency is the corpus intend of DMAC [28] by consuming less energy in WSNs. Figure 6(b) depicts the DMAC in which slots are assigned to the bulk of nodes based on data gathering trees. DMAC is the enhanced form of Slotted Aloha algorithm. Hence, the child nodes contend for the channel while their parent node is in receiving state. The nodes that are successive in the data transmission path are assigned subsequent slots to achieve the low latency.

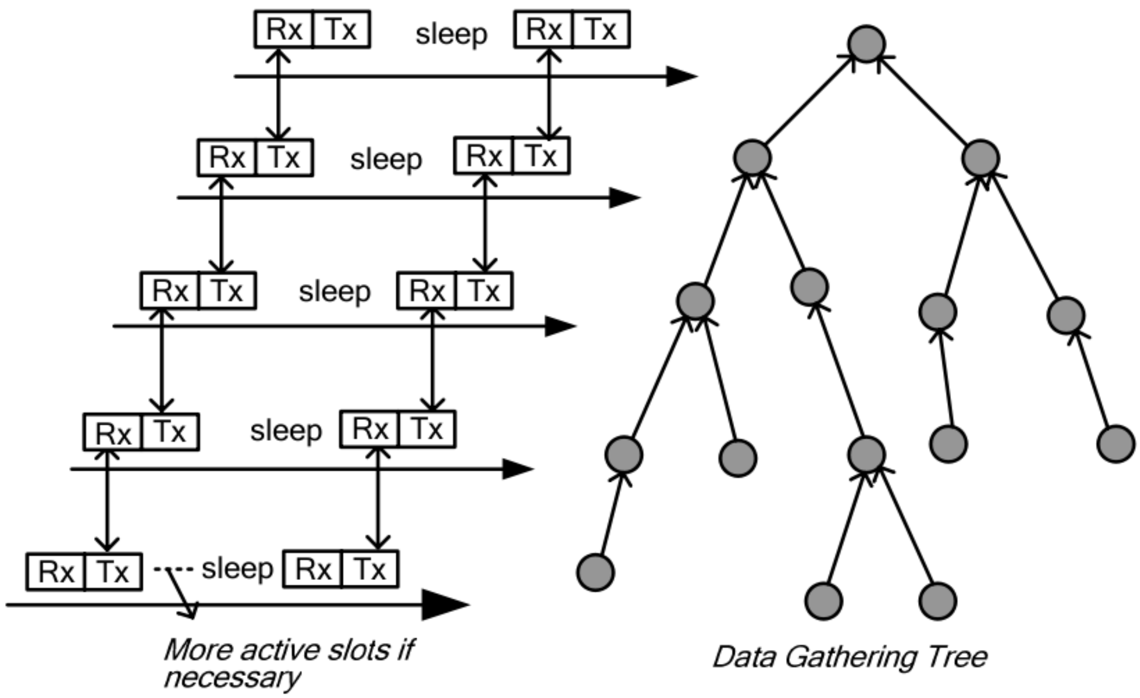


Fig. 6(b). A data gathering tree and its DMAC implementation [28]

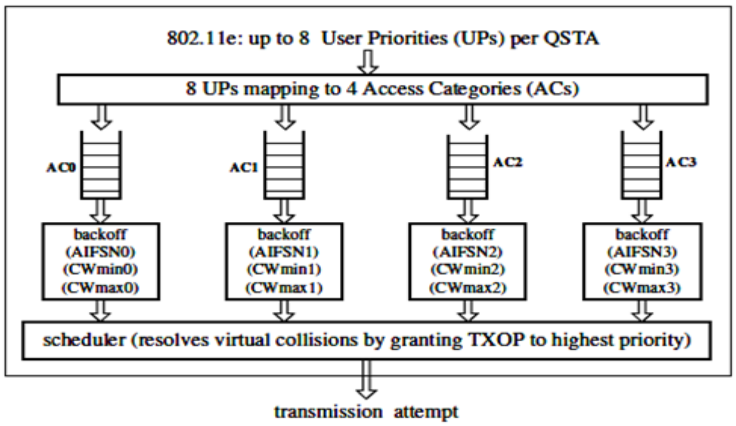
Advantages: low latency is achieved much well than other sleep/listen assignment methods in DMAC. Thus, the scenarios in which latency could be one of the most important factors, DMAC is a valuable candidate.

Disadvantages: in DMAC collision avoidance is not managed well. Therefore, when a number of nodes that has the same level in the tree, try to transfer data to the same level of node, collisions will occur which is a possible scenario in event-triggered sensor networks. Also in DMAC, there may not be data transferring paths are known in advance, which results in preventing data gathering tree formation.

2.8 MAC 802.11e

QoS is supported in IEEE 802.11e by innovating priority mechanism. Different types of data traffic are assigned different priorities to cater the QoS, intead, in legacy 802.11 protocol each type of data trafic is treated evenly. The IEEE 802.11e standard [23] delineates the Hybrid Coordination Function (HCF) which enables prioritized and parameterized Quality-of-Service (QoS) services at the MAC layer. The HCF combines both distributed contention-based channel access mechanism, referred to as Enhanced

Distributed Channel Access (EDCA), and a centralized polling-based channel access mechanism, referred to as HCF Controlled Channel Access (HCCA). Since QEMAC is designed for distributed WMSN, we confine our analysis to the EDCA scheme, which uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and slotted Binary Exponential Backoff (BEB) mechanism as the basic access method.



Above Figure depicts that how EDCF delimitates multiple Access Categories (ACs) to support MAC-level QoS and prioritization with Arbitration Interframe Space (AIFS) values, AC-specific Contention Window (CW) sizes, and Transmit Opportunity (TXOP) limits. EDCF is an enhaced form of IEEE 802.11 Distributed Coordination Function (DCF) with the extension of QoS support. The preeminent enhancement to cater QoS support is that EDCF differentiates data frames by assigning them different priorities and maps them to the ACs accordingly which then buffered in separate queues at each station. If there is a packet ready for transmission in the MAC queue of an AC, the EDCA function must sense the channel to be idle for a complete AIFS before it can start the transmission. If the channel is idle when the first packet arrives at the AC queue, and if the channel is not to be sensed as idel then the backoff procedure is called following the completion of AIFS before the transmission of this packet. A uniformly distributed random integer, namely a backoff value, is selected from the range [0, W]. The backoff counter is decremented at the slot boundary if the previous time slot is idle. If the channel be sensed busy at any time slot during AIFS or backoff, the backoff procedure will be suspended at the current backoff value. The backoff resumes as soon as the channel is sensed to be idle for AIFS again. When the backoff counter reaches zero, the packet is transmitted in the following slot. The value of W depends on the number of retransmissions the current packet experienced. The initial value of W is set to the AC-specific CWmin. If the transmitter cannot receive an Acknowledgment (ACK) packet from the receiver in a timeout interval, the transmission is labeled as unsuccessful and the packet is scheduled for retransmission. At each unsuccessful transmission, the value of W is doubled until the maximum AC-specific CWmax limit is reached. The value of W is reset to the AC-specific CWmin if the transmission is successful, or the retry limit is reached thus the packet is dropped. The higher priority ACs can either transmit or decrement their backoff counters while lower priority ACs are still waiting in AIFS. This results in higher priority ACs facing a lower average probability of collision and relatively faster progress through backoff slots.

The main advantage of MAC 802.11e is the support of QoS to the multimedia applications where the disadvantage is not the fairness feature is catered in 802.11e as some time in multi type application environment the lower priority nodes stuck for a long time.

CHAPTER 3

PROPOSED APPROACH

3.1 Introduction to Proposed Approach

QEMAC is designed for QoS support to the multimedia applications on the basis of IEEE 802.11e MAC protocol as well as fairness feature with energy-conservation for the Wireless Multimedia Sensor Networks. The objectives of the proposed QoS supported energy-efficient MAC (QEMAC) protocol is twofold; support of guaranteed QoS for multimedia applications in WMSN with fairness feature and energy conservation. The QoS support is based on IEEE 802.11e and adaptive duty cycling is employed to achieve energy efficiency where fairness is achieved by enhancing EDCA TxOP mechanism. Prior to the discussion on the design of QEMAC, we first describe the QoS approach adopted in IEEE 802.11e.

3.2 IEEE 802.11e [7]

QoS is supported in IEEE 802.11e by innovating priority mechanism. Different types of data traffic are assigned different priorities to cater the QoS, instead, in legacy 802.11 protocol each type of data traffic is treated evenly. The IEEE 802.11e standard [23] delineates the Hybrid Coordination Function (HCF) which enables prioritized and parameterized Quality-of-Service (QoS) services at the MAC layer. The HCF combines both distributed contention-based channel access mechanism, referred to as Enhanced Distributed Channel Access (EDCA), and a centralized polling-based channel access mechanism, referred to as HCF Controlled Channel Access (HCCA). Since QEMAC is designed for distributed WMSN, we confine our analysis to the EDCA scheme, which uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and slotted Binary Exponential Backoff (BEB) mechanism as the basic access method.

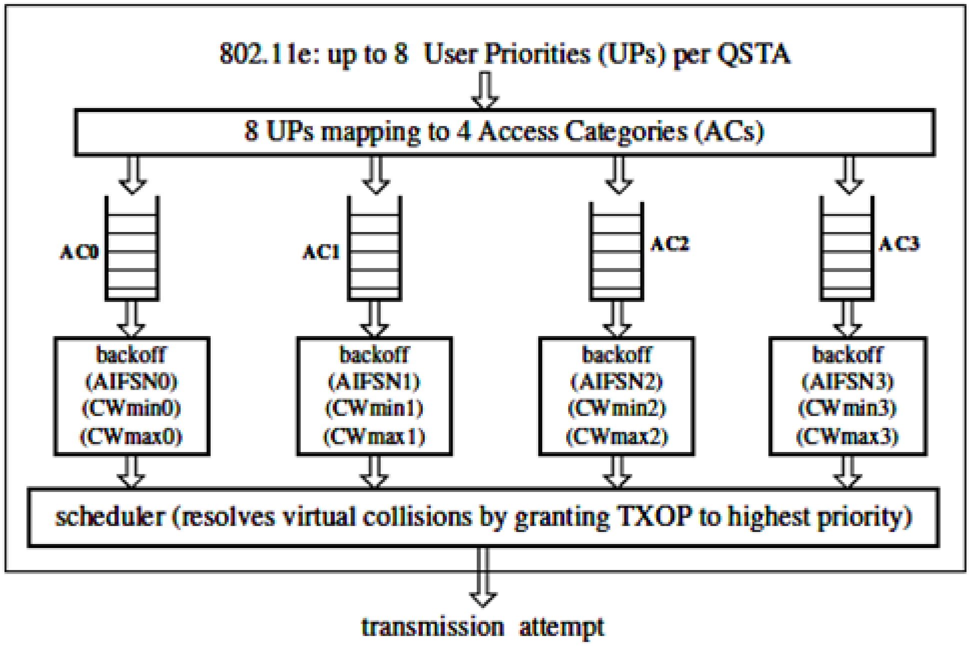


Fig. 7: EDCF proposed by 802.11e [22]

Fig. 7 depicts that how EDCF delimitates multiple Access Categories (ACs) to support MAC-level QoS and prioritization with Arbitration Interframe Space (AIFS) values, AC-specific Contention Window (CW) sizes, and Transmit Opportunity (TXOP) limits. EDCF is an enhanced form of IEEE 802.11 Distributed Coordination Function (DCF) with the extension of QoS support. The preeminent enhancement to cater QoS support is that EDCF differentiates data frames by assigning them different priorities and maps them to the ACs accordingly which then buffered in separate queues at each station. In EDCA contention for the access of the channel of each ACi (0 ≤ i ≤ imax, imax = 3 [23]) having its own parameters within a station is independent with each other. Levels of services are provided through different assignments of the AC-specific EDCF parameters; AIFS, CW, and TXOP limits. If there is a packet ready for transmission in the MAC queue of an AC, the EDCA function must sense the channel to be idle for a complete AIFS before it can start the transmission, which is evaluated by using the MAC Information Base (MIB) parameters as: AIFS = SIFS + AIFSN × Tslot, where AIFSN is the AC-specific AIFS number, SIFS is the length of the Short Interframe Space, and Tslot is the duration of a time slot. If the channel is idle when the first packet arrives at the AC queue and if the channel is not to be sensed as idle then the backoff procedure is called following the completion of AIFS before the transmission of this packet. A uniformly distributed random integer, namely a backoff value, is selected from the range [*0, W*]. The backoff counter is decremented at the slot boundary if the previous time slot is idle. If the channel be sensed busy at any time slot during AIFS or backoff, the backoff procedure will be suspended at the current backoff value. The backoff resumes as soon as the channel is sensed to be idle for AIFS again. When the backoff counter reaches zero, the packet is transmitted in the following slot. The value of W depends on the number of retransmissions the current packet experienced. The initial value of *w* is set to the AC-specific *CWmin*. If the transmitter cannot receive an Acknowledgment (ACK) packet from the receiver in a timeout interval, the transmission is labeled as unsuccessful and the packet is scheduled for retransmission. At each unsuccessful transmission, the value of W is doubled until the maximum AC-specific *CWmax* limit is reached. The value of W is reset to the AC-specific *CWmin* if the transmission is successful, or the retry limit is reached thus the packet is dropped.

The higher priority ACs is assigned smaller AIFSN. Therefore, the higher priority ACs can either transmit or decrement their backoff counters while lower priority ACs are still waiting in AIFS. This results in higher priority ACs facing a lower average probability of collision and relatively faster progress through backoff slots. Moreover, in EDCA, the ACs with higher priority may select backoff values from a comparably smaller CW range.

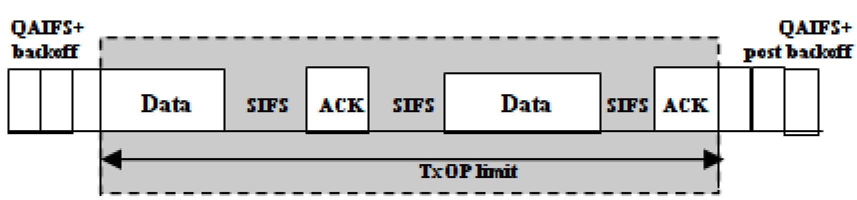


Fig. 8: TxOP depicting Contention Free Bursting

Upon gaining the access to the medium, each AC may carry out multiple frame exchange sequences as long as the total access duration does not go over a TXOP limit as shown in the Fig. 8. Within a TXOP, the transmissions are separated by SIFS. Multiple frame transmissions in a TXOP can reduce the overhead due to contention. A TXOP limit of zero corresponds to only one frame exchange per access. An internal (virtual) collision within a station is handled by granting the access to the AC with the highest priority. The ACs with lower priority, suffering from a virtual collision, run the collision procedure as if an outside collision has occurred.

3.3 Design of QEMAC

An enhancement in 802.11e MAC protocol is made to adapt it for WMSNs. Since energy conservation is the most crucial issue for the sensory networks, we add a dynamic sleep/awake mechanism which save the energy consumption without violating the QoS constraints. QEMAC also handles the internal collision and cater some sort of security mechanism as well as fairness feature to provide much better QoS to WMSNs. We discourse the contingents in the following section.

3.3.1 QoS with Fairness in EDCA – In the Fig. 2.1, EDCF is depicted in which TxOP time is allotted to the AC that wins the channel access, according to its priority. There are still some serious problems like internal collision, no option to continue interrupted real time communications until it intends and win the channel again. For example if the highest priority AC wins the channel access and TxOP is assigned to it for sending some frames which could not be enough for the completion of its transmission. But it must have to pause its transmission after the end of TxOP time limit and again have to be intended for the channel access to continue its residual transmission. QEMAC eliminates these problems by enhancing the scheduler algorithm for assigning TxOP time limit to the ACs by providing better flexibility according to their priorities, i.e. facilitating an AC to continue its communication without doing intention for the channel access after the end of its TxOP time by borrowing from the other ACs if any of them could have spare time slots in their allocated TxOP. Another important feature in QEMAC is to provide fairness by giving access to the channel to each AC turn by turn from the higher priority to lower priorities as shown in the Fig. 9(b) below. Also in QEMAC EDCA, CW size is assigned according to the priority of ACs, so that every lower priority AC's CW_{min} size is started from the CW_{max} size of its upper priority. Thusly, much better QoS is provided with fairness in QEMAC by enhancing the 802.11e scheduler algorithm. Fairness Schedule Algorithm (FSA) assigns TxOP to ACs on the basis of how much frames could be sent in a single TxOP time limit as shown in the table below, where δ is value assigned according to the traffic of the network.

AC Type	**Size of CW**	**Frames could be sent in a single TxOP time limit**
AC_VO	0-a	δ frames
AC_VI	a-b	δ/2-4 frames
AC_BE	b-c	δ/4-8 frames
AC_BK	c-d	δ/8-16 frames

Table 1: CW and TxOP time limits according to AC type in QEMAC

3.3.2 No Internal Collision – In the Fig. 9, it is shown that in the legacy EDCA (Fig. 9(a)) there are chances of internal collision by which real time communications could be interrupted and performance could be decreased because of latency problems. The problem is overcome in the QEMAC EDCA as shown in the Fig. 9(b), there can never be internal collision by the cause of giving the access to each AC turn by turn. Where the higher ACs get more time as compare to the lower ones but it is not that the lower categories can be stuck because of the continue access of the higher priority ACs.

The Fig. 9 shows the comparison between the legacy and QEMAC EDCA access mechanism in which it is clearly depicts that QEMAC caters much better QoS support by avoiding internal collision with the feature of fairness.

3.3.3 Dynamic Duty Cycling – Preserving the energy of the sensors is one of the most significant requisite for the sensory networks. There are several available MAC protocols for sensor networks which cater the beauty of energy conservation but most of them without caring about the QoS support. The beauty of proposed MAC protocol is to provide the best QoSs because the stem of our protocol is 802.11e which is peculiarly designed for supporting the best QoS to the Wireless Networks. The need to vanquish over the energy consumption problem without violating the QoS restrain is exquisitely achieved by introducing the dynamic duty cycling (sleep/awake mechanism) on the bases of AC priorities.

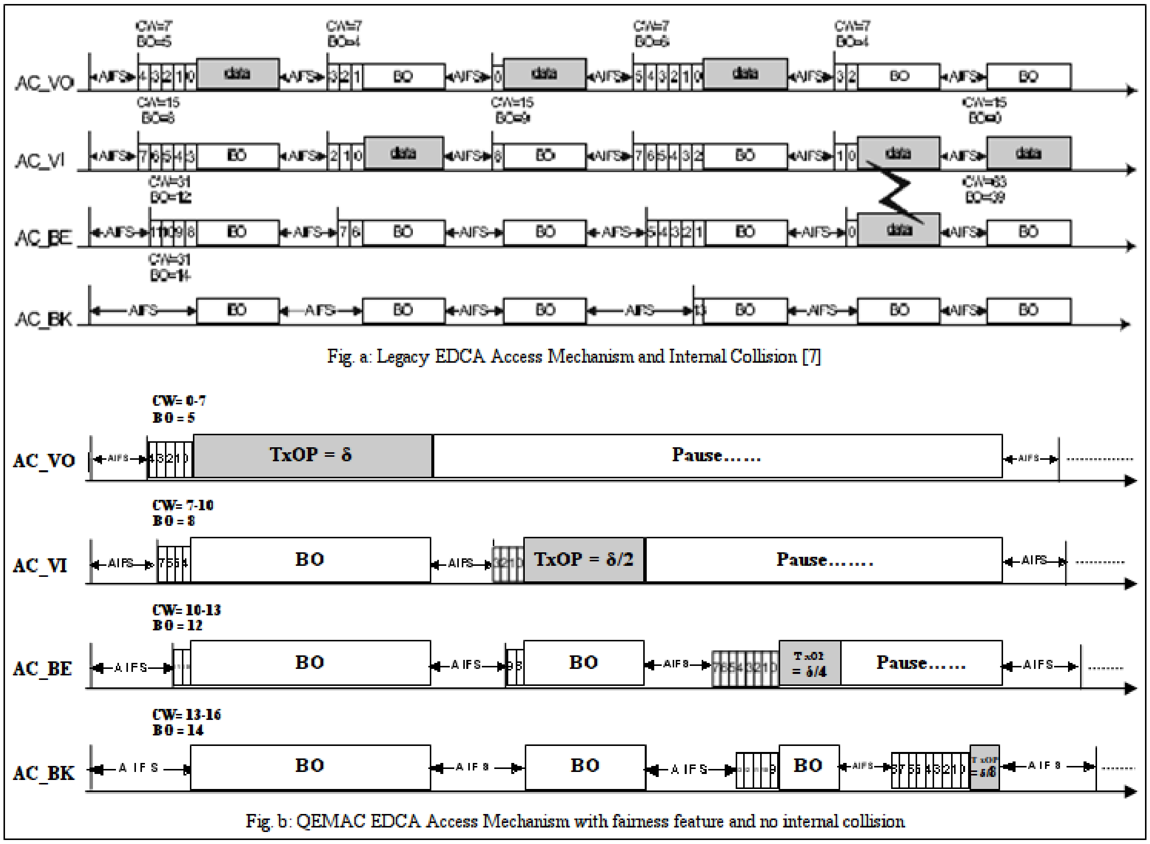


Fig. a: Legacy EDCA Access Mechanism and Internal Collision [7]

Fig. b: QEMAC EDCA Access Mechanism with fairness feature and no internal collision

Fig. 9: Comparison between Legacy and QEMAC EDCA Virtual Access Mechanisms

Since EDCA scheme uses CSMA/CA mechanism as the basic access method, in which CSMA/CA can optionally be supplemented by the exchange of a **Request to Send** (RTS) packet sent by the sender, and a **Clear to Send** (CTS) packet sent by the intended receiver, alerting all nodes within range of the sender, the receiver, or both, to keep quiet for the duration of the main packet. This is known as the IEEE 802.11 RTS/CTS exchange.

As we discussed in the previous section that QEMAC provides fairness feature by which each AC will get the access from the higher to lower priorities without any internal collision. And assigning the TxOP to an AC means to transfer a fix number of packets if it has, not a fix time limit. Thus time of two TxOP of same packets length could vary on the basis of their frame lengths and the interruptions faced by the same ACs from the other nodes. Therefore in QEMAC, TxOP is used for the avoidance of internal collision not for the sleep/awake mechanism. The sleep/awake mechanism depends on the RTS/CTS exchange which could be used multiple times in a single TxOP on the basis of the destination addresses of the frames to be sent. is For example in the Fig. below node B's AC get the access and it is assigned TxOP of 8 frames length.

The sleep/awake timings will vary from highest priority to lowest priority AC. Thusly, for real time multimedia packets, with very stringent delay guarantee, there would be least idle time and more energy consumption as compare to the low priority ACs, the objective is to reduce the energy consumption while sacrificing some delay and throughput. Hence, the sensor nodes periodically need to check the packets received and adjust the idle time based on the *traffic category dominating* the received packets. Fig. 10 depicts the mechanism of dynamic duty cycling, is being used in QEMAC.

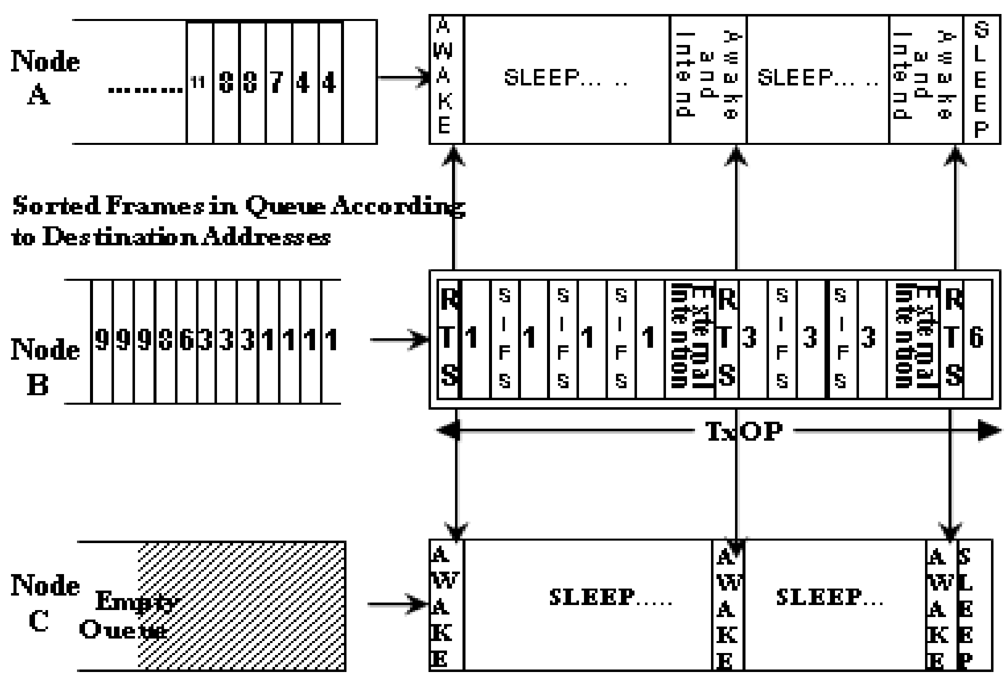


Fig. 10: Sleep\Awake Mechanism in QEMAC

CHAPTER 4

EXPERIMENTS AND RESULTS

4.1 Simulation Parameters and Results

In this section, we evaluate the performance of QEMAC by comparing the results with the existing protocols 802.11b and 802.11e MAC protocols. The protocol is implemented in ns2 [25] which is a scalable discrete event simulator. Basically, there are two part of simulation to get the results (Table 3.1). First part is simulation between legacy 802.11b, 802.11e and QEMAC protocol meanwhile second part is simulation of Access Categories in 802.11e and QEMAC. The final results of this work are graphs of two metrics computed from the OTcl scripts. These metrics are average throughput and average delay. From these metrics the graphs are plotted and evaluations are made from these graphs.

	Simulation	
	Part I	**Part II**
Otcl script	802.11b vs 802.11e vs QEMAC	802.11e with individual traffic type vs QEMAC with individual traffic type
Topology	Scenario 1	Scenario 2
Results and discussion	802.11b vs 802.11e vs QEMAC	802.11e with individual traffic type vs QEMAC with individual traffic type

Table 4.1. Simulation parts with Otcl scripts, topologies and Results

Parameter	Value
MAC Layer	IEEE 802.11/11e
Nodes	3
Node placement	Random
Field Area(X-Y Plane)	500-1000
Simulation time	100-500 sec
Packet Size	1024 bytes
Data type	Voice/video/background

Table 4.2. Simulation Parameters

Performance of the proposed QEMAC protocol design is evaluated using network simulator ns-2 and traffic scenario files are generated by implementing the source coding algorithm in MATLAB. The simulation scenario consists of 3 mobile nodes having different kind of trafic voice, video and background data deployed in 600m by 600m square field. Varying the TxOP frame size in QEMAC, average throughput and delay is compared with legacy MAC 11b and 11e protocols with all the mobile nodes. Also throughput and delay is compared with each AC in of QEMAC and 11e MAC protocols.

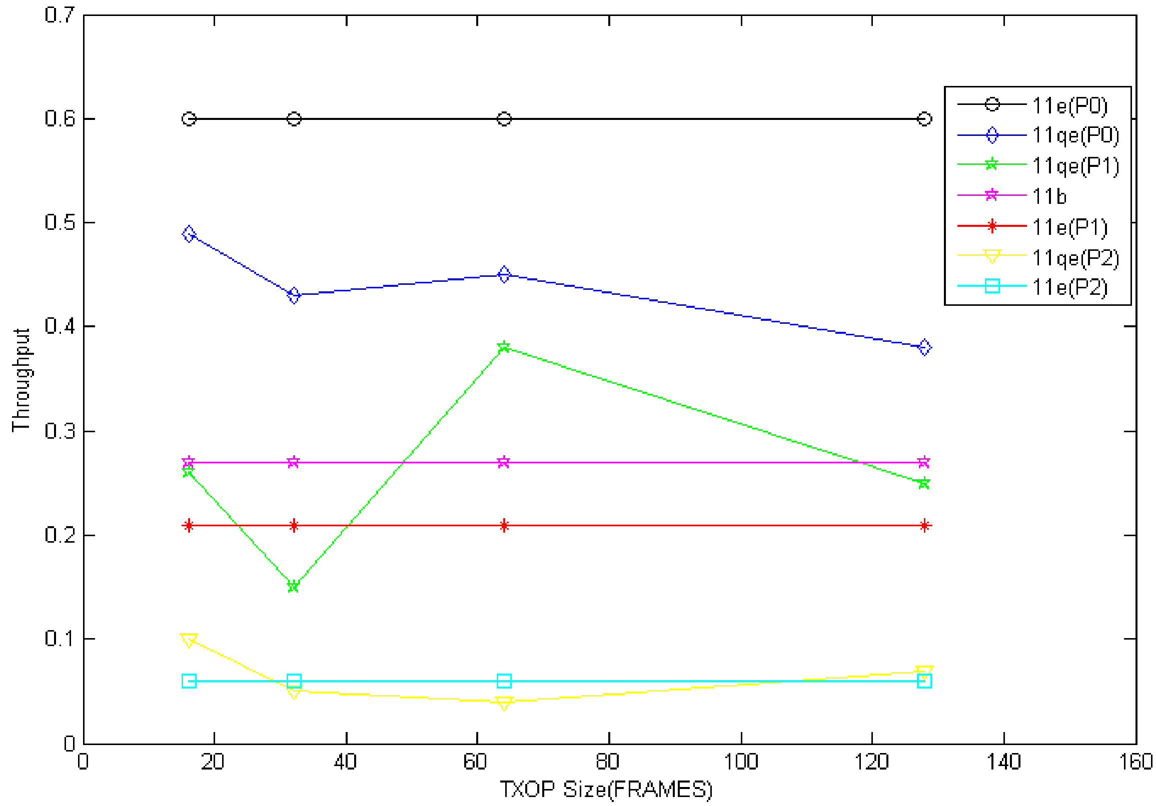


Fig. 11. Average Throughput Comparison between 11e, 11b and QEMAC Protocols

Fig. 11 shows the Average Throughput comparison in which it is clearly observed that the highest priority ACs of both 11e and our QEMAC got the much better throughput than the legacy 11b MAC protocol, .whereas the QEMAC streams provides the fairness as it could be controlled by varying the frames size on x-axis which is not available in the 11e MAC Protocol since it uses fixed TxOP Size instead of varying Frame Size.

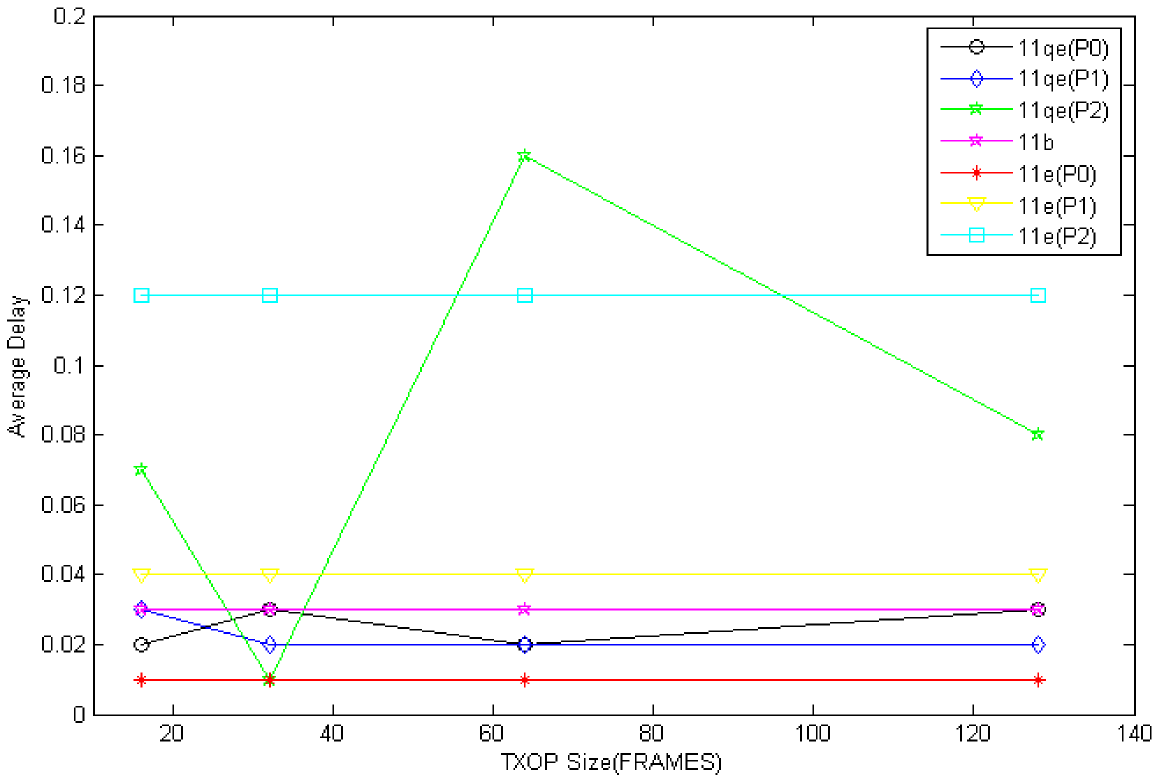


Fig. 12. Avg. Delay Comparison between 11e, 11b and QEMAC Protocols

Fig. 12 shows the Average Delay comparison in which the simulation results show the difference between the quality of service provided by QEMAC and the legacy MAC protocol. Once again the variation of delay in QEMAC on the basis of size of frames is provided by enhancing the 11e MAC protocol.

After comparing the external nodes average throughput and delay we will equate intra nodes i.e. ACs for legacy MAC 11e and QEMAC protocols by using three different ACs on three different flows. Fig. 13 shows the Delay comparison between the ACs of QEMAC and legacy 11e MAC protocol. In both the highest priority ACs QEMAC got lesser delay as compare to legacy 11e protocol whereas there is a minor difference in between lowest ACs.

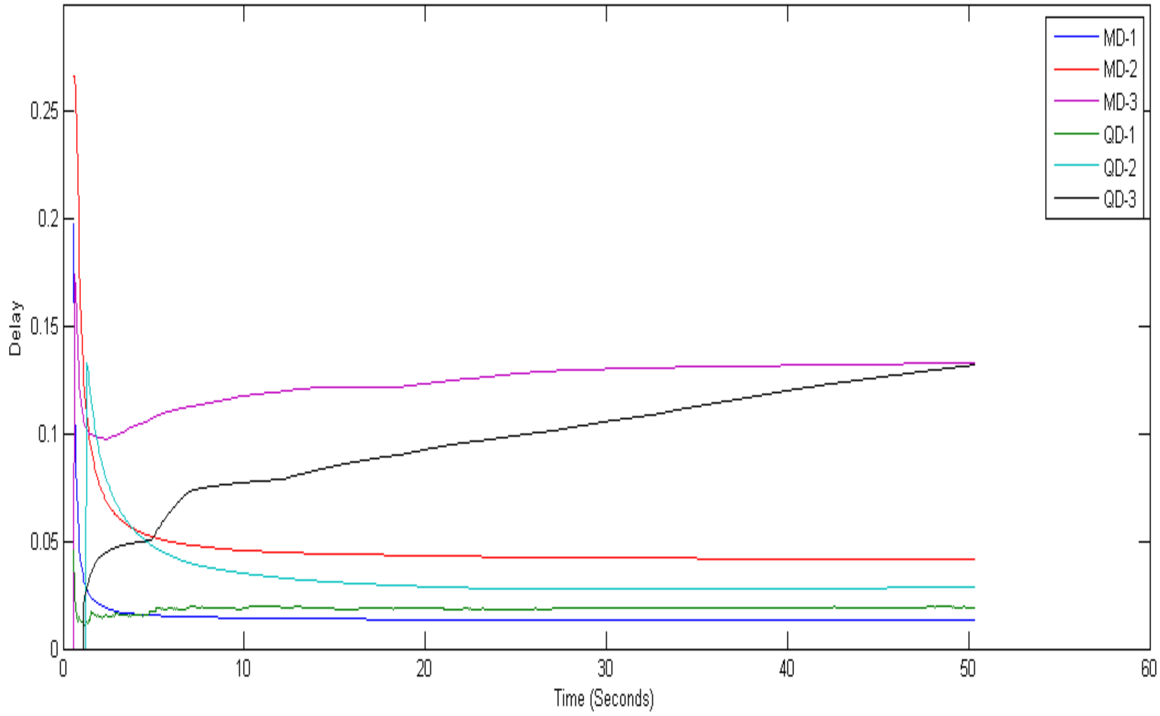


Fig. 13. Delay Comparison between 11e and QEMAC intra nodes(ACs)

Fig. 14 shows the throughput comparison between the ACs of legacy 11e and QEMAC. The result shows that the second category of QEMAC clearly got better throughput performance as it is not better in the 1st highest priority flow. where the lowest got almost the equivalent result in both the legacy and QEMAC protocols. The reason behind the better performance in highest priority flow in legacy 11e is to always give the high precedence as compare to the other lower ACs. Whereas in QEMAC fairness just provide that feature to give opportunity to the lowest priorities with no internal collision as it is shown in the Fig. 3. In the future we will try to improve QEMAC by invoking borrowing procedure as it is discussed in the future work section.

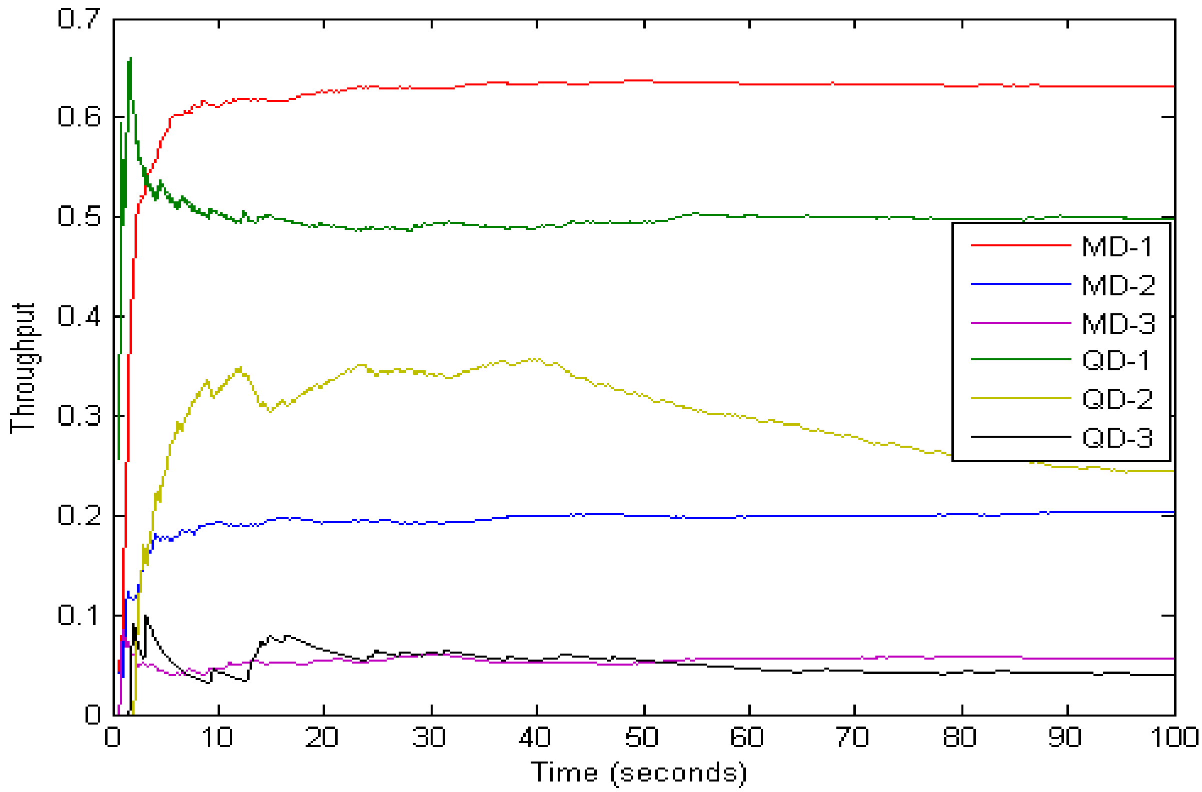


Fig.14. Delay Comparison between 11e(M) & QEMAC(Q) intra nodes(ACs)

Thus QEMAC is not only providing the best QoS support on the basis of 11e MAC protocol to the higher priority data up to 30% better performance on throughput and delay as compared to the legacy 11b MAC protocol but also caters the fairness feature by which not only the highest priorities get the opportunity to send and receive data but also the lowest priorities take part in the party.

4.2 Future Work

In the future work there could also be great chances to enhance the QEMAC in better way. The following techniques could be added in our QEMAC.

Borrowing Procedure: Borrowing time slots in QEMAC by an AC from the others to continue its communication without intending for the channel access could be the wondrous addition in the legacy ECA, to cater much better QoS support to the multimedia applications. Fig. 15 depicts the borrowing procedure in between two Access Categories x and y.

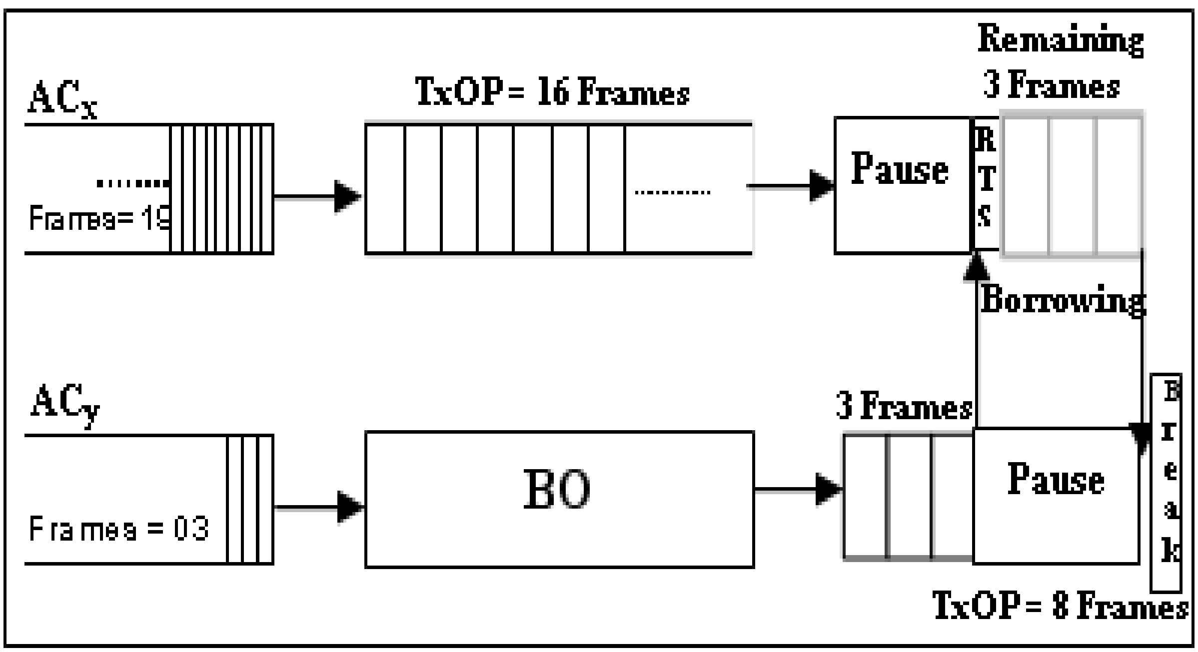


Fig. 15: Borrowing Procedure in QEDCA

Fig. 15 shows that $\mathbf{AC_x}$ has 19 frames in its queue, where the assigned TxOP allows it to send only 16 frames. To send the remaining 3 frames it asks for borrowing time slots from the other ACs, if any of them could have more slots than the frames in their queue. In Fig. 15 there is an $\mathbf{AC_y}$ which TxOP time limit allows it to send 8 frames where it has only 3 frames in the queue. It got 5 spare slots available, from which it could fulfill the requirement of $\mathbf{AC_x}$ by giving it 3 slots. Thus it first send its own 3 frames and shift the control to the $\mathbf{AC_x}$ which first send the RTS and then start sending its remaining 3 frames. After completing its communication it return the control back to the $\mathbf{AC_y}$, which has no more frame to send but still 2 slots are available. But it will not wait for it and break its TxOP at 6 slots. Hence, shifting the control from one AC to the other and breaking it down to the lower ACs makes the TxOP more flexible by which better performance and lower latency is achieved.

Chapter 5

METHODOLOGY

5.1 Introduction

In this chapter we will discuss the way to get the results. In this project, I decomposed our work into several steps as illustrated in Figure 16. It consists of editing the script, then compiled by Network simulator NS-2. The outputs of this compiler are trace files. Then this trace file will be processed using MATLAB to get the relevant information in the form of graphs.

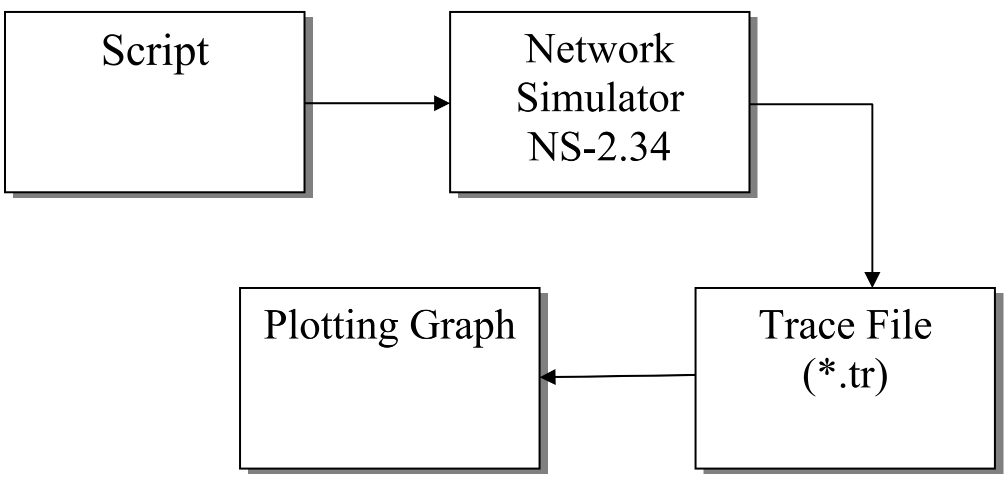


Figure 16. Process Block Diagram

5.2 Script

Script is written in OTcl (an object oriented extension of Tcl). In OTcl script, a particular network topology, the specific protocols and applications can be defined. This project includes:

1) Initialization and termination aspects of ns simulator. An ns simulation starts with the command: set ns [new Simulator]

Which is the first line in the OTcl script

The termination of the program was done using a "finish" procedure.

```
#Define a 'finish' procedure
Proc finish {} {
        global ns f1 f2
        $ns flush-trace
        close $f1
        close $f2
        exec nam out.nam &
        exit 0
}
```

It closes the trace files defined (e.g. f1, f2) before. The simulation can be begun using the command:

$ns run

2) Definition of network nodes (wireless station, wired station, base station and router), links, queues and topology (Ad hoc network configuration or infrastructure network configuration).

3) Definition of agents and applications, CBR (Constant Bit Rate) application over UDP (User Datagram Protocol).

4)

Tracing: When tracing is used, ns inserts four objects to objects in the link : EnqT, DeqT, RecvT and DrpT. EnqT registers information concerning a packet that arrives and is queued at the input queue of the link. If the packets overflows then information concerning the dropped packets are handled by DrpT. DeqT registers information at the instant the packet is dequed. Finally, RecvT gives information about packets that have been received at the output of the link.

5.3 Network Simulator-2(NS-2)

Ns-2 is a discrete event simulator which supports wired and wireless networking protocols. The simulator is an open source project, so the code as well as some patches are available on the Internet at [26]. The basic structure of ns-2 and the networking protocols are realized in the programming language C++. The script language Tcl is used for easy control and assembly of new simulations.

The idea of a discrete event simulator is that actions may only be started as a result of further events or inputs. Therefore ns-2 consists of a scheduler and a scheduling list. Each event has to be inserted into the scheduling list together with its expiration date. The scheduler goes through the scheduling list at runtime and starts the actions which are associated with the expired date.

The ns-2 MAC simulation model can be found in the directory../ns-2.26/mac/. The Logical Link Control (LLC) hands packets to the MAC through a priority interface queue. It is an advanced drop-tail queue which facilitates the insertion of routing packets

at its head. The MAC itself consists of the IEEE 802.11 DCF. The DCF MAC protocol is RTS/CTS/DATA/ACK and broadcast capable. It is able to scan the medium by virtual and physical carrier sense. The MAC provides the interframe spaces SIFS, PIFS, DIFS as well as EIFS. The EIFS is applied after every detected unsuccessful transmission attempt. It assures that a station may be able to answer with an ACK. The ns MAC includes several timers:

defer timer: is used when the MAC has to sense the medium being idle for the period of DIFS or if the MAC has to wait a period of SIFS

backoff timer: counts down the residual time of a backoff

interface timer: indicates, how long the interface will be in transmit mode when sending a packet

send timer: is used for the indication of the time up to which an ACK should be received after a transmission attempt

nav timer: is started

– for EIFS if a collision has been detected

– for the period contained in the duration field of a successful received data frame

– for the duration of a RTS/CTS/DATA/ACK exchange

These timers have start, stop, pause, resume and handle methods which are implemented in ../ns-2.34/mac/mac-timers.cc/h [27].

Ns-2 is used for a wide area research such as for TCP, integrated and differentiated services, scheduling or queue management in routers, multimedia, multicast and so on that can be found in www.isi.edu/nsnam/ns/ns-research.html.

Basically, this project uses network simulator NS-2 version 2.34 which has IEEE 802.11 DCF functionality. Then, the simulator has been extended by adding implementations of 802.11e and then enhance the 802.11e to QEMAC. The simulation scripts were executed to produce the Trace files. For the first part, the simulation scenario is used to compare the average throughput and average delay between DCF, EDCF, and QEMAC where in the second part EDCF and QEMAC's internal Access Categoris are compared with different types of data attached on them.

5.4 Trace File

Trace file (*.tr) records each individual packet as it arrives, departs or is dropped at a link or queue. By using the trace files we fetch the columns of data and then use them to draw the graphs using matlab.

5.5 Matlab to Plotting Graphs

After getting the trace files Matlab is used to plot the output files that contain two values (in x and y axis) for throughput and delay in the form of graphs to determine the performance of each metric (throughput and delay) that has been computed.

5.6 Extending MAC 802.11b to MAC 802.11e

The ns-2 already has IEEE 802.11 DCF functionality and has been extended by

adding implementation of EDCF. These are the necessary changes to extend the DCF to

EDCF as specified in [27] with the following step:

(1)

Change into the directory ns-allinone-version/ns-x.y/mac/ and unpack the

file mac80211e.tgz,

(2)

Changes to Makefile.in in ns-allinone-version/ns-x.y/ :

–

add to INCLUDES:

-I./mac/802_11e

–

add to OBJ_CC:

mac/802_11e/mac-802_11e.o mac/802_11e/priq.o

mac/802_11e/d-tail.o mac/802_11e/mac-timers_802_11e.o

exclude in NS_TCL_LIB:

tcl/lib/ns-mobilenode.tcl

add to NS_TCL_LIB:

mac/802_11e/ns-mobilenode_802_11e.tcl

mac/802_11e/priority.tcl

(3)

Changes to ns-allinone-version/ns-x.y/tcl/lib/ns-lib.tcl:

exclude from the source list:

source ns-mobilenode.tcl

add to the source list:

source /ns-allinone-2.26/ns-2.26/mac/802_11e/ns-

mobilenode_802_11e.tcl

source /ns-allinone-2.26/ns-2.26/mac/802_11e/priority.tcl

(4)

Adds to ns-allinone-version/ns-x.y/tcl/lib/ns-default.tcl:

Queue/DTail set drop_front_ false

Queue/DTail set summarystats_ false

Queue/DTail set queue_in_bytes_ false

Queue/DTail set mean_pktsize_ 500

Queue/DTail/PriQ set Prefer_Routing_Protocols 1

Queue/DTail/PriQ set Max_Levels 4

Queue/DTail/PriQ set Levels 4

(5)

add to tcl/lan/ns-mac.tcl:

if[TclObject is-class Mac/802_11e]{

...

copy settings of Mac/802.11 (which are contained in this file) into this section and change them into Mac/802.11e

...

Mac/802_11e cfb_ 0 ;# disables CFB

}

(6)

run ./configure; make depend; make in the ns directory.

(7)

To enable 802.11e simulations the following parameters must be inserted in Tcl-simulation script:

add MAC and queue type

set opt(mac) Mac/802_11e

set opt(ifq) Queue/DTail/PriQ

after defining the transport_agent

% set transport_agent [new Agent/UDP]

, just add

% $your_transport_agent prio_ x

to give a certain flow a specific priority (x between 0 and 3, 0 being the

highest, 3 being the lowest priority)

REFERENCES

[1] Akyildiz, I.F.; Su, W.; Sankarasubramaniam, Y.; Cayirci, E. Wireless sensor networks: a survey.Comput. Netw. 2002, 38, 393–422.

[2] Min, R.; Bhardwaj, M.; Cho, S.H.; shih, E.; Sinha, A.; Wang, A.; Chandrakasan, A.; Sinha, E.S.A.Low-Power Wireless Sensor Networks. In Proceedings of 14th International Conference on VLSI Design (VLSI Design 2001), Bangalore, India, 3-7 January 2001; pp. 205–210.

[3] Al-karaki, J.N.; Kamal, A.E. Routing Techniques in Wireless Sensor Networks: A Survey. IEEE Wireless Commun. 2004, 11, 6–28.

[4] Akkaya, K.; Younis, M. A survey on routing protocols for wireless sensor networks. Ad Hoc. Netw. 2005, 3, 325–349.

[5] Salhieh, A.; Schwiebert, L. Power Aware Metrics for Wireless Sensor Networks.In the 14th IASTED Conference on Parallel and Distributed Computing and Systems (PDCS 2002) Symposium, Boston, MA, USA, November 2002; pp. 326–331.

[6] Akyildiz, I.F.; Melodia, T.; Chowdhury, K.R. A survey on wireless multimedia sensor networks.Comput. Netw. 2007, 51, 921–960.

[7] An Overview of Wireless LAN Standards IEEE 802.11 and IEEE 802.11e, by *Jahanzeb Farooq, Bilal Rauf,* Department of Computing Science, Umeå University, Sweden, 2006, (tipputhegreat@hotmail.com)

[8] Kredo, II.K.; Mohapatra, P. Medium access control in wireless sensor networks. Comput. Netw. 2007, 51, 961–994.

[9] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: A survey,” Computer Networks, vol. 38, Pp.393-422, 2002 .

[10] A. A. Abbasi, and M. Younis, “A survey on clustering algorithms for wireless sensor networks,” Computer Communication vol. 30, no. 14-15, pp. 2826-2841, Oct. 2007.

[11] IEEE 802.11 WG, Reference number ISO/IEC 8802-11:1999(E) IEEE Std 802.11, 1999 edition. International Standard [for] Information Technology - Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific Requirements – Part11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, 1999.

[12] IEEE 802.11 WG, Draft Supplement to STANDARD FOR Telecommunications and Information Exchange Between Systems-LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS), IEEE 802.11e/Draft 4.2, February 2003.

[13] W. Ye, J. Heidemann, D. Estrin, “Medium Access Control With Coordinated adaptive Sleeping for Wireless Sensor Networks”, IEEE/ACM Transactions on Networking, Volume: 12, Issue: 3, Pages:493 - 506, June 2004.

[14] A. El-Hoiydi, “Spatial TDMA and CSMA with preamble sampling for low power ad hoc wireless sensor networks”, Proceedings of ISCC 2002, Seventh International Symposium on Computers and Communications, Pages:685 - 692, 1-4 July 2002.

[15] C. C. Enz, A. El-Hoiydi, J-D. Decotignie, V. Peiris, “WiseNET: An Ultralow-Power Wireless Sensor Network Solution”, IEEE Computer, Volume: 37, Issue: 8, August 2004.

[16] K. Jamieson, H. Balakrishnan, and Y. C. Tay, “Sift: A MAC Protocol for Event-Driven Wireless Sensor Networks,” MIT Laboratory for Computer Science, Tech. Rep. 894, May 2003, http://www.lcs.mit.edu/publications/pubs/pdf/MIT-LCS-TR-894.pdf.

[17] Y.C. Tay, K.Jamieson, H. Balakrishnan, “Collision-minimizing CSMA and Its Applications to Wireless Sensor Networks”, IEEE Journal on Selected Areas in Communications, Volume: 22, Issue: 6, Pages: 1048 – 1057, Aug. 2004.

[18] T.V. Dam and K. Langendoen, “An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks”, The First ACM Conference on Embedded Networked Sensor Systems (Sensys‘03), Los Angeles, CA, USA, November, 2003.

[19] P. Lin, C. Qiao, and X. Wang, “Medium access control with a dynamic duty cycle for sensor networks”, IEEE Wireless Communications and Networking Conference, Volume: 3, Pages: 1534 - 1539, 21-25 March 2004.

[20] MAC protocols for WSNs: A survey, Ilker Demirkol, Cem Ersoy, and Fatih Alagöz are with the Network Research Laboratory (NETLAB) of the Computer Engineering Department of Bogazici University, Bebek, Istanbul, TURKEY (e-mail: {ilker,ersoy,alagoz}@boun.edu.tr).

[21] JOURNAL of COMMUNICATIONS and NETWORKS, vol. 7, no. 4, December 2005 “An Adaptive FEC Code Control Algorithm for Mobile Wireless Sensor Networks”, Jong-Suk Ahn, Seung-Wook Hong, and John Heidemann

[22] Qiang Ni, et al. Journal of Wireless Communications and Mobile Computing, Wiley. 2004: Volume 4, Issue 5: pp.547-566 A Survey of QoS Enhancements for IEEE 802.11

Wireless LAN Qiang Ni*, Lamia Romdhani, Thierry Turletti Planete Group, NRIA, 2004 route des Lucioles BP93, 06902 Sophia Antipolis, France

[23] IEEE Standard 802.11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: Medium access control (MAC) Quality of Service (QoS) Enhancements, IEEE 802.11e Std., 2005.

[24] Cucchiara, R. Multimedia surveillance systems. In Proceedings of the Third ACM International Workshop on Video Surveillance & Sensor Networks, VSSN'05, ACM: New York, NY, USA, 17-20 April 2005; pp. 3–10.

[25] UCB/LBNL/VINT Network Simulator,
Available: http://www.isi.edu/nsnam/ns/.

[26] The Network Simulator - ns-2,
http://www.isi.edu/nsnam/ns/ns-documentation.html, Jun 2004

[27] Sven Wietholter, Christian Hoene, "Design and Verification of An IEEE 802.11e EDCF Simulation Model in NS 2.26", TKN Technical Report TKN-03-19, Berlin, November 2003

[28] G.Lu, B.Krishnamachari, C.S. Raghavendra, "An adaptive energy-efficient and low-latency MAC for data gathering in wireless sensor networks", Proceedings of 18th International Parallel and Distributed Processing Symposium April 2004