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Evaluation and Comparison of MAC Protocols in Wireless Sensor Networks

Sharmila Kollipara
Cleveland State University

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SHARMILA KOLLIPARA

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Thesis Committee Chairperson, Dr. Nigamanth Sridhar

Department/Date

Dr. Chansu Yu

Department/Date

Dr. Wenbing Zhao

Department/Date

To my mom and dad

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ABSTRACT

Wireless sensor network applications call for different kinds of network protocols at different levels of the network stack based on application requirements. A number of medium access control (MAC) protocols have been proposed in the literature. Evaluation of most of these MAC protocols have typically been based on simulation, and while such simulation provides interesting insight into the behavior of these protocols, artifacts caused by behavior of hardware is ignored. Further more, MAC protocols are usually evaluated by comparing the new protocol with others based on one or two metrics, the ones that determined the design decisions for the protocol under evaluation. In this thesis, we present a comprehensive evaluation of MAC protocols based on a set of common metrics. The evaluation is conducted by way of experiments on a test bed of real sensor hardware for different scenarios and work loads that would match different application requirements.

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CHAPTER I

INTRODUCTION

Wireless sensor network (WSN) applications involve deployment of battery powered nodes which are active for a considerable time and they usually do not have any control by humans after deployment. As the battery capacity of a node is limited, this draws the attention for energy management of a node in the network. It has been observed that the radio on the node is the major energy consuming component [4]. So the radio is duty cycled by switching it off for a certain period of time which saves energy. Along with energy efficiency, more metrics are to be considered which may impact the performance of a protocol in a network. An application developer should be careful while selecting a medium access control (MAC) protocol that meets the needs of the application. So there is need to understand the operation of a protocol on specific conditions on a real sensor network. There are limited studies on comparing different protocols on a common platform for all the different metrics.

In this thesis we first analyze different protocols and use the designed framework for more accurate comparison in a number of realistic traffic patterns.

1.1 The Thesis

This thesis explores the performance of different MAC protocols which are designed on Unified Radio Power Management Architecture (UPMA) [20] platform. We present an analysis system model of evaluation and comparison of protocols for different topologies (ring, line, star and multi-hop), performance metrics (duty cycle, latency, power consumption, throughput and fairness) and parameters (traffic load, packet size and network size). The test bed used in this model consists of TelosB [4] motes. The analysis of protocol performance done using this model is presented.

1.2 The Solution Approach

Evaluation of MAC protocols is mostly done through simulations. There is a need to evaluate protocols on real sensor networks. Most of the existing evaluation methods consider one or two metrics either of which may be energy consumption, throughput, fairness, duty cycle, latency for evaluation but consideration of all the metrics is not done. All the MAC protocols are not evaluated for all the metrics. So there is a need for a solution that can evaluate and compare different MAC protocols for all metrics on a real sensor network.

The MAC protocol evaluation and comparison method that we present in this thesis is designed on real sensor test bed which can be used by any MAC protocol for evaluation and comparison on UPMA platform. Doing all the experiments manually for all type of experiment to evaluate the protocols is difficult. So we designed a system to automate on real sensor network. The output values are transmitted to the computer to which the test bed is connected. The values are further analyzed for different scenarios.

1.2.1 Contribution

Contributions of this thesis are as follows. First, we present model for evaluation and comparison of MAC protocols on a real sensor network. Second, we present analysis on different settings by varying the packet size, packet interval and network size. Third, we explore different application scenarios where different metrics such as duty cycle, power consumption, fairness, throughput or latency are major requirements. However, this model can be used to evaluate and compare a new MAC protocols and the analysis can be used by any application developer to choose a protocol that suits their application requirements.

1.3 Organization of the Thesis

The thesis is organized as follows. Chapter 2 presents on introduction about wireless sensor networks. Chapter 3 explains the system framework and its design. Chapter 3 discusses about the software services used by the system which run on the computer. MAC protocols are compared and analyzed in Chapter 5 for different topologies and scenarios. Chapter 6 presents related work. We conclude in chapter 7 with pointers to future work.

CHAPTER II

WIRELESS SENSOR NETWORKS

2.1 Introduction

Wireless sensor networks consist of small, cheap, low-powered embedded devices called motes or nodes. A set of nodes communicate wirelessly with each other in a network to perform a particular task. Each node consists of a microcontroller, a radio for wireless communication and sensors for sensing the environment. To establish wireless communication between the nodes in the network MAC protocols are used. Wireless sensor networks are usually used for monitoring the environment or surrounding conditions. According to the requirement of the application each node in the network has different types of sensors embedded on them such as temperature, humidity, light motion etc.

2.2 Hardware

Hardware used in wireless sensor network is mainly tiny, cheap and low powered sensor nodes. Most of the currently used sensor nodes are mostly prototypes. Some of the embedded devises used in this field are TelosB [4], mica2 [2], Imote [3] etc.

Typically each sensor mote mainly consists of micro controller, radio and few sensors all together embedded on it.

The microcontroller is used to control the processing of the node with limited memory and capacity so that it decreases the size of the node. Radio is mainly used to establish wireless communication between the nodes. Commonly used radios are CC2420 [5], CC1000 [6] etc. Various sensors such as light, ultrasonic, temperature, magnetic sensors, etc are embedded on the nodes to sense the physical world.

2.3 Software

TinyOS is an open source component based operating system designed to meet the requirements of platforms in wireless sensor network. It is based on event driven programming model. It is an embedded operating system written in NesC programming language composed of task and processes.

2.3.1 Networked embedded systems C

NesC is a dialect of C programming language used to build application in TinyOS platform. Programs are composed of event handlers and tasks. It is built of components which are wired together through interfaces to run a specific application on TinyOS [8] operating system. Race condition between event handlers and tasks are detected by NesC [1].

2.4 MAC protocols for wireless sensor network

MAC protocols are used in wireless sensor network to emulate successful communication. Radios in the sensor nodes consume more energy than any other component. There has been a lot of research to reduce the energy consumption by designing a low power device [22]. Due to power and hardware limitations there is a need to reduce the energy consumption by design of an efficient communication protocol. The communication protocol ensures successful wireless communication in the network. The main function of a MAC protocol is to avoid collisions from other nodes, share the communication medium efficiently and establish network infrastructure.

MAC protocols are used for providing a data link layer in sensor networks. Various MAC protocols with different objectives are proposed for wireless sensor networks with different design methodologies, each one have their own strengths. An efficient MAC protocol for a wireless sensor network should have the following attributes.

- Most important attribute is energy efficiency [21], since sensor nodes run on battery power and it is difficult to change the battery of the node when deployed in the network. If the protocol is energy efficient it increases the life time of a network.

- Duty cycle is the fraction of time the node is in active state. Duty cycling is mainly considered as it conserves energy consumption of the system.

- Throughput is important in a network to see how many messages are delivered successfully over communication channel.

- Fairness determines the share of all the nodes in the network to use the radio channel.

- Latency measurement is required as it determines how fast the data can be sent in a network.

Examples of MAC protocols used in wireless sensor network are BMAC, XMAC, SCP-WUSTL, TDMA, SS-TDMA etc. Most of the protocols are mainly based on following techniques:

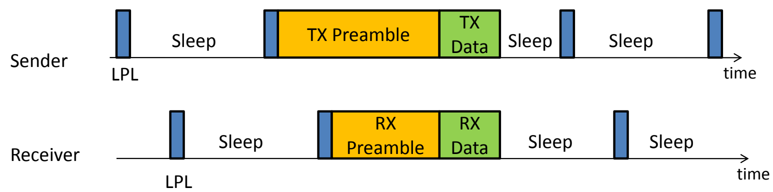

Figure 1: BMAC protocol with long preamble approach

- Carrier Sense Medium Access (CSMA): Each node in the network listens to the channel and if the channel is idle it will start transmitting the data, if not it will wait for a random time and again start listening. Collision Avoidance (CA) is used in CSMA to improve its performance in wireless communication.

- Time Division Medium Access (TDMA): This technique shares the frequency channel by dividing the channel into different time slots. So each node a particular time slot in which it communicated with the communication channel.

Most of the MAC protocols existing can be categorized to one of the protocols as follows. In channel polling (CP) protocols radio channel is checked for activity periodically. There is no need for synchronization between nodes, each node can wake up independently and listen to the channel. While channel polling, if an activity is detected the radio is turned ON to receive mode, if not, the radio goes to the sleep mode until the next polling interval. Preamble sampling is used where sender node sends a long byte of preamble along with data so that receiver node can detect the radio activity. BMAC [9] uses a preamble of length of at least the receivers sleep interval. XMAC [10] improves over BMAC's latency, throughput and energy consumption by sending streams of short preambles instead of a long preamble along with a early acknowledgement to send a data packet. Figure 1 and 2 presents the concept of BMAC and XMAC protocol respectively. In Wise MAC [11] protocol preamble sampling is synchronized with the neighboring nodes to reduce power consumption and latency.

In scheduled contention protocols all the nodes are synchronized to have the

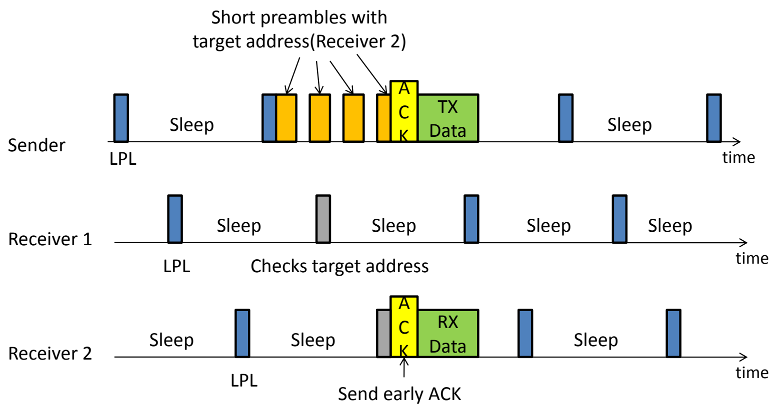

Figure 2: XMAC protocol with short preambles and early acknowledgement

same active and sleep cycles. In active period the transmitting node sends data through CSMA/CA process. In SMAC and TMAC protocols do not use preamble sampling as in CP protocols since the receiving node is also awake in the sync period. In TMAC [12] protocol uses a timeout method which turns off the radio if there is no communication occurring in the active period which reduces the radio energy consumption. These types of protocols have synchronization over head of wake up intervals.

In time division multiple access protocols eliminate contention between nodes by diving the time into slots and scheduling which node is supposed to send in which slot. As one node sends at a data at a time there is reduction in the collisions and packet loss. TDMA also required time synchronization between all the nodes in the communication range. This protocol gives lower throughput than channel pooling and schedule contention protocols, as a node cannot send a data whenever it wants and has to wait for the next slot for large size network.

Hybrid protocols basically try to combine all the advantages of the above protocols. It is a combination of TDMA and CSMA/CA methods. Scheduled contention and low power listening are combined together to propose SCP [13] protocol as illustrated in figure 3. In SCP the radio channel is sampled at the synchronized wake

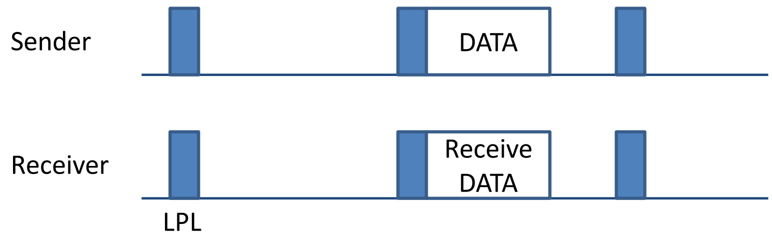

Figure 3: SCP MAC protocol

up times. SS-TDMA is another hybrid type of protocol which combines TDMA and CSMA methods. ZMAC [14], Funneling MAC [16], and Crankshaft [15] are few examples of hybrid type of protocols which combine any of the above protocols to get a better performance.

CHAPTER III

FRAMEWORK ARCHITECTURE AND DESIGN

3.1 Overview of the System

There are many MAC protocols introduced in wireless sensor network, so there is a need to evaluate and compare the protocols, such that the best protocol can be selected for a specific application. We focus on evaluating the protocols on a real sensor network for varying traffic loads, packet sizes and packet intervals on different topologies.

In simulation the values are not accurate to that of real sensor network. We run each of the experiment for 5-10 times. We present the framework model to evaluate any MAC protocol on our system and compare with the rest of the protocols. All the required experiments are done automatically on the test bed without any manual work. Software used on the computer to automate the running of the experiments is presented in Section 4.

3.1.1 Experiment Setup

To evaluate the MAC protocols in a wireless sensor network we use a test bed of 20 nodes all connected to a PC. Nodes in our test bed are TelosB motes with Chipcon CC2420 radio and TI MSP430 processor. All the nodes in the test bed are connected to the computer which runs all the evaluation experiments.

We use tinyos-2.x-contrib UPMA architecture [20] framework on which different MAC protocols are implemented. BMAC, XMAC and SCP-WUSTL are implemented for multi-hop network where as PURE-TDMA, SS-TDMA are implemented for single-hop network only. For different topologies as mentioned below all the metrics are calculated.

3.1.2 Hardware Design

A set of TelosB motes all together make a test bed. All the motes in the test bed are connected to the computer to take the reading of each experiment run on the test bed. The whole test bed contains:

- *Motes*: We use TelosB [4] motes in our experiment test bed. It is the communication and processing unit. All the motes are motes are programmed to perform a certain task and communicate with each other. TelosB motes are connected to the computer through USB connector to communicate with the PC using serial communication.

- *USB Switch*: Switch is used to power ON and OFF the USB power supply to the motes i.e. power reset the test bed. USB switch is operated by a TelosB mote. MOSFET is used to switch the power supply to the test bed. The switch is connected to the USB cable which is in return connected to the whole test bed.

- *USB hub*: We use ProConnect Compact USB 4-Port Hub [7] to connect all the Tmotes in the test bed. It operates on bus power supply so it is easy to power reset the USB hub. It can handle up to 127 devices at a time.

3.2 Topologies

Different topologies are considered in this thesis for evaluation. Each one has different patterns so that the MAC protocols can be properly evaluated for different scenarios. Topologies considered are:

- *Ring topology*: N nodes are arranged on a circle equally spaced from each other. All the nodes in this topology have the same function to perform and same number of neighbors. Message packet is supposed to travel through all the nodes.

- *Line topology*: N nodes are placed in a line with 1 unit distance between the nodes. This topology is asymmetric [19] the first and last node in the line have fewer neighbors. All the nodes do not have the same function to perform.

- *Star topology*: N nodes are connected to a single node with a unit distance between them. The central node needs to have good capacity to handle messages, load and make decisions.

- *Fixed routing tree topology*: N nodes are connected to each other in the form of a tree so that the messages are routed according to the fixed structured. This type of fixed routing tree multi-hop topology removes the influence of other components other than MAC protocol. All the nodes in the network have different functions and load to handle according to the position of the node in the network.

3.3 Metrics

To evaluate a MAC protocol different metrics are to be considered. All the metrics are calculated for all the topologies as mentioned above. Evaluation is done by varying the packet size, traffic loads and packet interval. Metrics considered in this thesis to compare and evaluate a protocol are as follows.

- *Latency*: Latency is the amount of time it takes for a message packet to be sent from one source to a destination node. Average packet latency is calculated for single-hop and multi-hop networks.
- *Throughput*: Throughput is the total number of packets delivered by a node per unit time. Packets sent and received are properly calculated while evaluating a protocol for this metric.
- *Duty cycle*: Duty cycle is calculated by measuring the time of the voltage, oscillator and radio of the mote is ON. We calculate the duty cycle by using a counter to count the voltage, oscillator and radio time they are turned ON.
- *Power consumption*: It is the amount of power consumed by a mote to transmit and receive a packet. Energy consumed is calculated by measuring the time radio is in different states. Unit of energy consumption is Joules.
- *Fairness*: This metric is used to measure the share of the channel by all the motes in the network. Fairness is measured by calculating the standard deviation of number of packets sent by all the motes in the sensor network.

3.4 MAC Models

All the MAC protocols are implemented by UPMA which is available online [20]. Below we discuss about different protocols we consider.

- *BMAC*: This is a CSMA/CA type of protocol. BMAC uses adaptive preamble sampling. The sender node sends a long preamble of length at least as long as the low power listening interval as waits for acknowledgment (ACK) message from the receiver. If the receiver node is awake, it sends the acknowledgment message to the sender. As the sender receives the ACK message, it stops sending the preamble and starts sending the data message. BMAC on a whole uses clear channel assessment, packet back off, low power listening and preamble acknowledgment techniques.

- *XMAC*: It improves over BMAC by using multiple short preambles bytes instead of a long preamble byte. The sender sends short preambles in series with the receiver information. If the receiver is awake it receives the preamble with the target id and it sends the early acknowledgment to the sender. Sender sends the data to the receiver as it receives the ACK packet.

- *SCP-WUSTL*: This protocol is designed to attain lower duty cycle by combing scheduled synchronization and low power listening. Synchronized channel polling is done by all the nodes in the network at regular intervals. Two phase contention is used where the sender node contents the channel before and after the wake up tone so that the collisions can be reduced. The sender node first contends for the channel to see if the channel is idle, if the channel is idle it sends the wake up tone. If the node had sent the wake up tone successfully it goes for the second contention window and if it finds the channel to be idle for the second contention window it sends the data.

- *TDMA*: This protocol divides the time into slots and the slots are allocated to different nodes in the neighborhood network. Nodes access the channel in that particular slot to send their data. Each node has a different slot to access the channel so there are less chance of collision and packet loss.

- *SS-TDMA*: As TDMA protocol SS-TDMA protocol also divides the time into slots of activity and sleep intervals. Slots are allocated to all the nodes in the network. SS stands for slot stealing where other nodes can steal the slot of other nodes. Node with the allocated slot are given the preference to send the data, if the node does not have any data to send other nodes can contend the channel in that slot after some delay.

3.5 Radio states

Using a counter in software we count the time of the radio in each state. Time the radio is in listening, sleep, receive, send mode is calculated and multiplied by the power drawn in respective modes by the radio to get the total power consumed. Energy measurement interface is built which measures the time of the radio goes to different states for all the MAC protocols. It also measures the total time, voltage, oscillator and radio duty cycle. It is placed in between the MAC protocol layer and the radio core layer of UPMA architecture.

CHAPTER IV

SOFTWARE SERVICES ON THE PC

To run all the evaluation experiments for different combinations one after another manually is a cumbersome task. So there is a need to automate running of all the experiments for varying packet interval, network size and payload size. We use shell scripting to automate all the experiments. All the output values are saved in text files which are further analyzed to evaluate the MAC protocols. Analysis part is explained in Chapter 5. Data from the motes are sent to the PC for evaluation.

After all the motes in the test bed are programmed to run a specific experiment using the code written in tinyos [8] the whole test bed is power reset so that all the motes can restart or reboot at a time. Reset.sh is used to power reset the test bed. makeTelosb.sh USB is used to install a program on a TelosB mote. Xtermkill.sh is used to end an experiment.

4.1 Shell scripting

In this thesis we consider 4 topologies: star, ring, line and fixed routing tree topology. For running the metric measurement in each of these topologies we developed 5 shell scripts. For fixed routing tree topology we consider node to sink and sink to node multi-hop scenarios. By changing the MAC protocols names in the script we run the experiment. At the start of an experiment we program all the motes with the Blink program so that the radio of the motes is not active to make sure that no mote radio affects the running experiment. By changing the MAC protocols, packet size, packet intervals bellow each experiment runs for 5-10 times. Below we explain different shell script experiments.

- *Star shell script*: In main program we first program all the motes with Blink program and start the experiment. We consider one receiver and 8 senders. Using makeTelosb.sh a specific mote can be programmed in the test bed with required address and the USB number. By varying the number of senders we run the each experiment for 60 seconds. After getting the output values from the Telosb motes the experiment is terminated. Number of senders is increased from 1 to 8 and after before starting of each experiment the whole test bed is power reset so that all the motes start at a time. Power reset of the test bed is done using reset.sh. Output values from the motes are stored in the computer in different folders for analysis.

- *Line shell script*: In line shell scripts we consider 5 hop networks of 6 motes to be programmed which are arranged in a line in the test bed. Number of hops is changed by using num-hoplatency.sh file. For N number of number of hops it programs N+ 1 mote with addresses from 0 to N. Value of N is varied from 1 to 5. After all the motes are programmed test bed is reset to start all the motes at a time. After the mote with address 0 send the output value to the computer the experiment is terminated and it starts the new experiment by increasing the number of hops. For line topology all the motes are programmed for each experiment.

- *Ring shell script*: This is same as the line shell script only difference is that the motes we program on the test bed changes. For Ring topology also we consider 5 hop networks with 6 motes to be programmed. We use ring program in tinyos to program all the motes.

- *Node to sink shell script*: This shell script is for running the multi-hop network experiments. We use fixed routing tree topology for multi-hop network. All the nodes in the network are programmed with a node id and the parent of the node is declared using myparent.sh. Sink node is programmed with node id 0 without any parent node. After all the nodes in the network are programmed the test bed is reset to start the experiment. After all the motes send its data to the computer it terminates the experiment and a new experiment is started with increase in number of motes. We run the node to sink multi hop network experiment for varying packet size ,packet interval and network size.

CHAPTER V

ANALYSIS

In this chapter we analyze different MAC protocols like XMAC, BMAC, SCP, TDMA and SS-TDMA which are built on UPMA architecture platform. We provide evaluation results of MAC protocols on different topologies with respect to metrics like latency, throughput, fairness, duty cycle and power consumption.

5.1 Star Topology

In star topology we place all the sender nodes (1 -8) equidistance from the receiver node. All the nodes send there data to the single receiver node.

5.1.1 Latency

Below we explain about the behavior of different MAC protocols for varying load (i.e. senders) and packet size.

- *For varying number of senders (load)*: In star topology we evaluate the latency for a single hop network where all the nodes communicate to the single base station node. We calculate the average time a packet takes to transit from

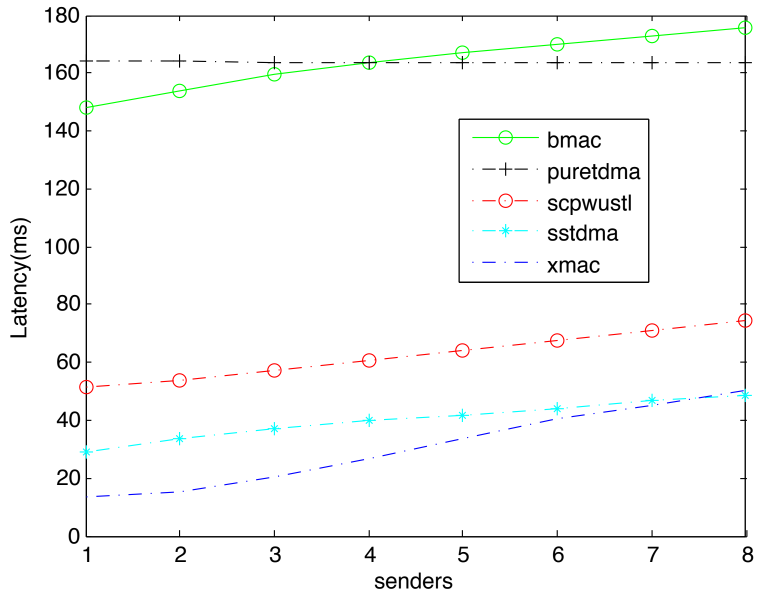

Figure 4: Average packet latency in star topology for varying number of senders with packet size 28 bytes.

receiver to the base station successfully. Figure 4 shows the performance of different MAC protocols for different senders. For TDMA protocol the latency is same (around 163ms) for different number of senders. Latency does not increase as each node is assigned a slot to transmit its data and as to wait for the next slot to send the next data. For SS-TDMA protocol which is hybrid type of protocol the latency increases as number of senders' increases because contention for the slot increases as each node wants to send data. In the case of CSMA based protocols like BMAC, XMAC the latency increases linearly with increase in nodes. XMAC has less latency than BMAC as it uses streams of short preambles. With more senders the latency increases as contention to use the channel increases and collisions also increase.

- *For varying packet size*: As the packet size increases the latency to send the data increases for CSMA and hybrid type protocols as shown in figure 5. For TDMA protocol the latency is same (163 ms) for any size of data because each node

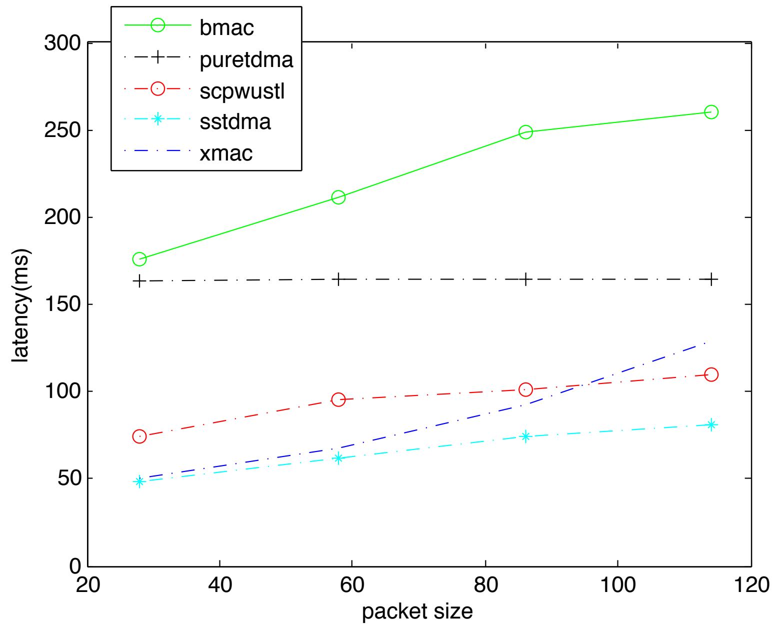

Figure 5: Average packet latency for varying packet size in star topology.

sends the whole data frame in the slot allocated to it so there is no contention for the channel use age. For hybrid type of protocols like SS-TDMA and SCP protocols the latency increases linearly with less slope. In SCP all the nodes in the network are synchronized, so there is less contention for the channel and there is less increase in latency as packet size increases. Long data packet takes more time to send data than a short data packet. BMAC and XMAC show more slope as packet size increases as there is more contention, collisions and more data load.

5.1.2 Fairness

We analyze fairness in a star topology for varying packet intervals, packet size and load in the network. For fairness of a network we the calculate Standard deviation between the numbers of packets send by all the nodes (i.e. 8 sender nodes).

- *For varying number of senders(load)*: SS-TDMA and SCP protocol has a steady fairness for varying nodes from 2 to 8. For BMAC protocol the fairness value

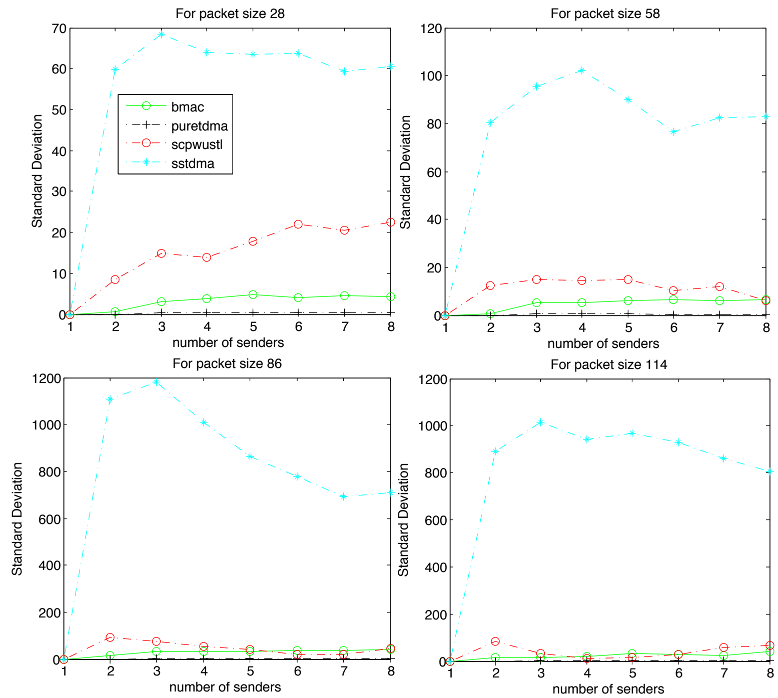

Figure 6: Fairness in star topology for varying number of nodes.

increase gradually form 0 to 4.2. Compared to SS-TDMA and SCP protocol BMAC performs better in terms of fairness in star topology. Figure 6 shows fairness metrics with respect to varying number of nodes for no packet interval. For packet interval for more than or equal to 1 sec the fairness value is almost zero for all the protocols for increase in number of nodes from 0 to 8.

- *For varying packet size*: BMAC and TDMA protocol has the same fairness value for varying packet size. Figure 7 shows the variation of fairness for different packet sizes. SS-TDMA shows a gradual increase in fairness value for increase in packet size for no packet interval as each node wants to send its data and tires to steal any other slot for transmission.

- *For varying packet interval*: More value of fairness shows that there is adequate share of the channel among the nodes in the network. Fairness value is more when there is no packet interval as shown in Figure 8. Figure 9 shows the

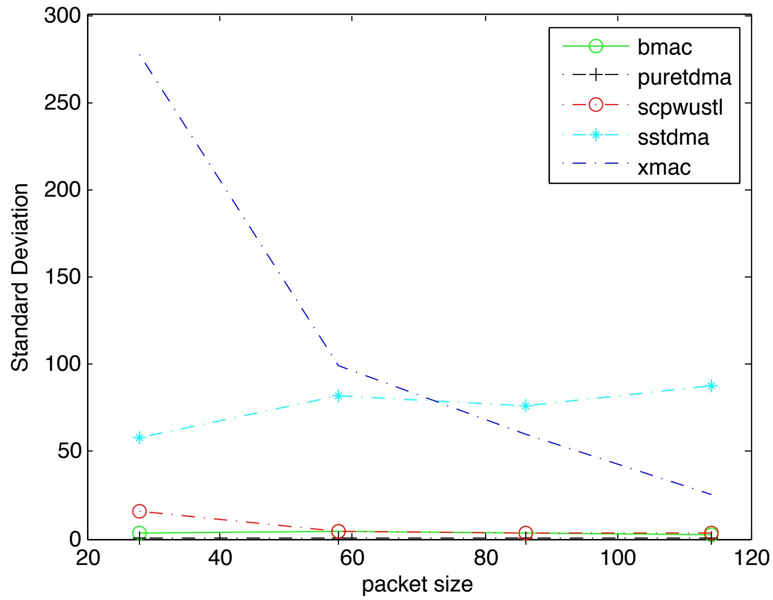

Figure 7: Fairness in star topology network for varying packet size with 8 sender nodes.

fairness when a packet interval is introduced. As the packet interval increases the fairness decrease because for more packet interval each node gets more time to send data. TDMA protocol has zero fairness for varying packet interval because each node gets an equal share of the channel through slot allocation. XMAC and SS-TDMA protocols show more Standard deviation value for no packet interval. For packet size is less SS-TDMA has less fairness value than XMAC but when the packet size increase it is vice versa.

5.1.3 Throughput

For throughput metric calculation we consider the number of packets successfully received by the receiver node in star topology for 60 seconds.

- *For varying number of senders(load)*: As shown in figure 10 the throughput or packets received increase gradually with number of nodes. XMAC shows much more throughput than BMAC value. TDMA protocol packet received increase in a straight line linearly because it receives all the data packets send

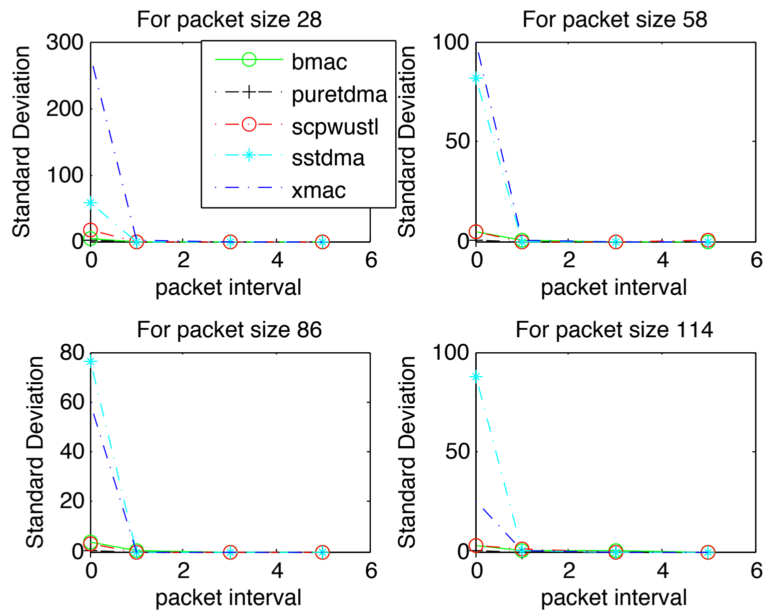

Figure 8: Fairness in star topology network for varying packet interval (0s to 5s) with 8 sender nodes.

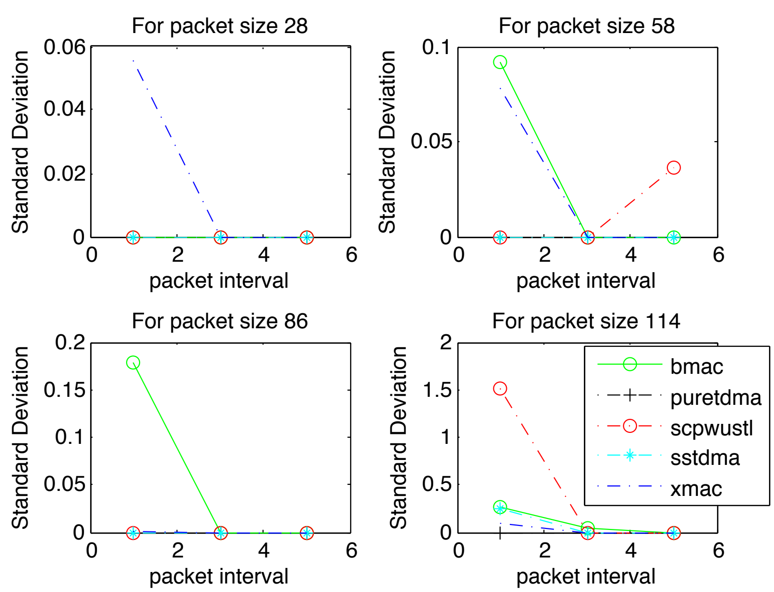

Figure 9: Fairness in star topology network for varying packet interval (1s to 5s) with 8 sender nodes.

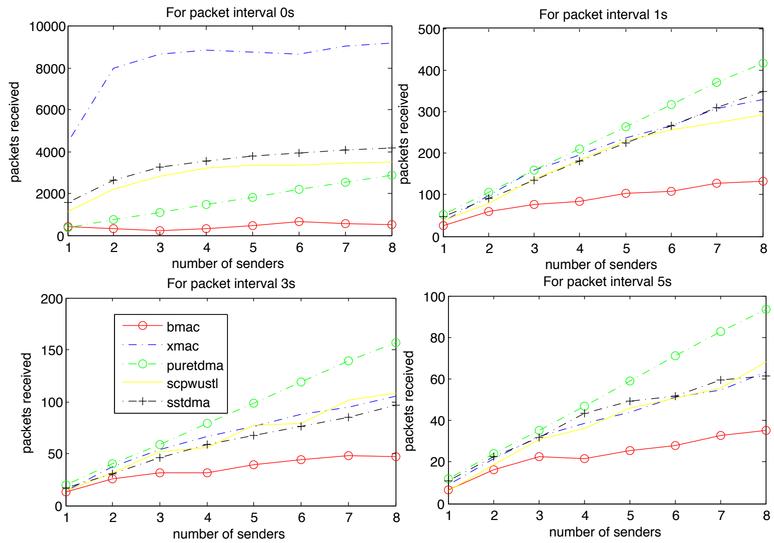

Figure 10: Throughput in star topology for varying number of sender nodes with packet size 28 bytes.

by all the nodes as it uses slot allocation for all the nodes. Compared to all the protocols BMAC has the less throughput value. As the packet interval increases XMAC and hybrid type of protocols like SCP, SS-TDMA show almost the same throughput value for different number of nodes.

- *Good put for varying packet size*: The packet received decrease as the packet size increase as it takes more time to send the long data packet size for no packet interval. SS-TDMA, SCP and TDMA have almost the same packet received values as shown in figure 11. For packet interval for 1 sec, 3 sec and 5 sec SCP, SS-TDMA and TDMA protocol received packet are reduced with increase in packet size which have synchronization with in nodes in the network. CSMA based protocol like XMAC and BMAC the packet received increase as packet size increase when packet interval is introduced.

- *For varying packet interval*: Packet received is decreased as the packet interval increases as there is less number of data sent. XMAC protocol has more packets received than any of the 5 MAC protocol considered. SCP has more packets

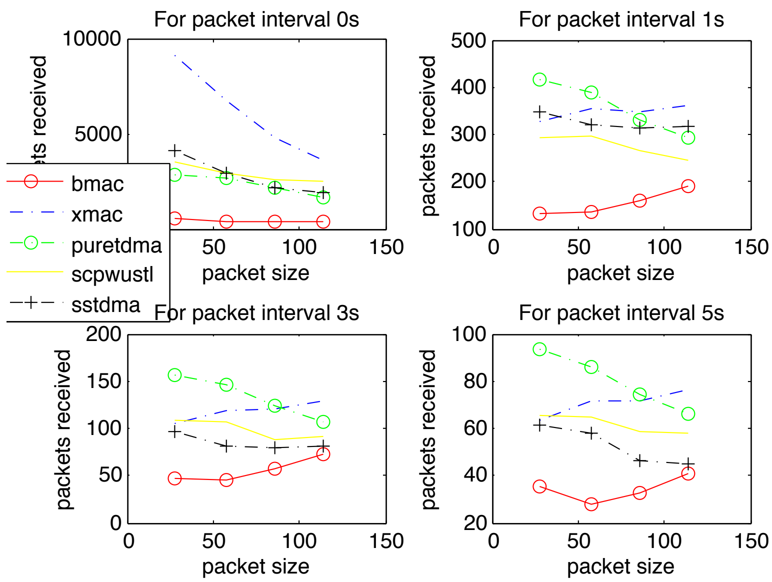

Figure 11: Good put in star topology for varying packet size with 8 sender nodes.

received for increase in packet size than TDMA and SS-TDMA. Figure 12 and 13 shows the throughput performance of protocols for varying packet interval.

5.1.4 Duty Cycle

For evaluation and comparison of MAC protocols with respect to duty cycle metric we consider average duty cycle of a node to receive or send a packet. In this experiment each sender node sends packet to the receiver, so the packet received and sent varies with the design of the protocol.

- *For varying number of senders*: Duty cycle of the receiver to receive a packet decreases as number of nodes increase as shown in figure 14. For data packets send without any interval TDMA shows more duty cycle than SS-TDMA but when we introduce packet interval SS-TDMA has more duty cycle this is because SS-TDMA tries to steal any empty slot when it has to send data.

  Performance of sender node to send a packet is different from receiving a packet is shown in Figure 12. TDMA has the same duty cycle for any number of sender

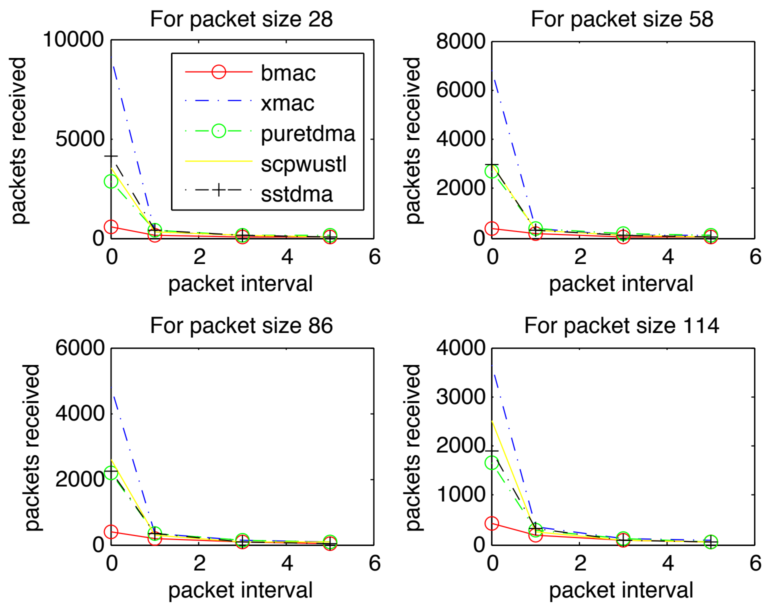

Figure 12: Throughput in star topology for varying packet interval (0s to 5s) with 8 sender nodes.

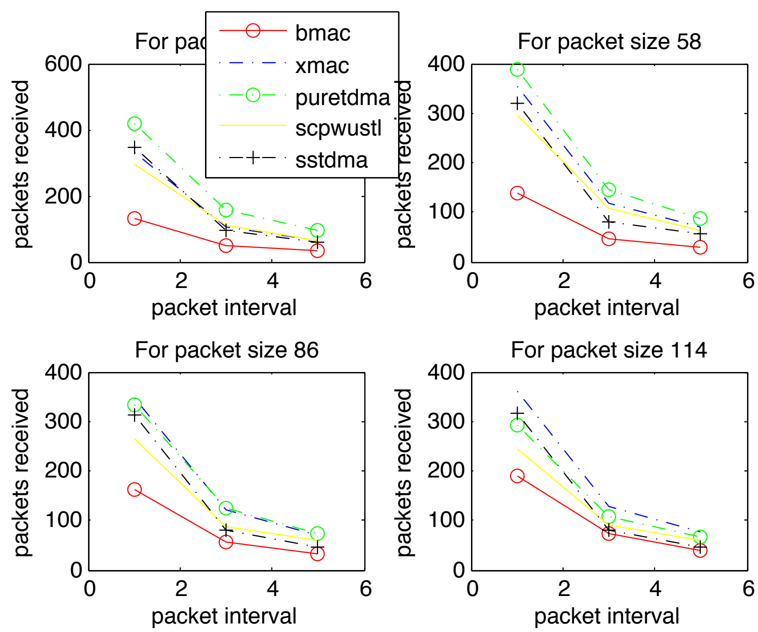

Figure 13: Throughput in star topology for varying packet interval (1s to 5s) with 8 sender nodes.

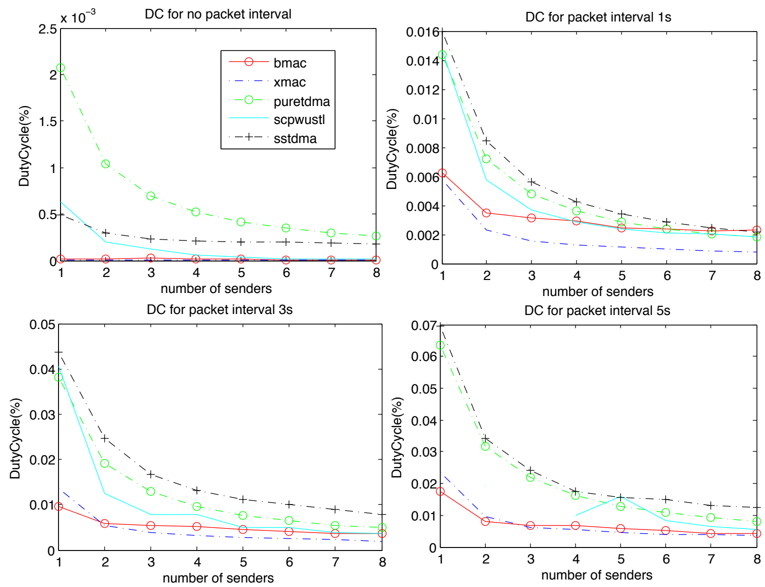

Figure 14: Average Duty Cycle of the receiver to receive a packet in star topology for varying number of nodes.

nodes i.e. any traffic load because each node send the same number of packets as slots allocated to it. Other protocols show decrease in duty cycle to send a packet for increase in load for no packet interval. If we introduce a packet interval SS-TDMA also shows the same duty cycle to send a packet for varying number of nodes. For more packet interval (i.e. more than 3 seconds) where the traffic load decrease TDMA and SS-TDMA has the same duty cycle because SS-TDMA has sufficient bandwidth to send it data.

- *For varying packet size*: Duty cycle to receive a packet increases as the packet size increase as it takes more time to receive a long data packet. TDMA protocol duty cycle increases in linearly for increase in packet size. Figure 15 shows the duty cycle performance to receive a packet for varying packet sizes. Figure 16 shows the average duty cycle sender nodes in the star topology. For sending a packet TDMA protocol has the same duty cycle for any packet size as it sends it long data packet in its slot and does not interfere with other nodes. Other protocols show a gradual increase in duty cycle to send a packet for increase in

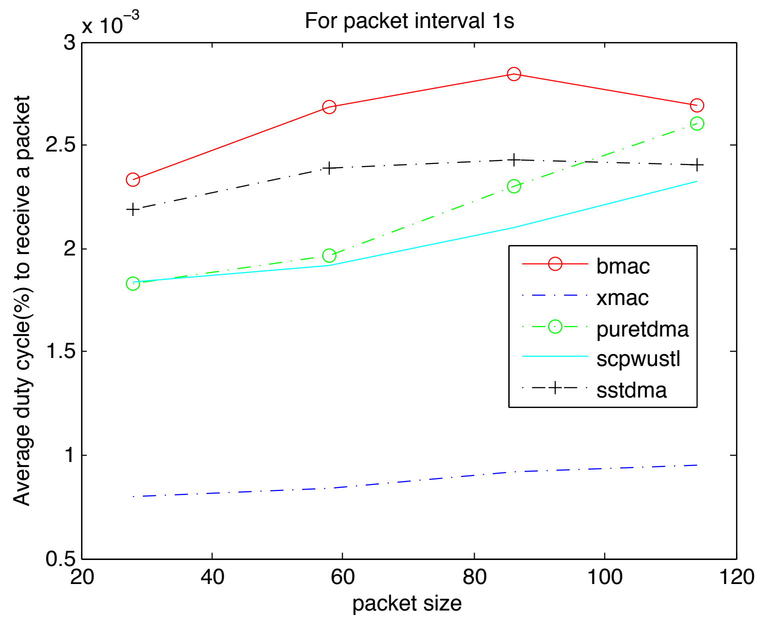

Figure 15: Average Duty Cycle of the receiver node to receive packet with 8 sender nodes in star topology for varying packet size.

packet size.

- *For varying packet interval*: As the packet interval increases the Duty Cycle also increases for receiving or sending a data packet as it spend more time in idle listening with no data to be received. Firstly, let us discuss about receiving a data packet. In CSMA based protocols the duty cycle to receive a packet increase as they spend more time in idle listening. In TDMA protocol the receiver duty cycle slope is very less as it wake up for every slot to receive data. When packet interval increases some senders does not send data to the receiver. Figure 17 shows the performance of different protocols for varying packet interval by the receiver node. Second case is duty cycle of a protocol for sending a packet. Figure 18 shows the variation of the sender duty cycle for different packet interval. SS-TDMA and TDMA has the same duty cycle for intervals form 3 to 5 seconds. As packet interval increase they spend more time in idle listening, checking the channel then doing the sending or receiving

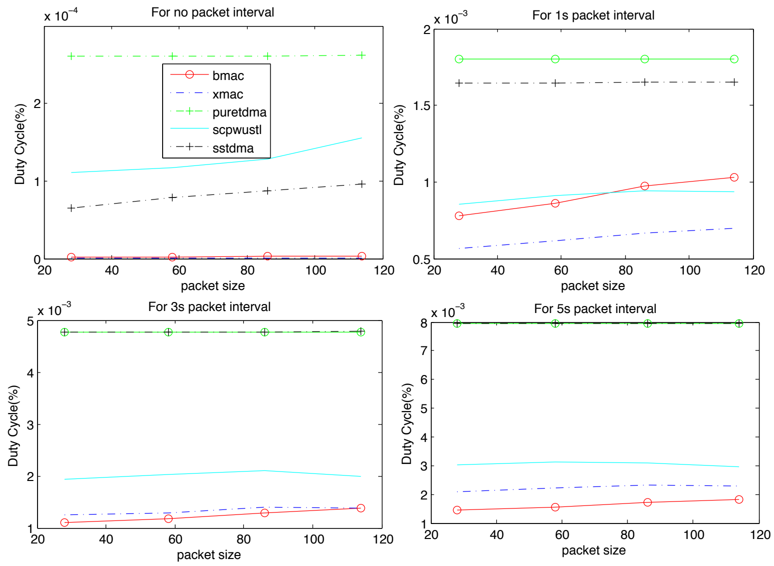

Figure 16: Average Duty Cycle of the sender nodes to send a data packet in star topology for varying packet size.

packets.

5.1.5 Power Consumption

For evaluation of power consumption we take the average power consumed by a node to receive a packet by the receiver node in the star topology network. Power consumption is measured by calculating the radio states of the node to receive or send a data packet.

- *For varying packet size*: As the packet size increase the power consumed by a node also increases as shown in figure 19. If the packet size to handle is more the radio of the node has to spend more time to receive a packet in receiving mode which increases the average power used.

- *For varying packet interval*: Figure 20 shows the variation of power consumed by the receiver node for varying packet interval i.e. the load in the network. CSMA based protocols like XMAC, BMAC and SCP show a decrease in power consumption as the traffic load decrease listening also decreases and packet lost

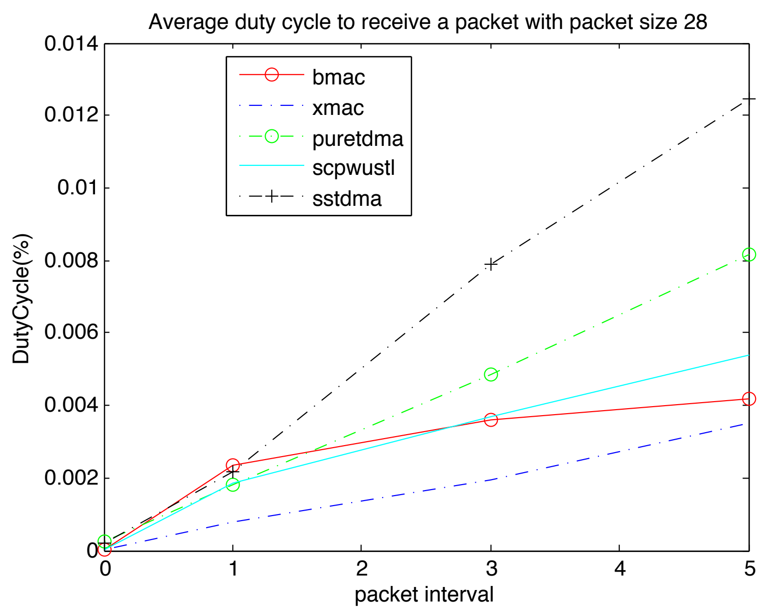

Figure 17: Average Duty Cycle of the receiver node to receive a packet with 8 sender nodes in star topology for varying packet interval.

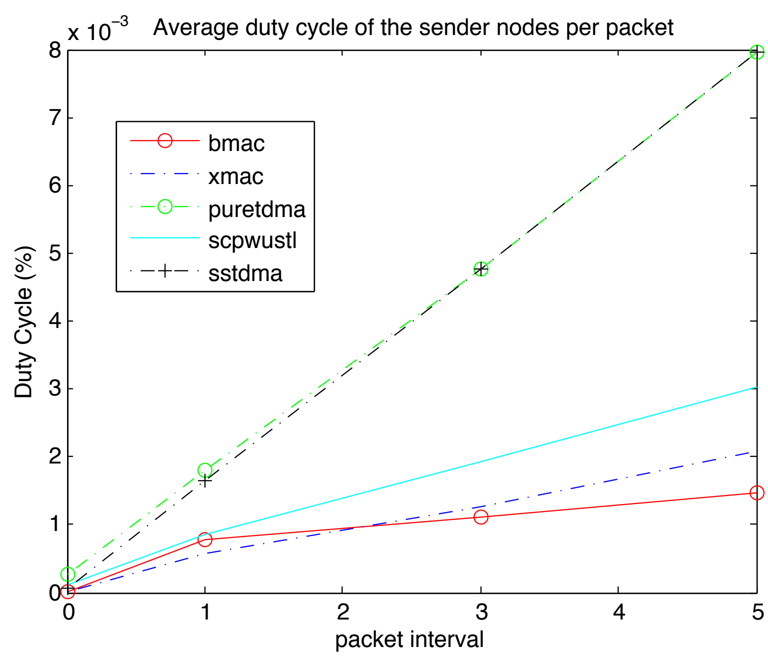

Figure 18: Average Duty Cycle of the sender nodes to send a data packet in star topology for varying packet interval.

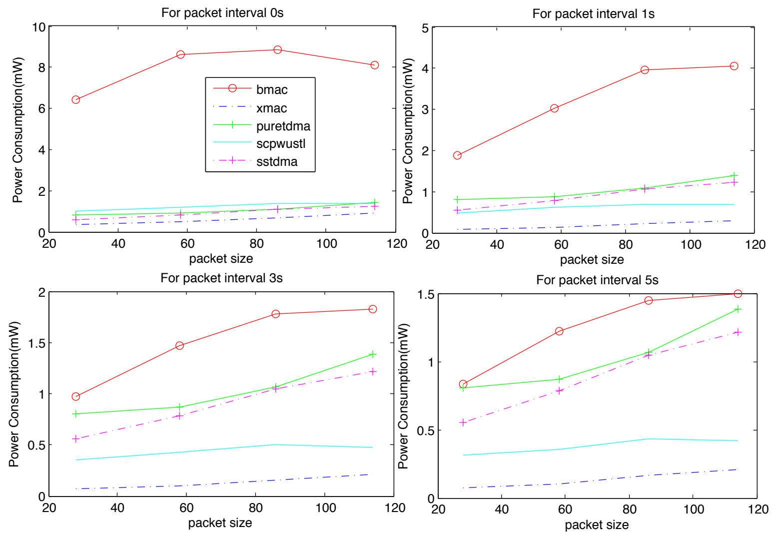

Figure 19: Power consumption to receive a packet with 8 sender nodes for varying packet size in a star topology.

also decreases. TDMA protocols have the same power consumption for different loads as it has allocated slots for each node in the network.

5.2 Line Topology

For line topology network we place 6 nodes in a line equally placed from each other. The first node in the line is the sink node. It is an asymmetric network with first and last node having one neighbor node and rest of the nodes have 2 neighborhood nodes to communicate.

5.2.1 Latency

We analyze latency performance of BMAC and XMAC protocols for varying packet size and network size. We reproduced the same experiment as in [17] but for different packet sizes and traffic loads.

- *For varying number of hops*: For line topology we vary the number of hops in the network. As the network increases the latency for a packet to take a round

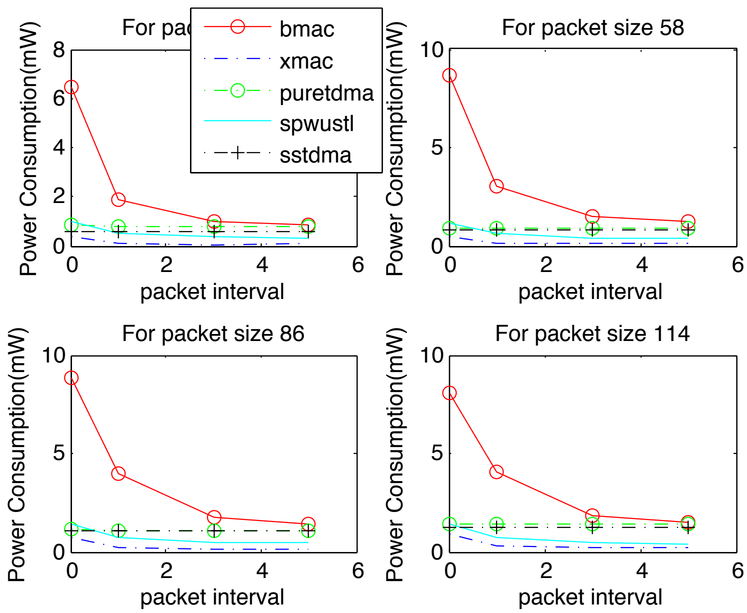

Figure 20: Power consumption to receive a packet with 8 sender nodes for varying packet interval(load) in a star topology.

trip increases as shown in figure 21. Increase in latency is less for XMAC as it uses small preamble to send the data. BMAC uses long preamble where it cannot send the data until the preamble is finished so it has relatively more latency than XMAC protocol.

- *For varying packet size*: As the packet size increase the latency to send a whole packet increases as it takes more time send a long byte of data. Figure 22 shows the performance of a protocol with respect to latency for varying packet size. XMAC has less increase in latency for more packet size than BMAC protocol.

5.2.2 Fairness

For fairness we calculate the standard deviation among the nodes in the network. If the standard deviation value is low it means that there is an adequate share among the nodes in the network to use the channel. To evaluate fairness value in a line topology we run experiment for 120 seconds. All the nodes in the network send

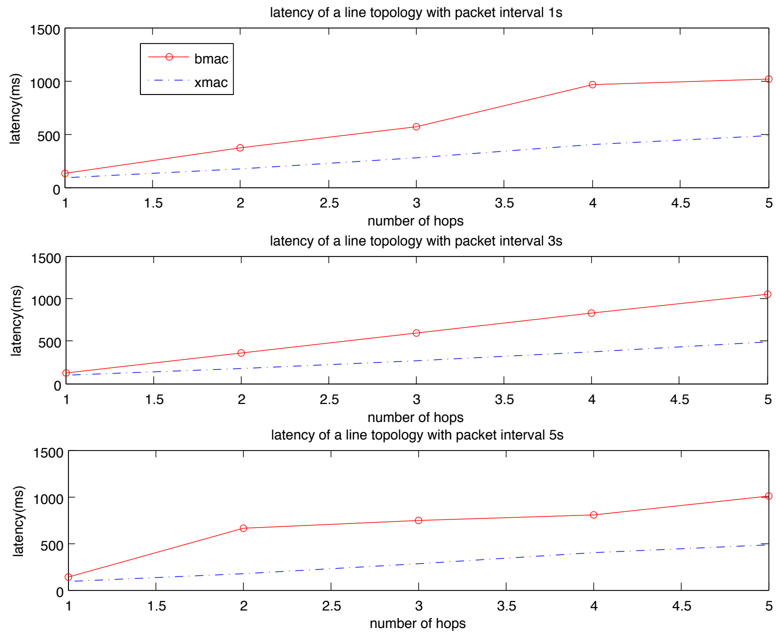

Figure 21: Latency in a line topology for varying number of nodes.

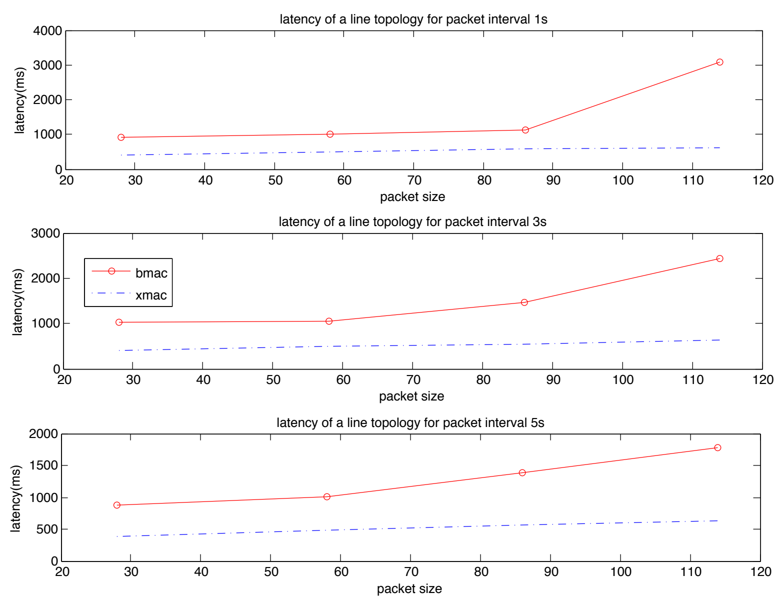

Figure 22: Latency in a line topology of 6 nodes for varying packet size.

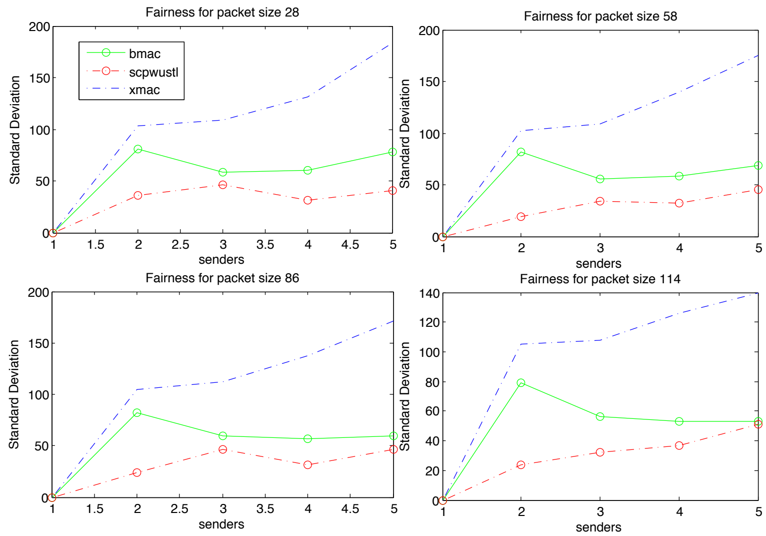

Figure 23: Fairness in a line topology for varying number of nodes.

the data periodically and forward the data from one node to another.

- *For varying number of nodes*: Figure 23 shows the change in fairness value for increase in number of nodes in the line topology. The fairness value increases as the number of nodes increase in the network. As the network size increase the traffic in the channel increases which leads to increase in standard deviation value.

- *For varying packet size*: On a comparison of three protocols SCP has less fairness value than BMAC and XMAC which is shown in figure 24. There is slight decrease in fairness value for XMAC protocol as it tries to send more packets as the design concentrates on latency and throughput. SCP protocol which uses synchronization has the same fairness value for different packet sizes.

- *For varying packet interval*: Fairness value decreases as the packet interval increases as shown in figure 25. As the packet interval is more the data packets sent by the node also reduces. As the data packet sent decreases the competition to use the channel by the nodes in the network decrease which results in better

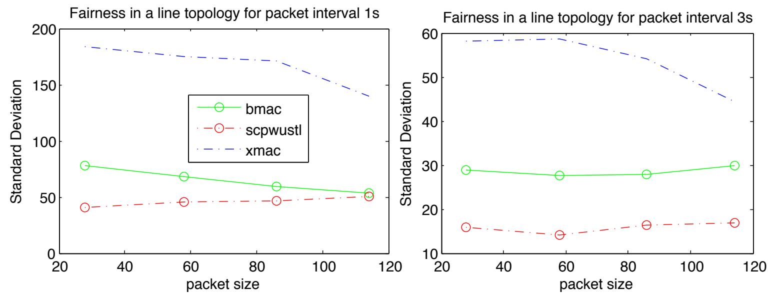

Figure 24: Fairness in a line topology of 6 nodes for varying packet size.

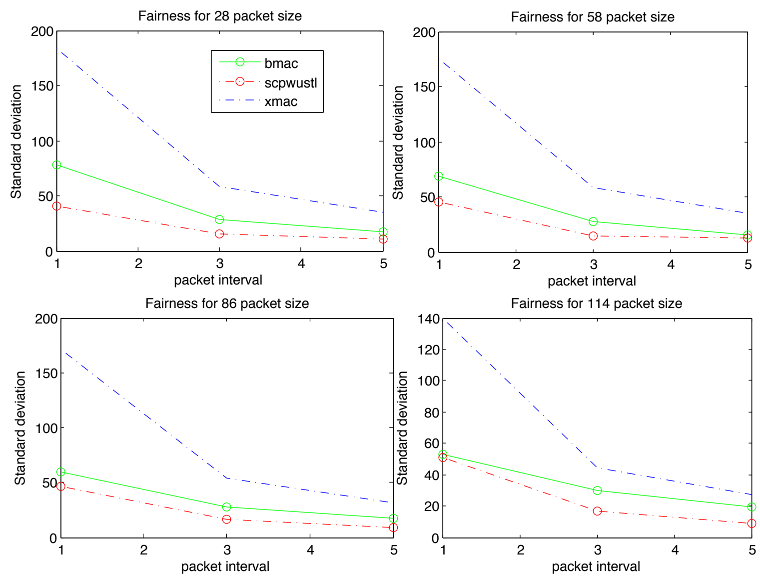

Figure 25: Fairness in a line topology of 6 nodes for varying packet interval(load).

fairness of the network. XMAC performs worst in terms of fairness for different packet interval as each node tries to send it data as soon as it can because of its short preamble.

5.2.3 Throughput

For measuring the throughput value in a line topology we consider the packet received by the sink node i.e. first node in the line. We consider first node as the sink node because in real application scenarios the first node is normally collects the data from the network and sends it to the computer for future analysis.

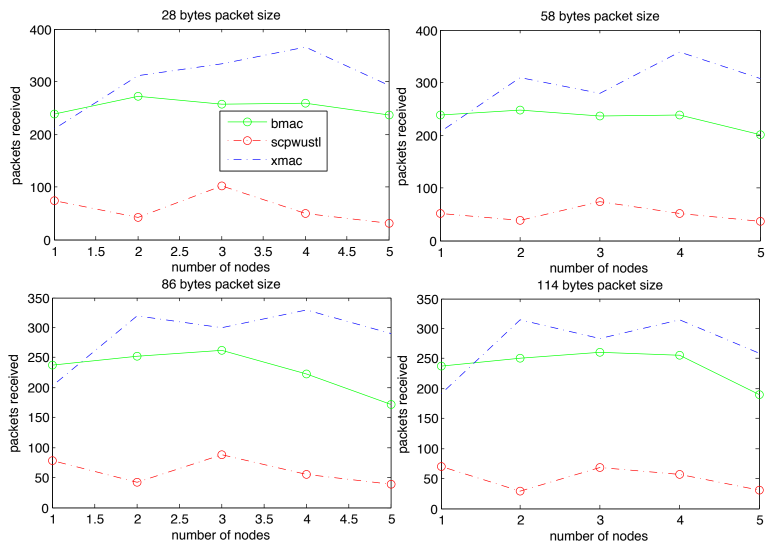

Figure 26: Throughput in a line topology for varying number of hops.

- *For varying number of hops*: In a line topology the first node and last node has only one neighborhood node to communicate. There is lot of packet lost in the network when taking a round trip. Figure 26 shows the throughput variation for varying network size. As the packets are received by a single node by the sink the throughput value is almost the same. When the number of hops increase there is packet lost due to which there is a slight decrease for 5 hop network.

- *For varying packet size*: We consider the number of packets received by the sink node to measure the throughput value. The throughput value decreases as the packet size increases becauce it takes more time to receive a long packet so there is a decrease in packet received for XMAC and BMAC which are CSMA protocols. Figure 27 shows the variation of throughput value for increase in packet size.

- *For varying packet interval*: Figure 28 shows the performance of protocols with respect to throughput for varying packet interval. Throughput decreases as there are less number of packets sends to the sink node for more packet interval. SCP protocol which is hybrid type has less change in throughput value for

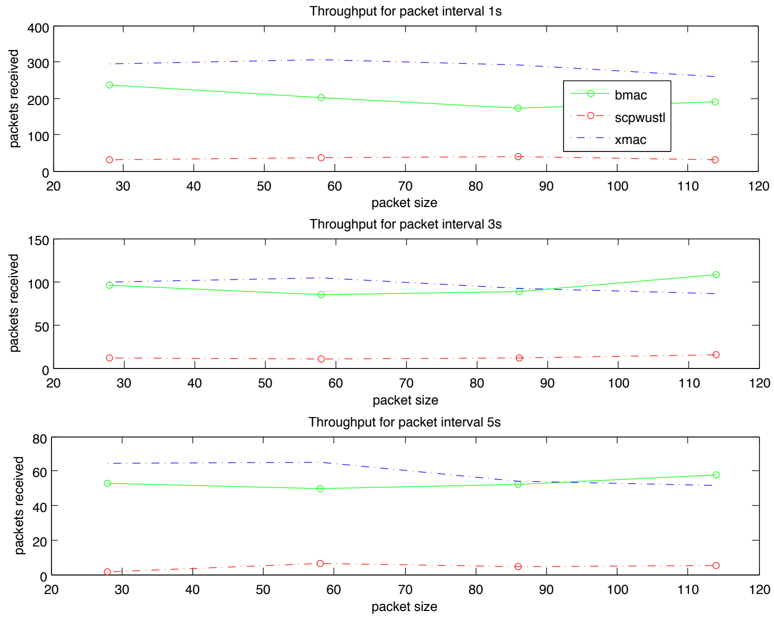

Figure 27: Throughput in a line topology of 6 nodes for varying packet size.

different packet intervals than XMAC and BMAC as it has synchronization over head.

5.2.4 Duty Cycle

For measuring the duty cycle of node in a line topology we calculate the average duty cycle of a node to send or receive a data packet. We evaluate BMAC, XMAC and SCP MAC protocols for a line topology network of 6 nodes.

- *For varying number of hops*: As shown in figure 29 duty cycle per packet of a node decreases as the network size of line topology increases as it handles more data packets. CSMA type of protocols such as BMAC and XMAC have almost the same duty cycle for varying network size with slight decrease. Hybrid protocol SCP has more slope i.e. there is much decrease in duty cycle to handle a data packet as it has over head of synchronization.

- *For varying packet size*: As shown in figure 30 there is not much difference in the average duty cycle of a node to receive or send a packet for different sizes.

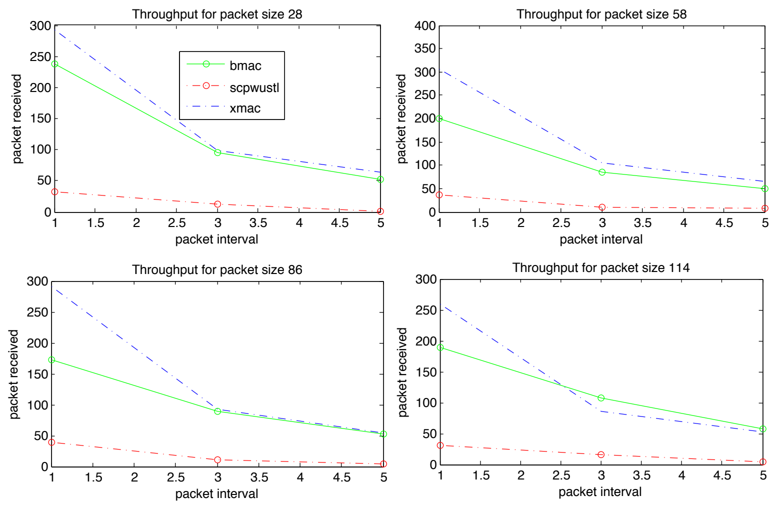

Figure 28: Throughput in a line topology of 6 nodes for varying packet interval(load).

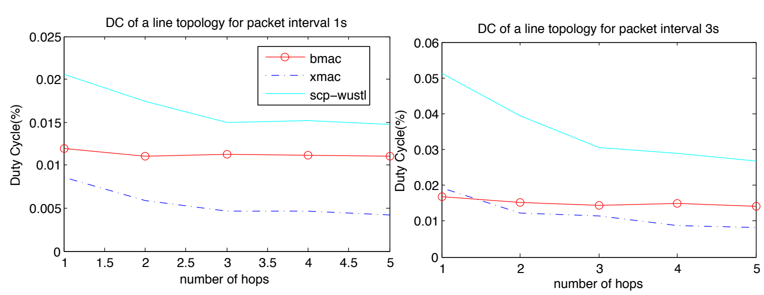

Figure 29: Average Duty Cycle in a line topology for varying number of hops.

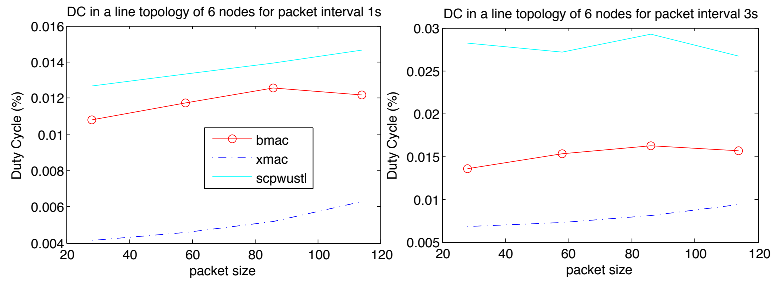

Figure 30: Average Duty Cycle in a line topology of 6 nodes for varying packet size.

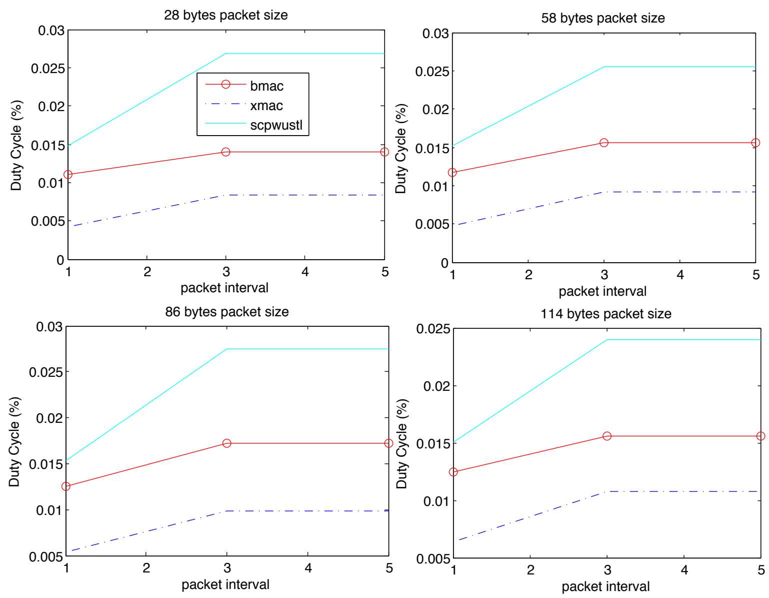

Figure 31: Average Duty Cycle in a line topology of 6 nodes for varying packet interval.

There is slight increase in duty cycle value from 0.0041% to 0.0063% for XMAC protocol and 0.0136% to 0.0157% for SCP protocol.

- *For varying packet interval*: As shown in figure 31 the duty cycle to send a data packet increases as the packet interval increase. As the packet interval increase most of the time is used for listening to the channel for CSMA and hybrid type of protocols and has less packets to handle. Duty cycle is almost the same when the packet interval is more i.e. less traffic in the network.

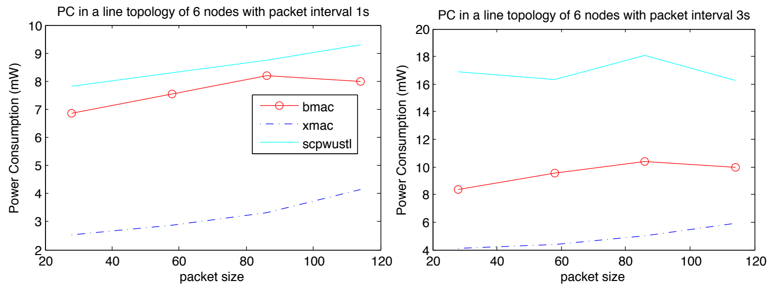

Figure 32: Average power consumption per data packet in a line topology of 6 nodes for varying packet size.

5.2.5 Power Consumption

Power consumption of a node is measured by calculating the time the radio is ON for different states. The time calculated by the software is multiplied by the power consumption of the mote in different states to get the total power consumed by the mote.

- *For varying packet size*: As shown in figure 32 there is slight increase in power consumption of a node to receive or sends a data packet as packet size increases. For more packet size the radio is operating for more time than the smaller packet size. XMAC shows the least power consumption than other protocols.

- *For varying packet interval*: As shown in figure 33 power consumption for a data packet increases as the packet interval increase as it takes more time to listen the channel to receive or send a data packet. The slope for SCP is more than BMAC and XMAC. SCP is hybrid type of protocol which has synchronization over head due to which the power consumed is more.

5.3 Ring Topology

In a ring topology all the nodes are arranged in a circle with equal distance between the motes. Below we explain about the analysis of the protocol performance

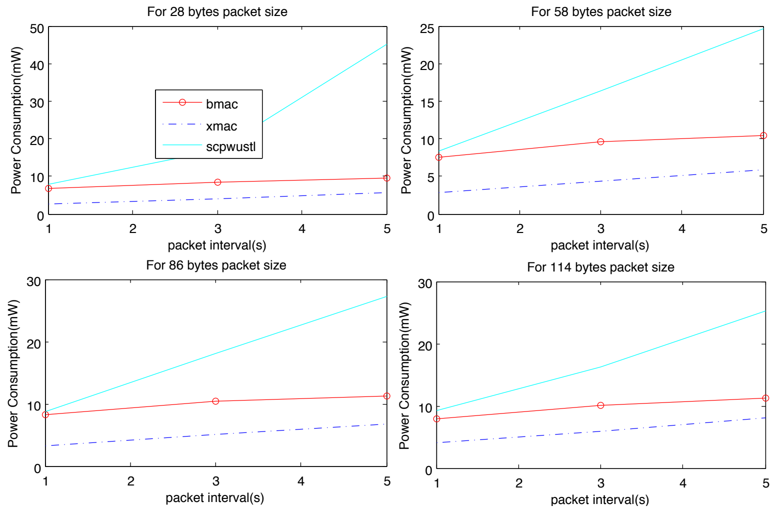

Figure 33: Average power consumption per data packet in a line topology of 6 nodes for varying packet interval.

in a ring topology.

5.3.1 Latency

We analyze the latency performance of CSMA based protocols like BMAC, XMAC on ring topology for varying packet size and network size. Latency is calculated by measuring the average time for a round trip.

- *For varying network size*: Figure 34 shows the variation in the performance of the protocols for varying hops from 1 to 5. XMAC protocol has less latency than BMAC because it uses short preambles and has an early acknowledgement. More number of hops the time taken for a round trip also increases. Ring topology has less latency than line topology network as it is a symmetric network with each node having equal load to handle.

- *For varying Packet size*: Figure 35 shows that as the packet size increase there is a gradual increase in latency to send or receive a packet. Average time taken for a round trip in a ring topology increases as the packet size increases as long byte of data tales more time to send and receive.

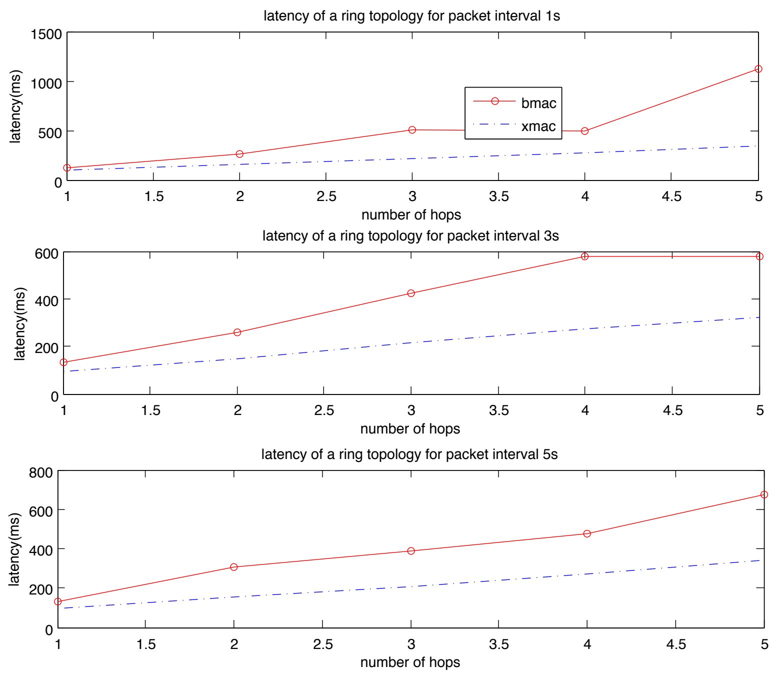

Figure 34: Latency in a ring topology for varying number of hops.

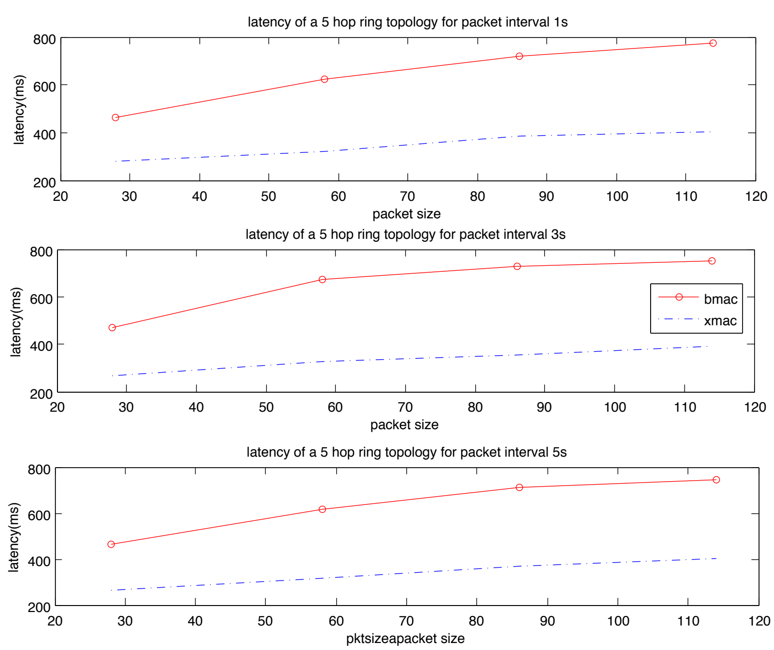

Figure 35: Latency in a ring topology of 6 nodes for varying packet size.

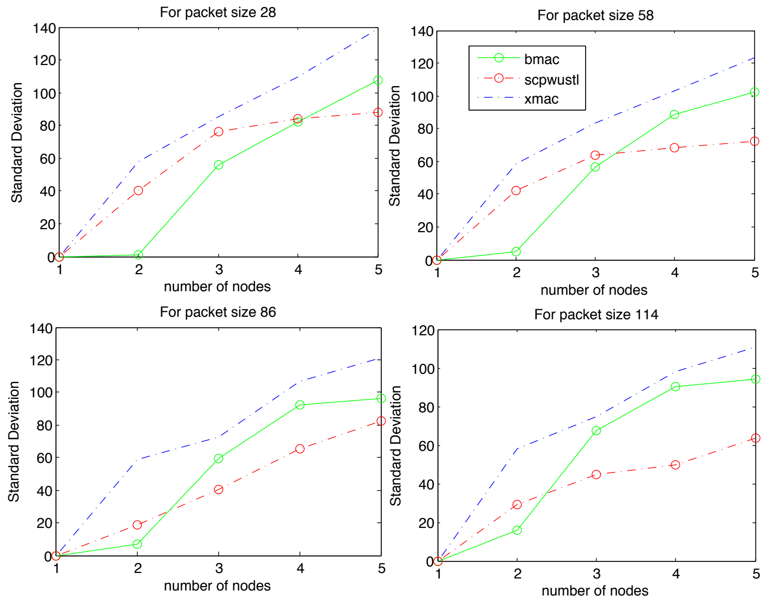

Figure 36: Fairness in a ring topology for varying number of nodes.

5.3.2 Fairness

For measuring the fairness for a ring topology network we run an experiment with each node in the network sends and forwards a data packet periodically from one node to another. For the 2 minutes experiments we measure the fairness of a MAC protocol for varying packet interval, packet size and network size. Standard deviation of the packets received by all the nodes is calculated as fairness.

- *For varying number of nodes*: Figure 36 shows the change in fairness value for increase in number of nodes in the network. Standard deviation value increases as the number of nodes increase as the share for a node to use the radio channel decrease as the network size increase. Performance of fairness in ring topology increases gradually has all the nodes in the network increase as each node has equal load to handle which is not the same in line topology which is asymmetric network(see figure 23.

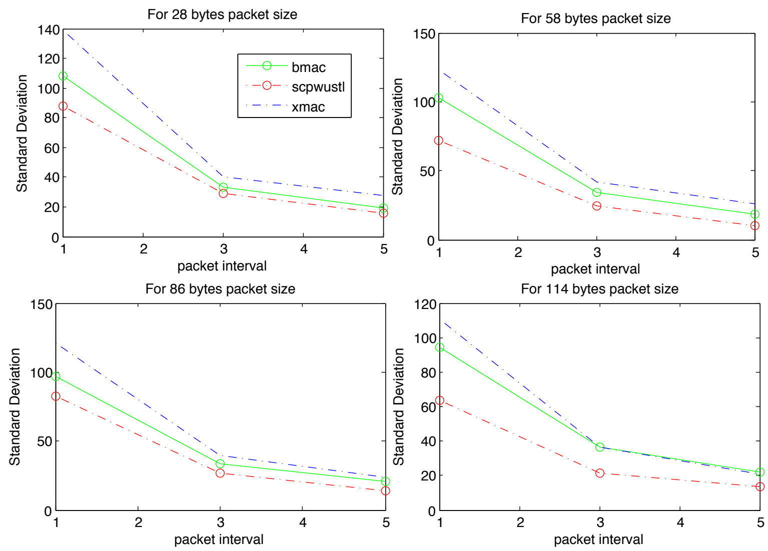

Figure 37: Fairness in a ring topology of 6 nodes for varying packet interval.

- *For varying packet interval*: For increase in packet interval the standard deviation value decreases for all the MAC protocols as shown in figure 37. Fairness performance of the protocol in ring is better than the line topology network(see figure 25). In ring topology each node has each neighborhood nodes and equal share to use the radio channel. In a comparison of BMAC, XMAC and SCP MAC protocols, the SCP shows less fairness as it a hybrid type of protocol which uses CSMA and synchronization.

5.3.3 Throughput

We measure the packet received by the sink node as throughput in the ring topology. Each experiment is run for 2 minutes where each node send and forwards the data packets.

- *For a varying number of nodes*: As shown in figure 38the throughput value i.e. the number of packets received by the sink node increases as the number of nodes increase as there are more packets to be send by each node. In line topology there is no increase in throughput value as it is asymmetric network.

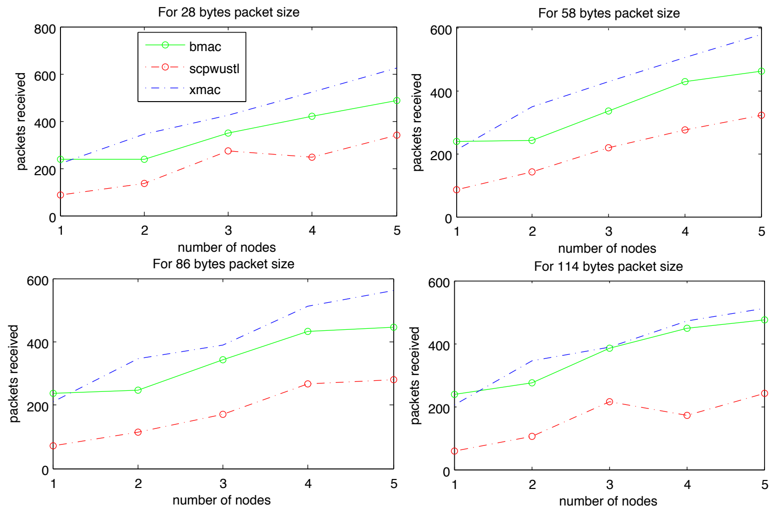

Figure 38: Throughput in a ring topology for varying number of nodes.

- *For varying packet size*: As shown in figure 39 packets received by the sink node slightly decreases for XMAC. For long data byte each node has to spend more time and more packet lost due to which packets received decreases.

- *For varying packet interval*: Throughput i.e. the packet received decrease as the packet interval increase. As the packet interval increase the number of data packets sent also decreases so the throughput also decreases shown in figure 40.

5.3.4 Duty Cycle

Duty Cycle is defined as the ratio of the time the mote is ON and total time taken.

- *For varying packet size*: Figure 41 shows the performance of the protocol in ring topology for varying packet size. Average duty cycle to send or receive a packet increases as the size increases as the radio is ON for more period of time to send or receive a long byte of data.

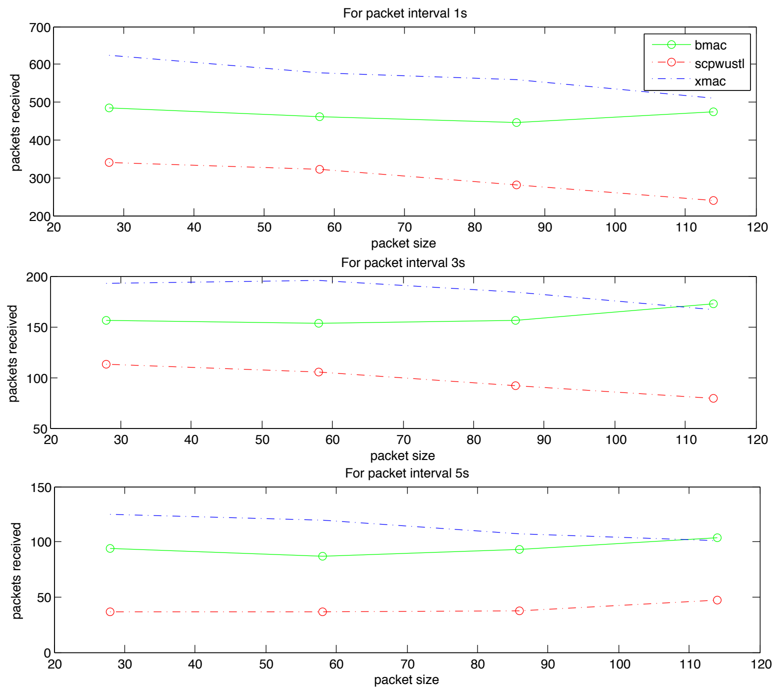

Figure 39: Throughput in a ring topology of 6 nodes for varying packet size.

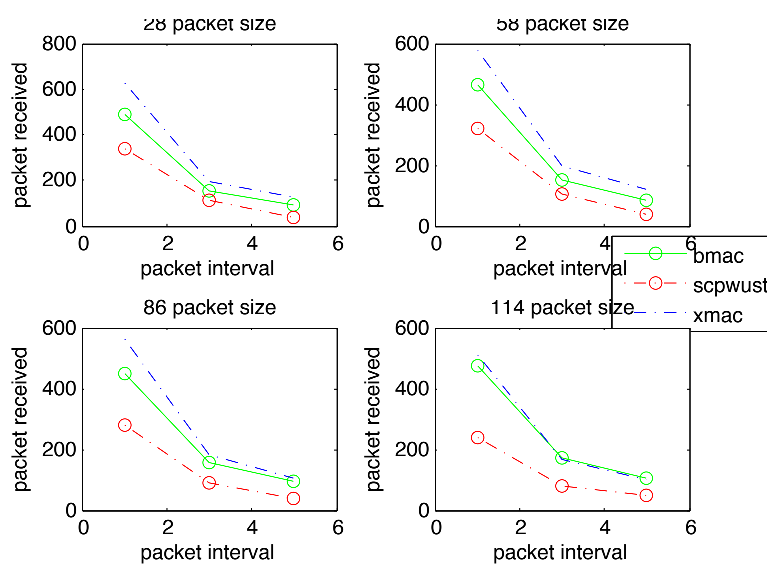

Figure 40: Throughput in a ring topology of 6 nodes for varying packet interval.

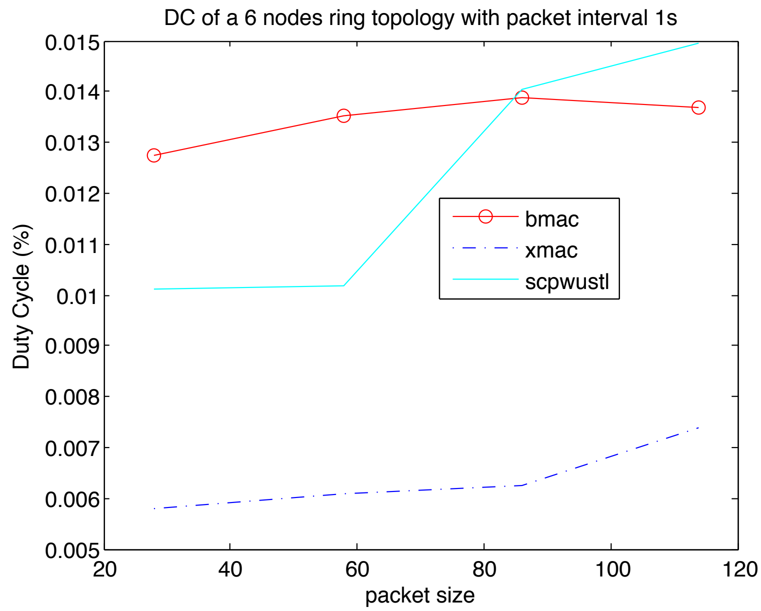

Figure 41: Average duty cycle per packet in a ring topology of 6 nodes for varying packet size.

- *For varying packet interval*: As shown in figure 42 the average duty cycle by a node to handle a data packet increases as the packet interval increase. When the packet interval is more each node handles less number of data packets and spends more time in idle listening.

5.3.5 Power Consumption

For evaluation of power consumption of MAC protocols we consider the average power a node consumes to send or receive a data packet i.e. power consumption per packet.

- *For varying packet size*: There is increase in the power consumption for increase in packet size. Figure 43 shows the performance of the MAC protocols in terms of power consumption for different packet sizes. Radio sends more time in handling a long data packet in receive and send mode which increases the power consumption of the node.

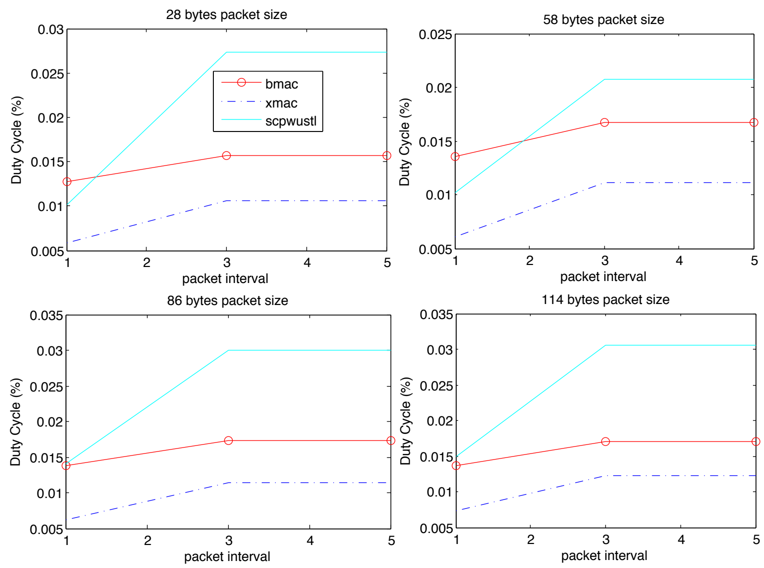

Figure 42: Average duty cycle per packet in a ring topology of 6 nodes for varying packet interval.

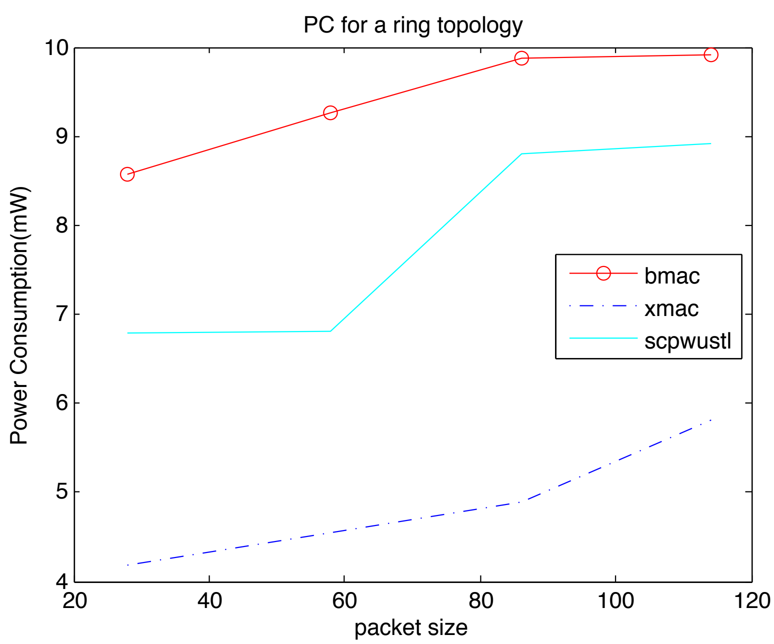

Figure 43: Average power consumption per data packet in a ring topology of 6 nodes for varying packet size.

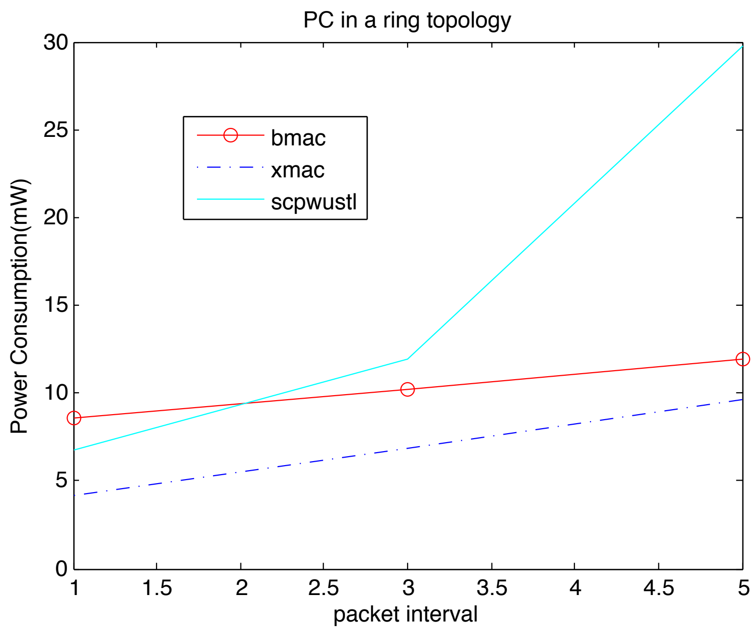

Figure 44: Average power consumption per data packet in a ring topology of 6 nodes for varying packet interval.

- *For varying packet interval*: As the packet interval increase power consumption of a node to handle a data packet increases as shown in figure 44. As the packet interval increase a node spends most of it time in listening rather than doing the actual work. On an average the power consumption per byte increase for less traffic loads.

5.4 Multi-hop Network

For evaluation and comparison of MAC protocols in a multi-hop network we consider fixed routing tree protocol so that there is no influence of other components. We consider 19 nodes with one node being the sink and other nodes send the data to the sink node using the fixed routing tree. Two possibilities of sink being in the center and corner of the network are considered.

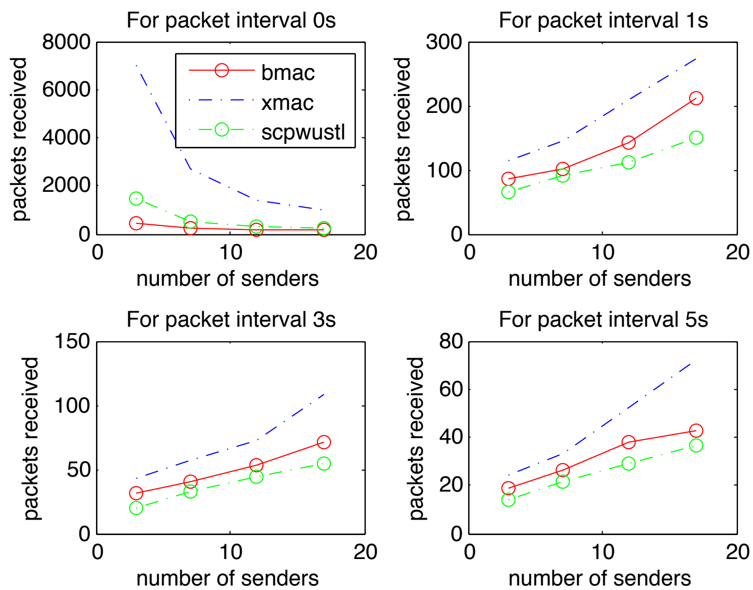

Figure 45: Throughput in a multi-hop network for varying number of nodes with sink at the corner of the network.

5.4.1 Throughput

First we will evaluate the throughput of multi-hop network with sink at the corner. We consider a network of 18 nodes each sending its data with different packet size, packet interval and varying number of senders.

- *For varying number of sender nodes*: Figure 45 shows the change in throughput value for different number of nodes. For no packet interval the throughput value decreases because there is more traffic in the radio channel. As the packet interval increases the traffic to use the channel decreases so there are more packets received by the sink node.

- *For varying packet size*: The packet received by the sink node decreases as the packet size increases as shown in figure 46. The slope of the XMAC is more for 1s i.e. the packet received for 28 packet sizes is more than 114 packet sizes as it uses shorter preamble and can send more packets.

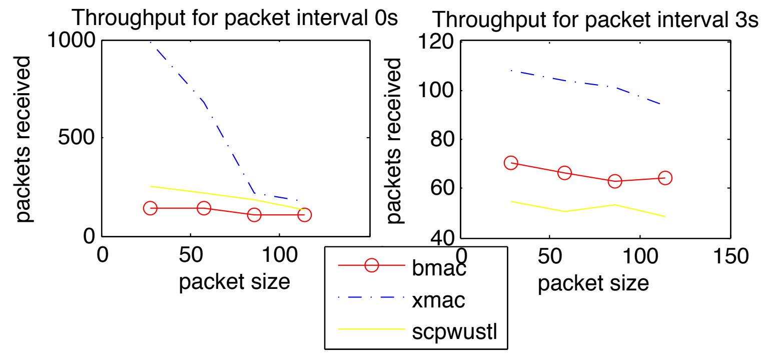

Figure 46: Throughput in a multi-hop network of 18 nodes for varying packet sizes with sink at the corner of the network.

- *For varying packet interval*: Variation of the throughput value i.e. the packet received by the sink node for different packet interval is shown in figure 47. Packet received by the sink node decreases for increase in interval foe 28 and 58 packet sizes as the number of sent packets also decreases. For packet size of 86 and 114 the packet received as increased for 0 seconds to 1 second packet interval. For more packet size and less packet interval the packet lost is more.

When the sink node is at the center of the network the performance plots of all the packets is the same only difference is that the packet received by the sink node i.e. throughput is more compared to when node is at the corner. As the sink node is at the center the number of hops from a node to the sink is less so there are less packet lost which makes the throughput value to increase.

5.4.2 Fairness

We evaluate the fairness value of a multi-hop network with all the nodes in the network sending its data to the sink node. Fairness of a network shows the share of a node to use the radio channel. We use 20 nodes which send the data periodically and forward the data from one node to another. We use the fixed routing tree for a

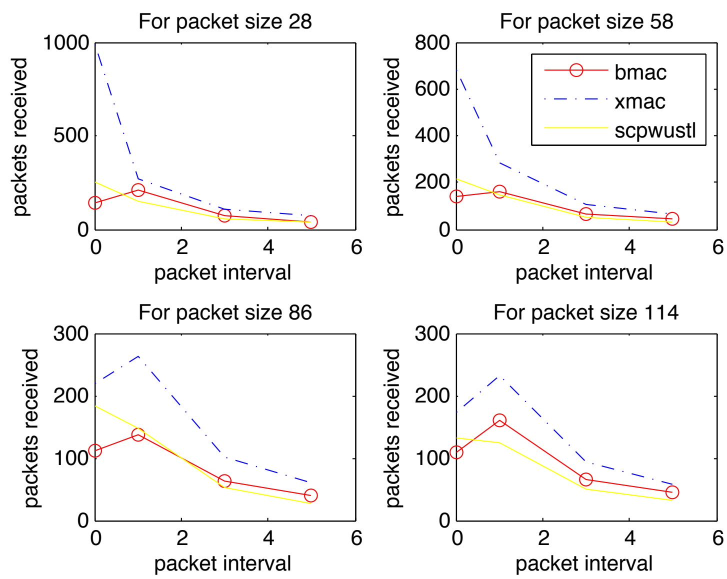

Figure 47: Throughput in a multi-hop network of 18 nodes for varying packet interval with sink at the corner of the network.

node to send its data. The lesser the standard deviation value the better is the share among the nodes in the network.

- *For varying number of sender nodes*: For a packet interval of 1 second the fairness value of a protocol increases with number of nodes as shown in figure 48. As the number of senders in the multi-hop network increases the channel usage by a node increases due to which fairness of the whole network becomes worst.

- *For varying packet size*: For a no packet interval where the nodes send the data back to back with heavy traffic load the fairness value decrease as the packet size increase as shown in figure 49. As the packet size increase the time to send the data increases due to which the contention for a node to use the radio channel is more.

- *For varying packet interval*: Fairness performance of a protocol for different packet interval is shown in figure 50. SCP protocol shows better fairness than

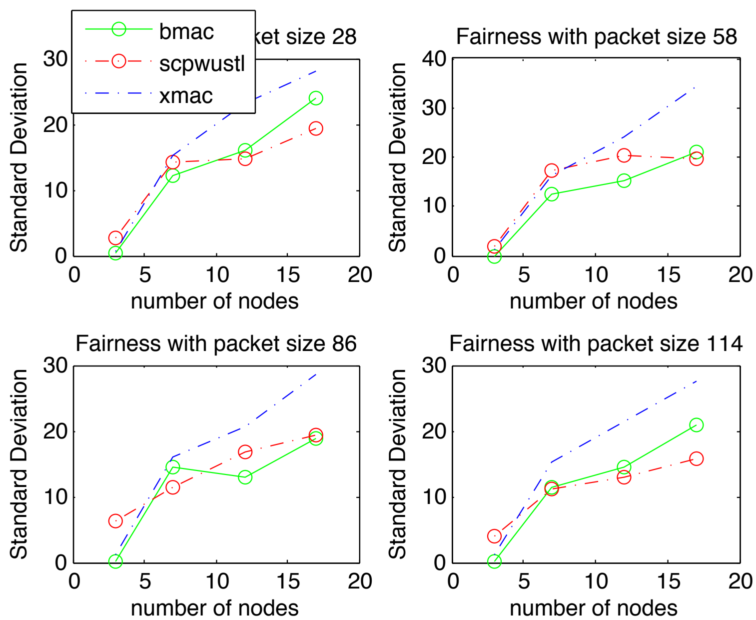

Figure 48: Fairness in a multi-hop network for varying number of nodes with sink at the corner of the network.

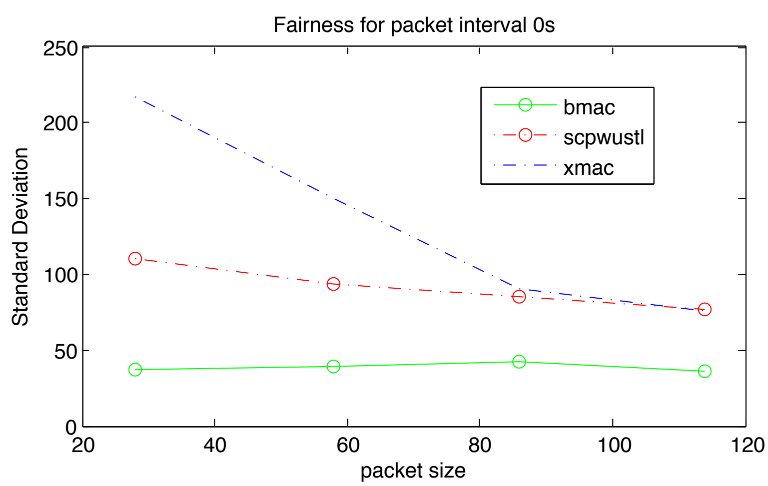

Figure 49: Fairness in a multi-hop network of 18 nodes for varying packet size with sink at the corner of the network.

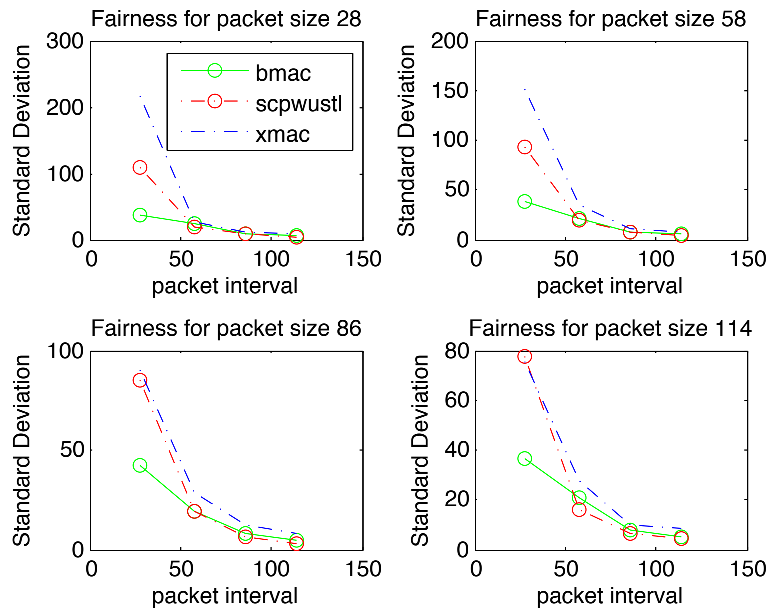

Figure 50: Fairness in a multi-hop network of 18 nodes for varying packet interval with sink at the corner of the network.

BMAC and XMAC as it uses synchronization. For more packet interval where is traffic is less the contention to use the channel decreases.

5.4.3 Duty Cycle

For duty cycle for a multi-hop network we measure the effective duty cycle of a node to receive or send a packet.

- *For varying sender nodes*: We measure the duty cycle per data packet received by the sink node for varying number of senders. For no packet interval the duty cycle increases as the number of sender's nodes or the network size increase as shown in figure 51. When the traffic is more the node spends more time in listening to the channel for which the radio is ON. When a packet interval is introduced i.e when traffic is less the duty cycle to receive a packet decreases.

- *For varying packet size*: Figure 52 shows the duty cycle performance of the MAC protocols for varying packet size. Duty Cycle increases with packet size

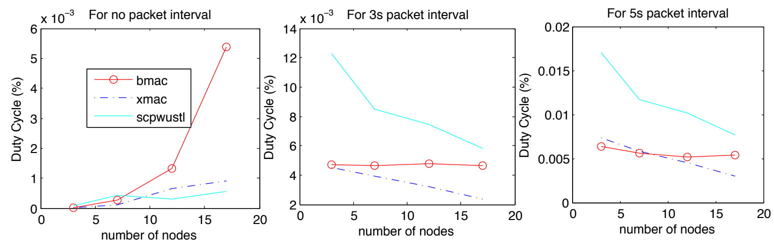

Figure 51: Duty Cycle of the sink node in a multi-hop network for varying network size.

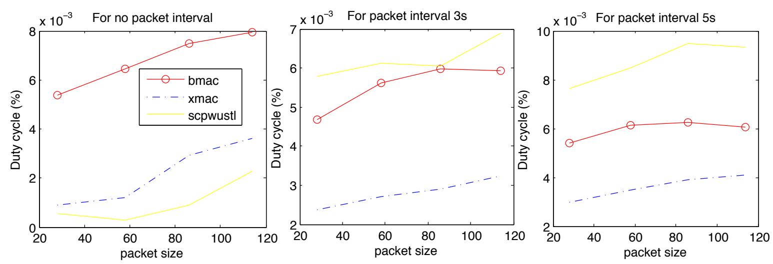

Figure 52: Duty Cycle of the sink node in a multi-hop network of 18 nodes for varying packet size.

as the radio usage is more for a long byte of data. BMAC has more duty cycle than other protocol as it uses long preamble for sending data. SCP has less duty cycle as it a hybrid type of protocol with a combination of synchronization and CSMA.

- *For varying packet interval*: For evaluation of duty cycle we consider the duty cycle of a mote to receive or send a data packet. Duty Cycle per data packet increases as the interval between the packets sent increases as shown in figure 53. For a multi hop network with no packet interval where the traffic is more the packet received by BMAC protocol is less and the duty cycle is more to receive a packet. For longer packet size like 86 and 114 byte XMAC and BMAC duty cycle decreases from interval 0s to 1s. As the packet interval is introduced the duty cycle increases as the interval increase.

While coming to the multi-hop network with sink at the center of the network. The variation of the duty cycle of the sink node for different scenarios is the same

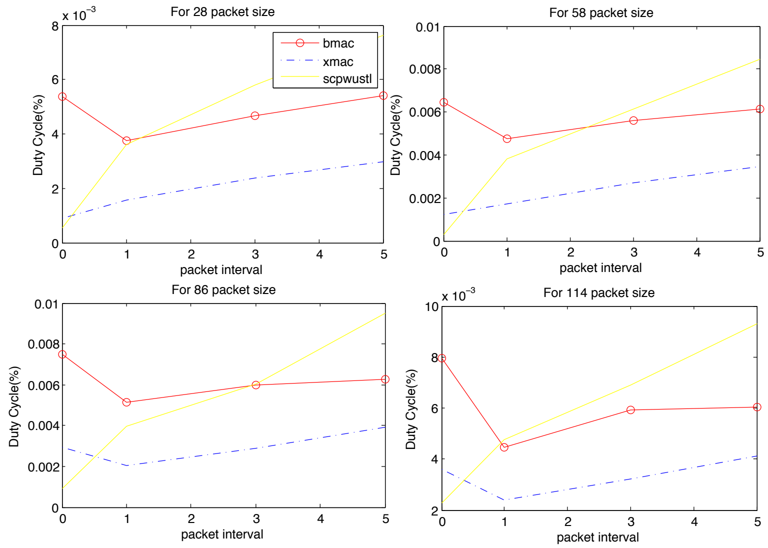

Figure 53: Duty Cycle of the sink node in a multi-hop network of 18 nodes for varying packet interval.

but the average duty cycle is less when the node is at the center when compared to corner sink.

5.4.4 Power Consumption

For evaluation of a MAC protocol with respect to power consumption we consider the average power consumed by the sink node to receive a packet.

- *For varying number of senders*: Figure 54 shows the variation of power consumption of the sink node for varying network size. For no packet interval where there is a heavy traffic the power consumed a node to receive a packet increases for more senders as it has to handle more packets and collisions in the network. As the packet interval is introduced SCP and XMAC show decrease in power consumed with increase in senders as it spend more power in idle listening.

- *For varying packet interval*: Figure 55 shows the variation of power consumed by a node to receive a data packet for varying packet interval. SCP shows more

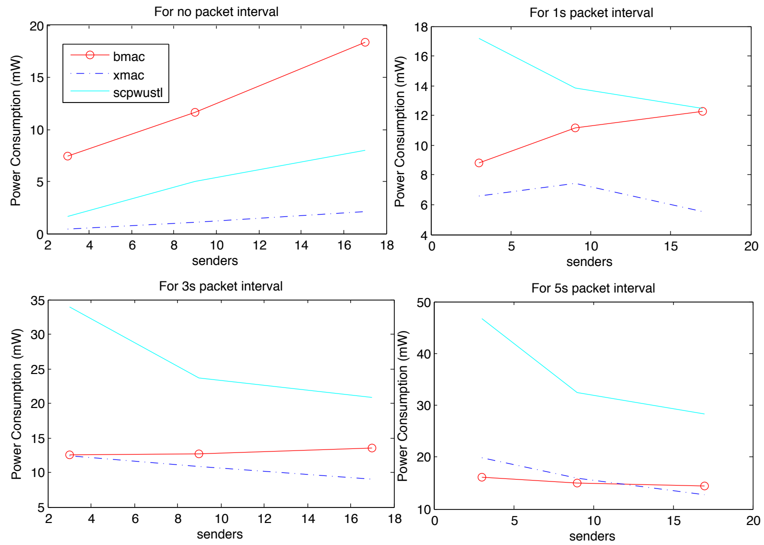

Figure 54: Power consumption of the sink node in a multi-hop network for varying network size.

increase in power consumption with packet interval as it as synchronization over head to be handled. BMAC and XMAC also increase for power consumption per packet but the increase is less as it uses CSMA with out synchronization.

5.5 Comparison with Analysis in MLA

In [17], they evaluated and compared there implementation of MAC protocols with the original ones. For their evaluation they have used star and line topology for evaluation of protocol with respect to throughput, latency and duty cycle. We adapted the same experiment set up for star and line topology. We also analyzed the performance of all MAC protocol with respect to throughput, latency and duty cycle on line and star topology but included the analysis for different traffic loads and packet sizes. In our analysis we included different topologies, traffic loads and packet sizes, so that it will be easy to see performance of a MAC protocol on different scenarios.

Comparison of our analysis with MLA for different metrics is as follows:

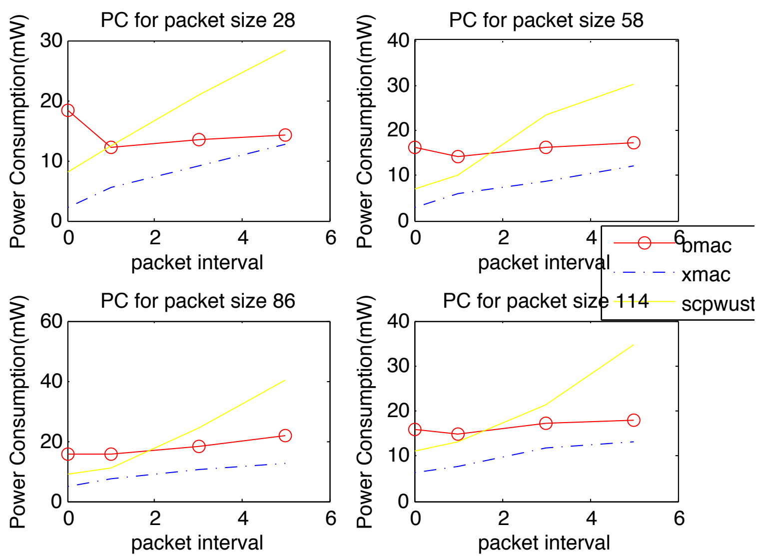

Figure 55: Power consumption of the sink node in a multi-hop network of 18 nodes for varying packet interval.

- *Latency:* For evaluation of latency in MLA they have used line and star topology. In line topology they calculated the time for a round trip for varying number of nodes from 1 to 6, when a packet is sent for every 3 seconds. We used the same method to calculate the latency with packet intervals of 1s, 3s and 5s. The values of the latency for packet interval 3s in MLA is almost the same with the values in our thesis. They used star topology to calculate the latency of pure-TDMA and SS-TDMA protocols as they are implemented for single hop network. In our analysis of star topology we calculated the latency in the same way as they did, but we show the latency all the 5 protocols. Latency of pure-TDMA and SS-TDMA in star topology is almost the same with the values in MLA.

- *Duty Cycle:* In MLA they calculated the average duty cycle of all the 6 nodes in a line topology latency benchmark experiment. In our analysis of line topology we calculated the average duty cycle of all the 6 nodes to handle a data packet, so that we can compare different protocols.

- *Throughput:* In MLA paper they calculated the throughput in kbits/s with star topology throughput benchmark experiment with packets sent with no packet interval i.e. each node sends data as fast as possible. In our analysis we consider number of packets received by the receiver node in a course of 60s. We vary the packet sizes and traffic loads for the same set up and analyze the protocol performance.

CHAPTER VI

RELATED WORK

There have been many papers that extensively evaluated the performance of different MAC protocol with respect to energy efficiency or duty cycle, but they do not consider all the metrics to evaluate performance. Various requirements in wireless sensor network make it necessary for designing different protocols. Previously, protocols are evaluated according to their design specification. Each MAC protocol has its own design goals. There is no common platform to evaluate a MAC protocol for a particular metrics. Many protocols are proposed in wireless sensor network each one has their own way of evaluating its performance it would be good to have a common method to evaluate different protocols. This paper focuses on experimenting on real sensor network.

In [21] analysis is done for the MAC protocols which are mainly used for applications with low data rate. All the experiments for evaluation are done using simulation with specific hardware, traffic load and network topology. Concentration of the work is on the protocol performance for latency and energy efficiency.

Evaluation of MAC protocols are mostly done through simulations. Simulation results are different from real sensor network. In [18] author uses signal to noise ratio (SNR) reception model in simulation to evaluate MAC protocols for different metrics through simulation. But the evaluation is not done on real sensor test bed. This paper they show SNR model gives almost accurate results for metrics such as energy consumption, latency and delivery ratio to evaluate protocols in a converge cast experiment setup. Only one topology is considered for evaluation and running experiments. Simulation results are compared with the real sensor network results. Fairness and duty cycle are not considered in this model.

In MLA layer architecture [17] paper, they have introduced component based architecture to implement the MAC protocols in wireless sensor networks. They have implemented BMAC, XMAC, SCP-WUSTL, PURE-TDMA and SS-TDMA protocols. Both the CSMA and TDMA type protocols can be implemented using this architecture. PURE-TDMA and SS-TDMA protocols are implemented for single hop network other three protocols are implemented for multi-hop network. Implemented protocols are evaluated just to see it functionality or performance with the original implementation. We adapted the few experiment set up from [17]. Evaluation with respect to all the metrics for different scenarios is not done.

In BMAC [9] which is CSMA based protocol is proposed to attain lower power consumption, duty cycle, latency compare to SMAC. The effective channel utilization is obtained by adapting preamble sampling. This has reduced the use of idle listening which consumes power when the mote is idle doing nothing. Fairness and good put of the network is not considered for evaluation.

In [19], they compare protocols in wireless sensor which are energy saving with standard CSMA/CA through simulation for a multi-hop network. They do the simulation by varying the time and location of the traffic in the network. They study about the MAC protocols which use carrier sense medium access technique. They conduct traffic driven experiments like event driven unicast and node to sink and evaluate the MAC protocol performance in the setup for throughput and fairness.

XMAC [10] protocol also reduces the power usage and duty cycle. It uses short preamble scheme which significantly reduces the power consumption of both the transmitter and receiver and the total latency. This protocol also has a advantage like flexible adaptation to high and low periodic traffic i.e. different traffic loads. Its performance is compared with low power listening MAC protocol for ring and line type topology network for different traffic.

SCP MAC protocol [13] is designed to obtain ultra low duty cycle of 0.1% and adapt to variable traffic loads. It is a hybrid type of protocol. Analysis of the protocol is based on single hop network and its performance is compared with LPL protocol. Multi-hop network analysis of the protocol is not done properly for this protocol evaluation.

Self stabilizing-TDMA (SS-TDMA) provides collision free communication and is customized for broadcast, converge cast and local gossip patterns. It gives a solution to TDMA type protocol for grid topology network. This protocol is evaluated against CSMA collision avoidance protocol through simulation and the results show that SS-TDMA provides better collision free communication.

In this thesis we consider analysis of protocol as a model of different metrics and scenarios where all experiments are done on real sensor network. The designed frame work model gives a extensive analysis of a protocol which can be used by researches to select or evaluate a protocol. We try to make a common platform for evaluation and comparison of MAC protocol on actual sensor network.

CHAPTER VII

CONCLUSION

We propose an analysis frame work model, where protocols can be measured easily on real sensor network for different networks and application scenarios. In this thesis we have evaluated different MAC protocols for various topologies, packet sizes and traffic loads.

We considered CSMA, TDMA and hybrid type of protocol like BMAC, XMAC, TDMA, SS-TDMA, and SCP which are build using UPMA architecture. We analyzed their performance on a common metrics of latency, fairness, throughput, power consumption and duty cycle. With exploration of protocols with respect to different parameters like traffic load, packet size and networks has given us interesting protocol features for different topologies.

From varied range of experiments of all the MAC protocols, we have found interesting features for different metrics as follows:

- In terms of latency, XMAC performances better than other protocols when the data packet is small but for long bytes of data SS-TDMA shows good performance.

- XMAC protocol has better throughput and power consumption per data packet values than other protocols as it uses CSMA with short preambles. On high traffic load XMAC shows high performance in terms of good put.

- In terms of fairness performance in a network pure-TDMA has the best performance as it uses slot allocation to all the nodes. In line and ring topology network SCP protocol shows better performance in fairness as it uses adaptive channel polling.

- Duty Cycle of XMAC protocol is less than other protocols but when there is heavy traffic load in multi-hop network SCP shows less duty cycle per data packet.

The work of this thesis analysis model and framework can be used by different research communities for selecting a protocol that suits their application, but as well help the protocol designers to see the significance of different designs and provide effortless comparison with the existing MAC protocols.

7.1 Future Work

Evaluation and comparison results in this thesis can be used to analyze which MAC protocol best suits a particular application in wireless sensor networks. A new MAC protocol can be evaluated to test the implemented harness. Furthermore, the evaluated results of different protocols on real sensor network are to be compared with the simulated values.

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