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# Evaluation of Cross-Layer Glowworm Swam-Oriented Medium Access Control Protocol in Wireless Sensor Networks: An In-Depth Analysis

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***Abstract***
Wireless sensor networks (WSN) are becoming widely used in collecting and sensing information in different fields such as in the medical area, smart phone industry and military environment. The main concern here is reducing the power consumption because it effects in the lifetime of wireless sensor during commutation because it may be work in some environment like sensor in the battlefields where is not easy to change the battery for a node and that may decrease the efficiency of that node and that may affect the network traffic may be interrupted because one or more nodes stop working. In this paper we evaluated Cross-Layered Glowworm Swam Oriented (CLGSO)S-MAC protocol and shows the sequence of events the sender and receiver go through. We tested some parameters and their impacts of on the performance including System throughput, number of packets successfully delivered per second, packet delay, average packet delay before successful transmission.

***Keywords:*** Wireless sensor Network, CLGSO-MAC, Power consumptions, Network lifetime, Error rate

## 1. Introduction

Wireless sensor network contains a huge number of nodes deployed in the fields with capability of communicating, computing and sensing in a certain way. Sensor nodes collect data in specific area and the main task is to exchange and transfer the information between nodes in wireless network. The CLGSO S-MAC protocol is designed in wireless network sensor nodes that have limited-energy batteries [1-3]. The MAC layer is responsible about the power management of and nodes are supposed to use the small amount of energy in order to increase the lifetime of the battery included in each sensor [4, 5]. Nodes periodically switch between two states; sleep and awake so the sensor nodes can lower the power consumption because it does not have to be active and use the power all the time, only periodically and in the case of sending or receiving date. Unlike CLGSO S-

MAC protocol, other MAC protocols consume more energy because it has to work continually to transfer and exchange packets while communicating with other nodes in the network [6-9].

To develop an energy-efficient MAC protocol in the wireless sensor networks, we should analyze the following factors which have the main effect on the power consumption:

1- **collision**: if two packets are exchanging date and in the state of sharing the wireless channel in competitive mode, there a high possibility of collision while communication and that will lead to retransferring the data frequently. That's will lead to more energy to be used which reduce the efficiency of the sensor.

2- **Idle listening**: it means the energy is expanded by having the node is on to show that the node is ready to exchange date. E very node in the network is not able to know when it is going to receive data from its neighboring node in the same network. RF module must be in the receiving state while receiving packets from other nodes. However, this will waste a large energy in the network and decrease the data rate in. The idle listening problem in wireless networks can be reduced by putting the node into sleep mode.

3- **Overhearing**: overhearing refers to the situation when the node is receiving date from other node, but that date is intended to another node in the same network. In this case, the node will be on continuously which means increasing the power wastage. This problem can be overcome by switching the node into off state to save energy in the sensor.

4- **Overhead**: one of the main challenges is the Control Packet Over-head. The Control Packet does not have any date but still important for the communication in the network. Control packet should be avoided to reduce the cost of sending the date. While exchanging the date or listening control packet the power is needed, we should decrease the control message as less as we can since there is no transferring data in that packet. That will increase the possibility of having the data sent correctly.

## 2. Related work

Power consumption is a critical factor in MAC protocols [10],[12], and they have a big impact on the network performance. There are efforts in the research that studied and analyzed power consumption for MAC protocols [11, 13, 14].

In [15] presented a new protocol that is a Traffic rate adaptive SMAC protocol in wireless sensor networks. The suggested work reduced the latency, improved the throughput, and reduce the power consumption significantly. The protocol can overcome any increase in the traffic of the data. There two main parts of the suggested work; robust transfer for the packets which is based on a requested in the network and adaptive duty cycle that is on rate of the traffic. They compared the work with XMAC and WMAC in terms of latency and throughput in each packet. They showed they their work outperformed these protocols in latency and throughput. In addition, it is more power efficient in a large network with a huge number of connected devices.

In [16] they studied and analyzed a duty cycled asynchronous XMAC protocol for wireless sensor networks. They evaluated the impact of the hidden terminal in such network. A Markov approach was proposed to investigate the quality of service for delay, the power consumption and throughput. The simulation results for their model showed that it their protocol is more accurate and efficient with variant network conditions compared to other protocols. Also, it provides designers a clear understanding of the impact of mobility on the sensor node and how could that affect the general performance. However, the

model could suffer from the hidden nodes that may cause collisions in the network which could leadto more power consumption.

In [17] a dynamic duty-cycle mission critical MAC protocol (MMAC) was presented that is based on regression. The analytical study shows that MMAC increase the lifetime of the network as it provides more power saving compared to SMAC by 40% for the whole network and close to 20% in critical node in the path to the base station. In Addition, it provides a better result in terms of delay, packet rate delivery, and throughput. They claimed that the MMAC performs well in case of high number of nodes in the network where it has high amountof sadden traffic. They showed that the arrival time is lessthan 1 second. However, in their work only 11 nodes were tested including the sink node and more investigation is required with higher number of nodes in the network to velate the results of the network performance.

Rehman and Masood [18] proposed an adaptive duty cycle protocol, VTA-SMAC (Variable Traffic-Adaptive Duty Cycle Sensor MAC). The presented work reduces the effect of the collisions and idle listening on power consumption compared to the traditional SMAC. To verify and evaluate the result, a simulation was implemented with variant date traffic[19],[20] to evaluate such variation effects on the power consumption. Also, other factors such as delay, collisions, and throughput were analyzed. Trade of between latency and power consumption was investigated. The results show that the proposed protocol reduce the power consumption by 19%, 14$ and 20% at low, medium, and high traffic. Also, the latency is reduced by 10.

**Description of the Implementation:**

We have used NS2 to simulate the wireless sensor network environment; we have also deployed the S-MAC protocol between the sensors when there is a connection in between. We performed two main scenarios to investigatethe effect of one factor each time.

The first scenario utilizes the CLGSO S-MAC protocol with thesynchronization flag is 0, the following parameters describes the scenario:

a. The number of sensor nodes is 20
b. The number of connections between the nodes is 8.
c. Data packet size is 512 byte.
d. The packet generation rate is 4 packets per second.
e. The control packets (RTS, CTS, ACK, and NAK)size is 10 byte.
f. The duration of simulation time is 200 seconds.
g. The time in which sensors communicates is overlapped.
h. The nodes are mobile.

The second scenario utilizes the CLGSO S-MAC protocol with the synchronization flag is 1 all the time, the following parameters describes the scenario:

a. The number of sensor nodes is 20
b. The number of connections between the nodes is 2.
c. Data packet size is 128 byte.
d. The packet generation rate is 2 packets per second.
e. The control packets (RTS, CTS, ACK, and NAK) size is 10 byte.
f. The duration of simulation time is 200 seconds.
g. The time in which sensors communicates is not overlapped.
h. The nodes are mobile.

**Performance analysis:**

In this section we investigate the effect of increasing/decreasing each factor on the

throughput (Kbps) and the average end-to-end delay before successful transmission.

**1. Packet generation per second:**

First scenario:

For this factor we can see that as packet generation increases the throughput increases too as in figure 1, this happens till we reach 10 packets per second after that the throughput decreases when the packet generation keep increasing. When we look at the delay, we can see that delay increases by increasing packet generation till we reach 20 packets per second, after that the increasing in delay is not significant.

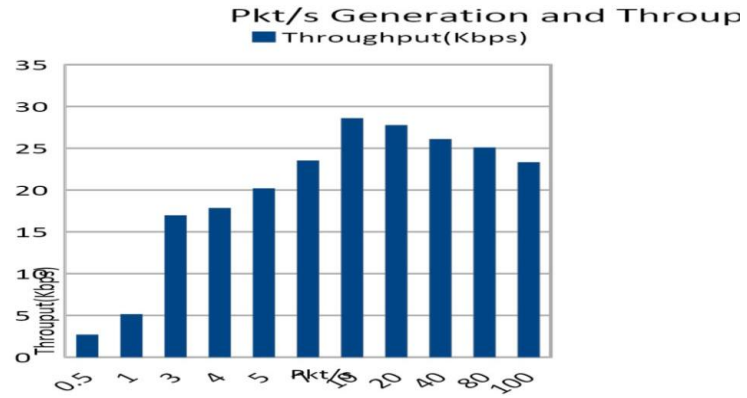


Figure 1: Packet Generation and Throughput

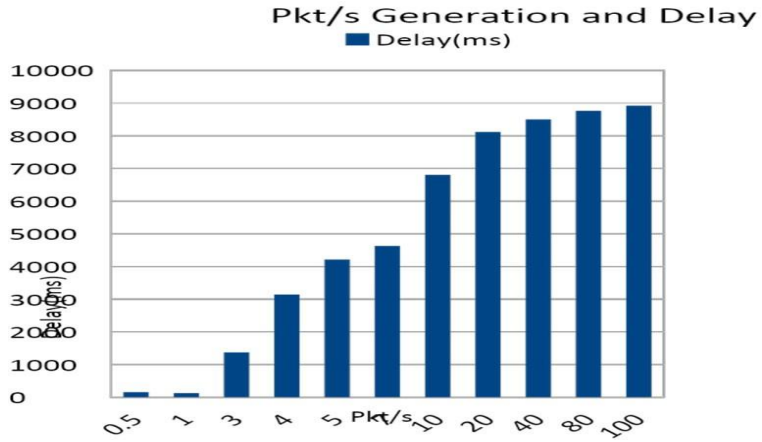


Figure 2: Packets generation and Delay

Second scenario as in figure 2: For this scenario we can see that the increasing in packet generation leads to decrease throughput although the decreasing is not regular as shown in figure 3. Another note is the increasing of packet generation is limited in this scenario. In figure 4 the delay, we can see that in the beginning as packet generation increases the delay increases too, after that it decreases.

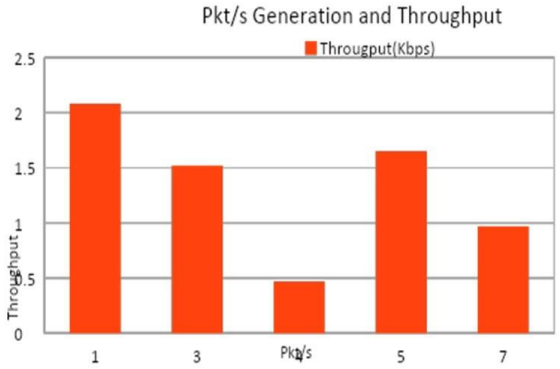


Figure 3: Pkt/s Generation and Throughput

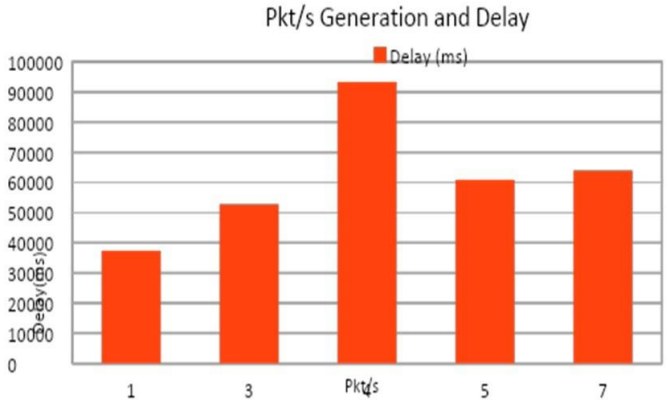


Figure 4: Packet Generation and Delay

**2. Packet length in bytes:**

First scenario: it's obvious in figure 5 when the packet size increases the throughput keep increasing too. For the delay as in figure 6, when the packet size is between 32-2000 bytes the delay is almost the same, but after that it increases.

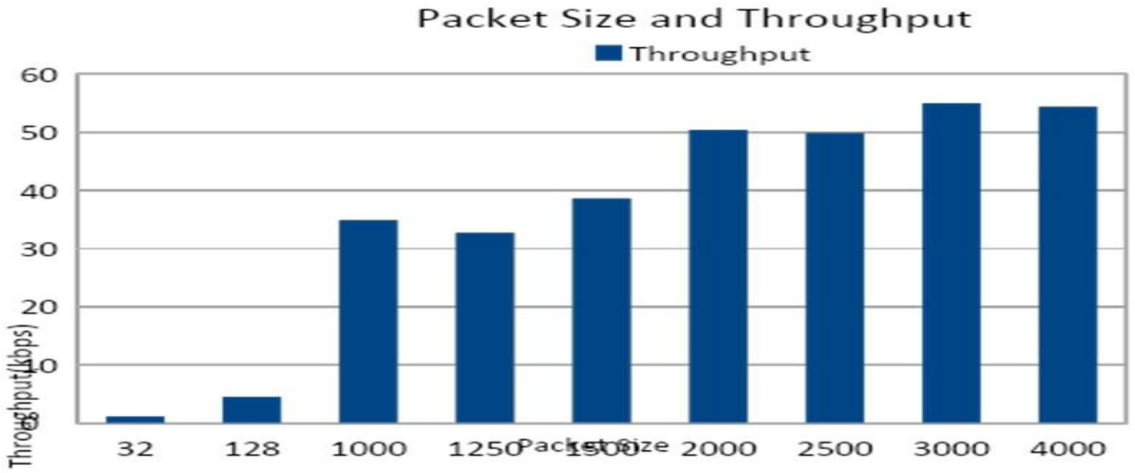


Figure 5: Packet Size and Throughput

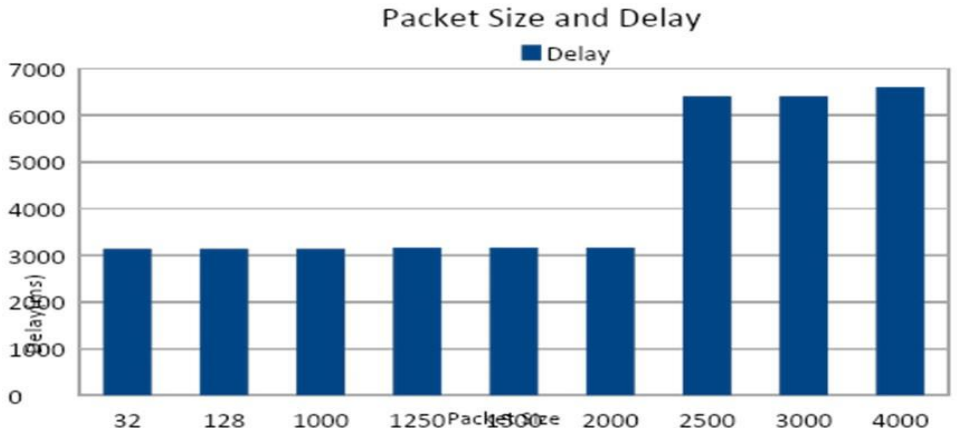

Figure 6: Packet Size and Delay

Second scenario: in figure 7 we can notice here as the packet size is between 32-1000 byte the throughput is less than or equal 0.5 kbps, but for 1500 byte packet the throughput is 2 kbps, in general it's a low value for both. For the delay as in figure 8, we can say the delay is high inthis scenario and almost the same for the different packetssizes.

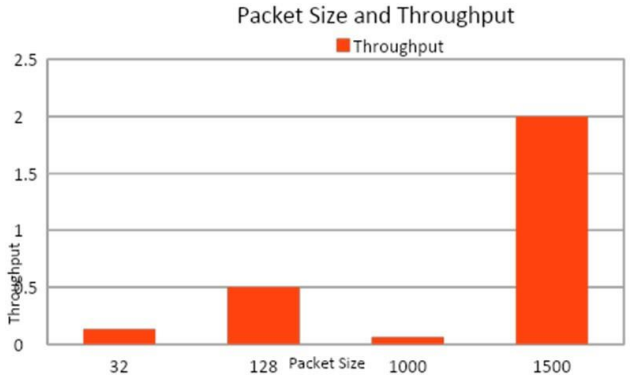

Figure 7: Packet Size and Throughput

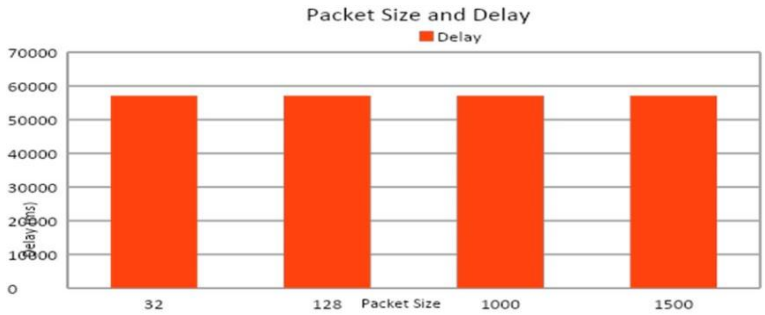

Figure 8: Packet Size and Delay

### 3. Control packet length (RTS, CTS, ACK, NAK) in bytes:

First scenario: we can see that the increase in control packet length will decrease the throughput as in figure 9 but not significant decrease. For the delay as in figure 10, it is also increases when control packet length increases.

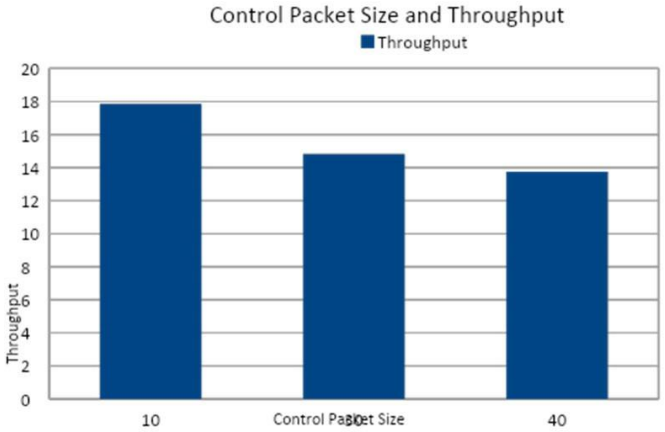


Figure 9: Control Packet Size and Throughput

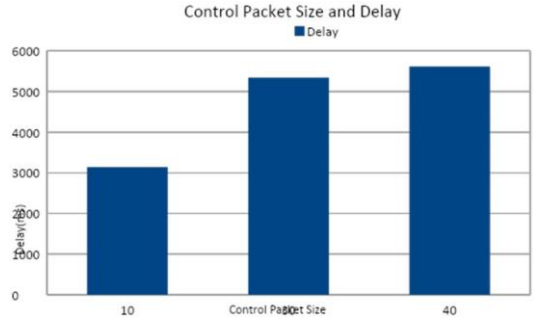


Figure 10: Control Packet Size and Delay

Second scenario: here, the increase in length will decrease the throughput significantly as in figure 11. For the delay as in figure 12, it is not a clear relation and the effect is not much.

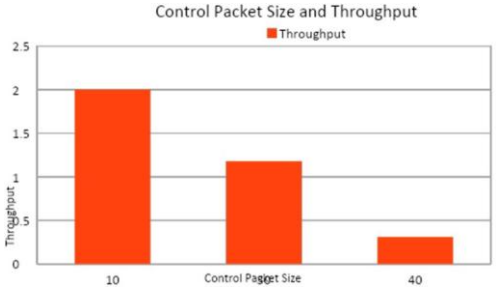


Figure 11:Control Packet Size and Throughput

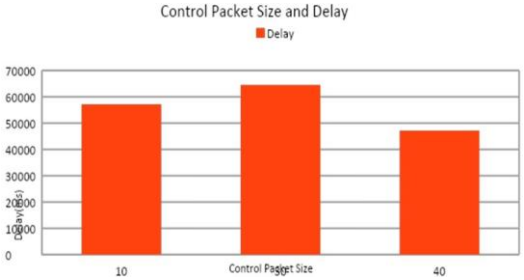


Figure 12:Control Packet Size and Delay

**4. Speed of nodes:**

First scenario: when we change the node speed from 5 (m/s) to 1000 (m/s) no change in throughput or end-to-end delay was noticed as in figure 13 and figure 14 respectively. Our observation is while the sender nodes in the range of receiver nodes no effect on the throughput when we change the speed.

Second scenario: as the speed of the nodes increases the throughput increases then decreases then increases again, here the speed helps nodes in the same synchronization state to become closer in short time and so increase t hroughput. The same logic applies for the delay since nodes communicates in shorter time by being synchronized shortly the delay decreases.

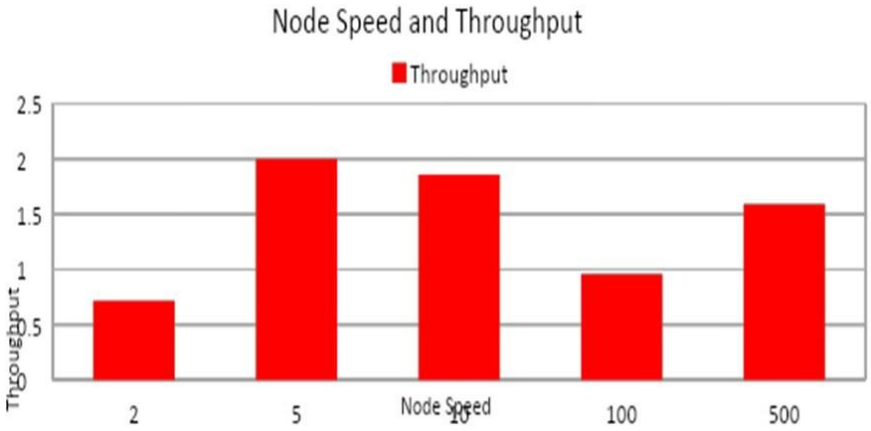


Figure 13:Node Speed and Throughput

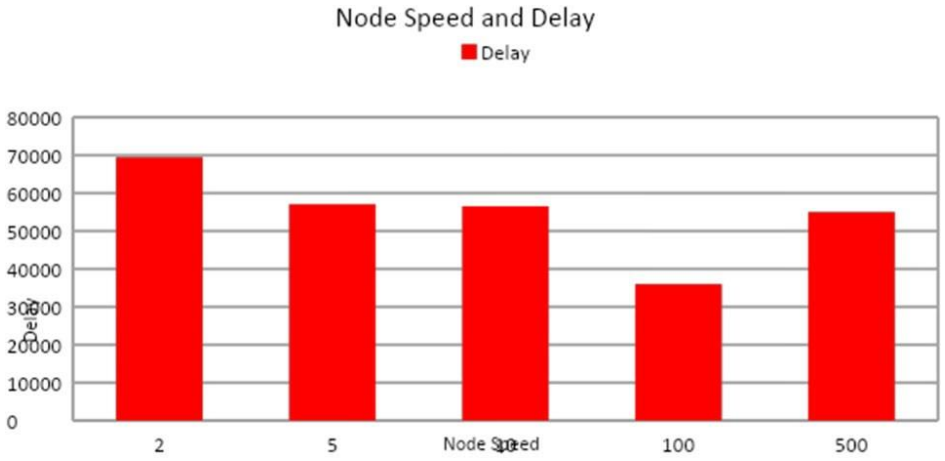


Figure 14: Node Speed and Delay

**5. Probability of error of any of the exchanged messages**

First scenario: in figure 15 when the error probability between 0.01 and 0.09 the effect on the throughput is limited, but when it reaches 0.1 and above the effect is obvious and significant which decreases throughput. For the delay, in figure 16 when the error probability between
0.01 and 0.1 the delay is almost the same. But when it reaches 0.5 and above the delay increases exponentially.

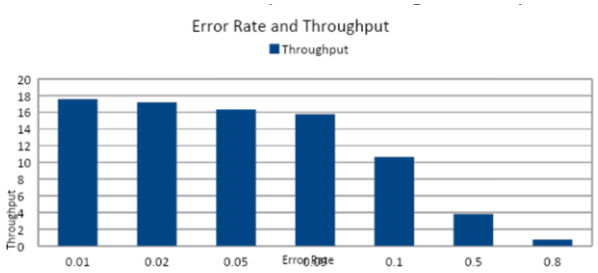


Figure 15:Error Rate and Throughput


Figure 16: Error Rate and Delay

Second scenario: in figure 17, as the error between 0.01 and 0.1 the throughput decreases but the difference is too small, but after 0.1 the throughput is almost zero. In figure 18, the same could be said about the delay, it increases between 0.01 and 0.1 with small difference, but after 0.1 the throughput reaches zero.

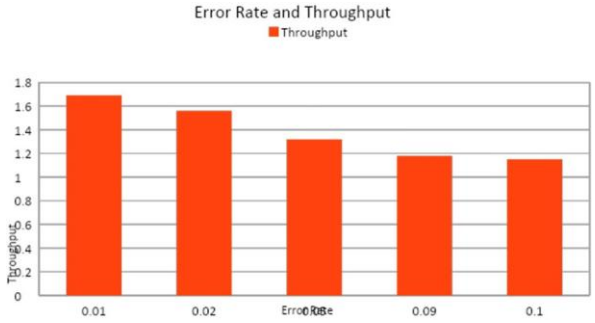


Figure 17: Error Rate and Throughput


Figure 18:Error Rate and Delay

## 6. Sender timeout period in seconds

First scenario: in figure 19, we can see that decreasing the sender timeout will not enhance the throughput of the nodes more than what was gained before, but increasing the sender timeout interval will decrease throughput. For the delay as in figure 20, when we

decrease the timeout for sender the overall end to end delay increases significantly, but increasing the timeout will decrease the total end to end delay.

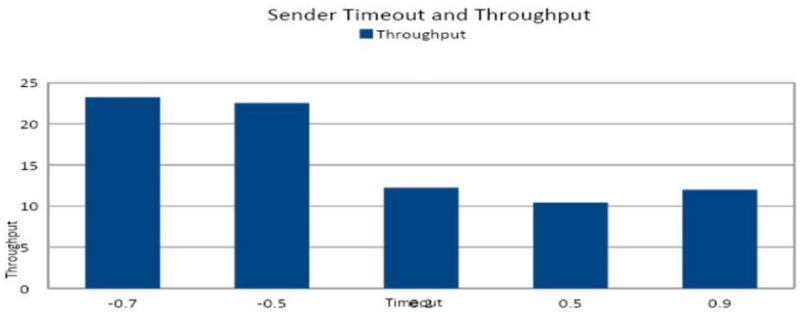


Figure 19:Sender Timeout and Throughput

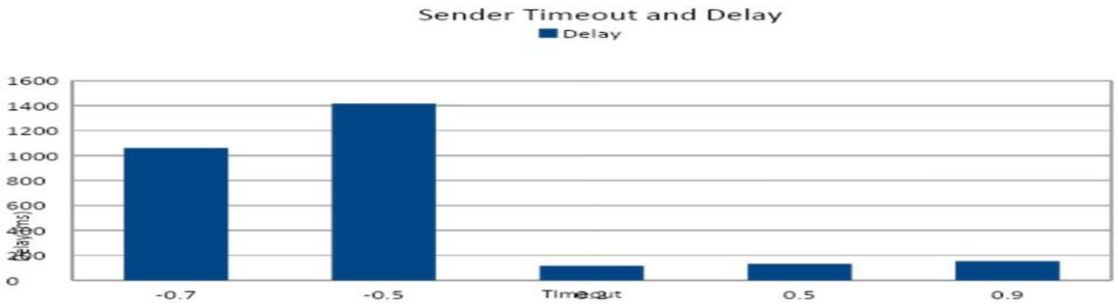


Figure 20:Sender Timeout and Delay

Second scenario: in figure 21, here throughput is not affected by either increasing or decreasing the timeout for sender, since it's not always awake. For total end to end delay it increases by increasing the timeout for sender as shown in figure 22.

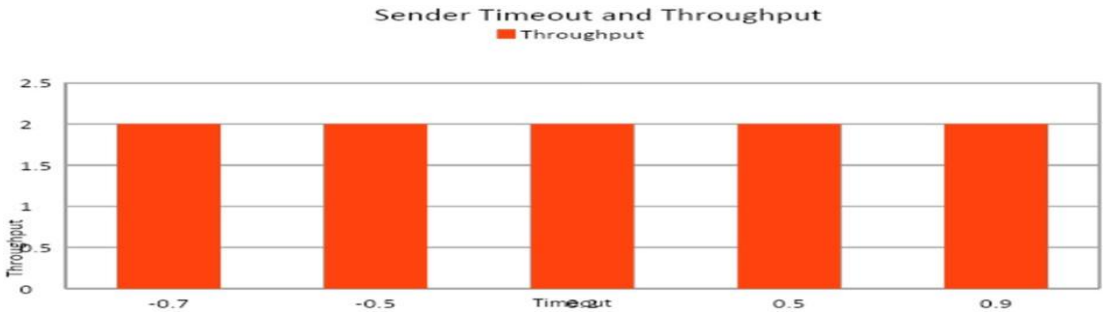


Figure 21:Sender Timeout and Throughput

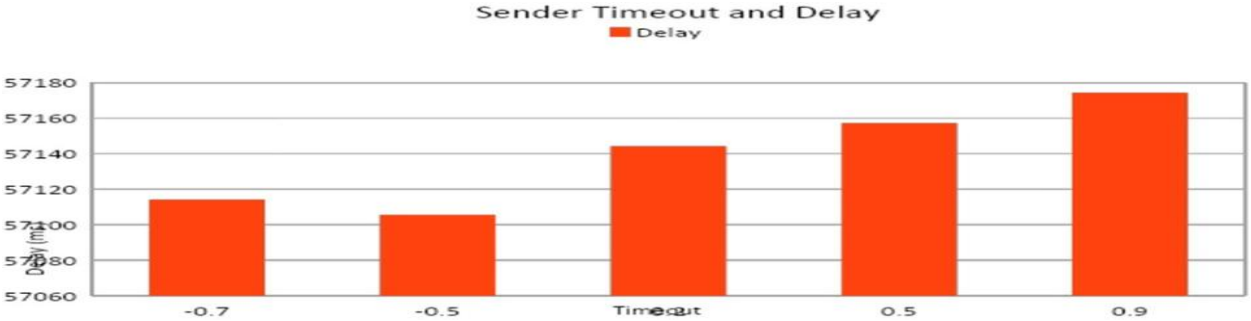


Figure 22:Sender Timeout and Throughput

**7. Receiver timeout period in seconds:**

First scenario: in figure 23, decreasing the receiver timeout will make throughput close to normal levels but increasing it will decrease throughput. For delay as in figure 24, decreasing receiver time out will decrease total end to end delay, and increasing receiver time out will increase total end to end delay.

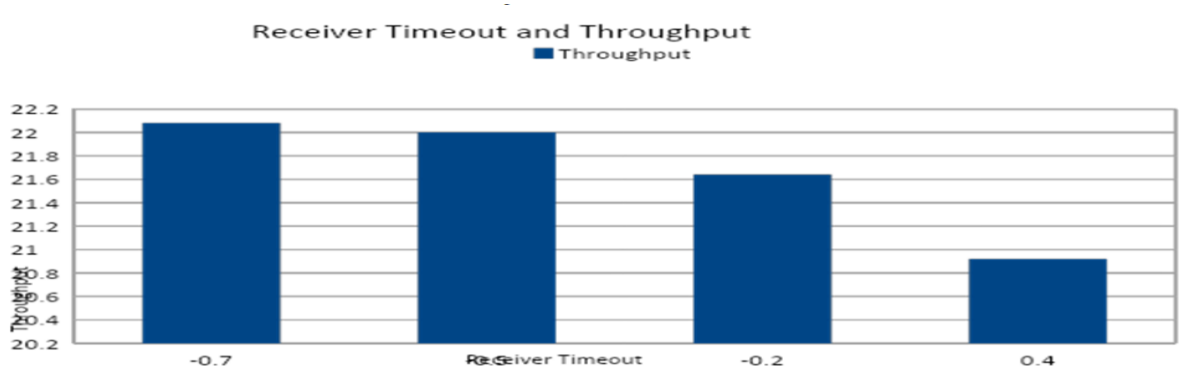


Figure 23:Receiver Timeout and Throughput

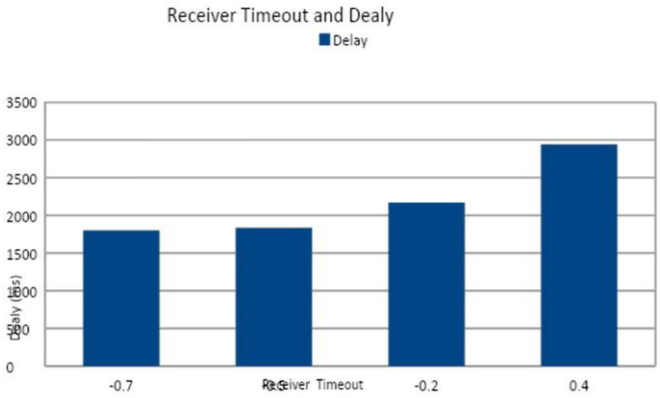


Figure 24:Receiver Timeout and Delay

Second scenario: in figure 25, here throughput is not affected by either decreasing the timeout for receiver, since it's not always awake. For total end to end delay it increases by decreasing the timeout for receiver as in figure 26.

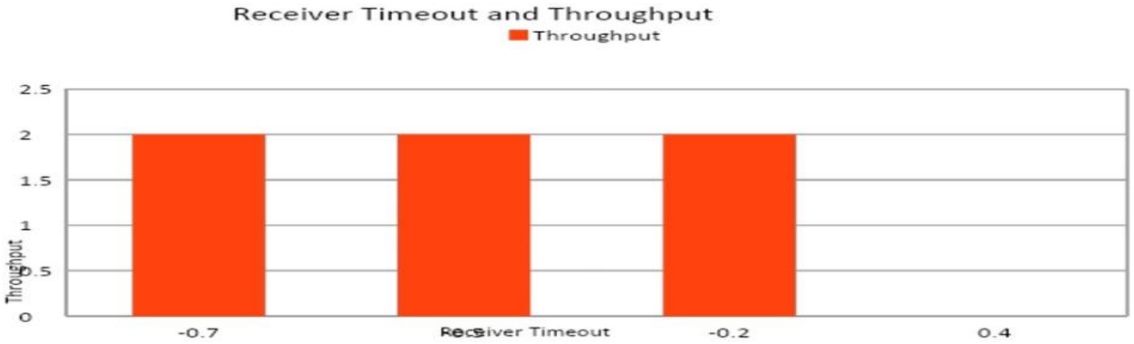


Figure 25:Receiver Timeout and Throughput

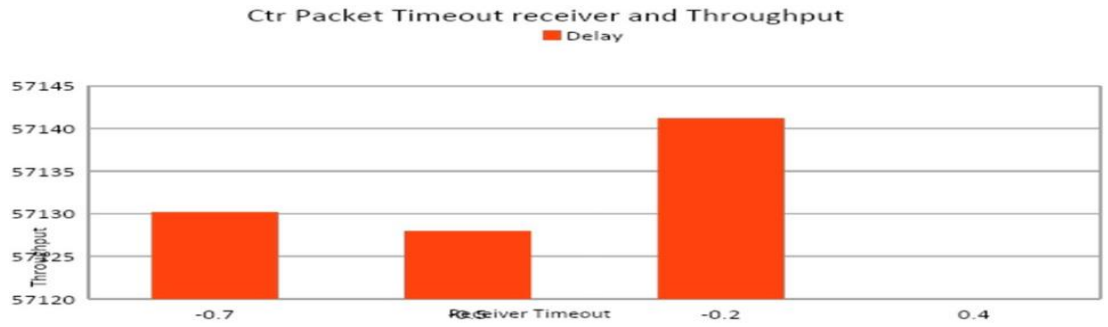


Figure 26:Packet Timeout and Delay

**Analysis of results**

For each of the previous factors, we can summarize the effect on the throughput and total end-to end delay as the following:

1. **Packet generation per second:**

- First scenario: as packet generation increases the throughput increases, and the delay increases by increasing packet generation.
- Second scenario: the increasing in packet generation leads to decrease throughput. For delay, in the beginning as packet generation increases the delay increases too, after that it decreases.

2. **Packet length in bytes:**

- First scenario: when the packet size increases the throughput keep increasing too. For the delay, when the packet size is between 32- 2000 bytes the delay is almost the same, but after that it increases.
- Second scenario: as the packet size is between 32-1000 byte the throughput is less than or equal 0.5 kbps, but for 1500 byte packet the throughput is 2 kbps. For the delay we can say the delay is high in this scenario and almost the same for the different packets sizes.

3. **Control packet length (RTS, CTS, ACK, and NAK) in bytes:**

- First scenario: we can see that the increase in control packet length will decrease the throughput but not significant decrease. For the delay, it is also increases when control packet length increases.
- Second scenario: here, the increase in length will decrease the throughput significantly. For the delay, it is not a clear relation and the effect is not much.

4. **Speed of nodes:**

- First scenario: when we change the node speed from 5 (m/s) to 1000 (m/s) no change in throughput or end-to-end delay was noticed. Our observation is while the sender nodes in the range of receiver nodes no effect on the throughput when we change the speed.
- Second scenario: as the speed of the nodes increases the throughput increases then decreases then increases again, here the speed helps nodes in the same synchronization state to become closer in short time and so increase throughput. The same logic applies for the delay, since nodes communicates in shorter time by being synchronized shortly the delay decreases.

5. **Probability of error of any of the exchanged messages**

- First scenario: when the error probability between 0.01 and 0.09 the effect on the throughput is limited, but when it reaches 0.1 and above the effect is obvious and significant which decreases throughput. For the delay, when the error probability between 0.01 and 0.1 the delay is almost the same. But when it reaches 0.5 and above the delay increases exponentially.
- Second scenario: as the error between 0.01 and 0.1 the throughput decreases but the difference is too small, but after 0.1 the throughput is almost zero. The same could be said about the delay, it increases between 0.01 and 0.1 with small difference, but after 0.1 the throughput reaches zero.

6. **Sender timeout period in seconds**

- First scenario: we can see that decreasing the sender timeout will not enhance the throughput of the nodes more than what was gained before but increasing the sender timeout interval will decrease throughput. For the delay, when we decrease the timeout for sender the overall end to end delay increases significantly but increasing the timeout will decrease the total end to end delay.
- Second scenario: here throughput is not affected by either increasing or decreasing the timeout for sender, since it's not always awake. For total end to end delay it increases by increasing the timeout for sender.

7. **Receiver timeout period in seconds:**

- First scenario: decreasing the receiver timeout will make throughput close to normal levels but increasing it will decrease throughput. For delay, decreasing receiver time out will decrease total end to end delay, and increasing receiver time out will increase total end to end delay.
- Second scenario: here throughput is not affected by either decreasing the timeout for receiver, since it's not always awake. For total end to end delay it increases by decreasing the timeout for receiver.

## 3. Conclusions

A comprehensive analysis have been conducted in this paper to evaluate the S-MAC protocol with mobility in terms of throughput, number of packets successfully delivered per second, packet delay, average packet delay before successful transmission. We can conclude that the S-MAC protocol will prolong the sensor nodes lifetime, but the cost will be a decreased throughput and, in some cases, increased delay. There should be some enhancement on the protocol to overcome the drawbacks by considering the best suited methods for further investigations.

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