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Packet Generation Rate Impact on Performance of Wireless Sensor Network Medium Access Control Protocols

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ABSTRACT
Energy is a limited resource in wireless sensor nodes. Radio transceiver is the main component of the wireless sensor node that consumes the highest amount of energy. MAC protocols play a vital role to control the operation of radio and it significantly affects the energy consumption of the whole wireless sensor network. An important issue in the design of Wireless Sensor Network is the choice of an energy efficient MAC protocol. The performance of MAC protocols is influenced or impacted by different network parameters such as sensor density, network diameter, physical layer properties etc. The goal is to study the impact of packet generation rate on the performance of different MAC protocols. The study was carried out using WSNet simulator and the key QoS parameters considered in this study are packet delivery ratio and energy consumption in nodes. Finally, the performance analysis and results of the MAC protocols under study were obtained and compared based on the simulation experiments. The results show that IEEE802.15.4 868bpsk MAC protocol has the highest network lifetime and highest packet delivery ratio at different application periods. The study also has proved that B-MAC protocol has a higher packet delivery rate than X-MAC protocols in all the considered packet generation intervals.
Keywords: *MAC Protocol, CBR Traffic, WSN, PDR, Energy Consumption.*

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I. INTRODUCTION

Wireless Sensor Network (WSN) is mainly a group of scattered and devoted sensors for checking and recording the physical states of the environment and arranging the gathered information at a focal area [1]. In a wireless sensor network, sensor nodes are regarded low cost, resource constrained devices and are often positioned randomly. In many applications they are placed in inaccessible locations, making battery replacement unfeasible. As a consequence, energy efficiency is an important requirement in all protocol stacks and especially in medium access control protocol for most wireless sensor networks. Medium Access Control (MAC) protocol in a wireless environment, determines state of the radio on a node sending, receiving, or sleeping [2] – [4]. Radio energy consumption is a major component contributing to the overall energy consumption at each node [5]. So, radio access is the major consumer of sensor energy and MAC protocols must be energy efficient enough to achieve longer network lifetime [6]. The choice of an optimal MAC protocol for an application considering the packet generation time is critical for reliable and efficient communications in wireless sensor networks. Also designing an efficient MAC layer protocol is an important task as it coordinates all the nodes to share the wireless medium. Hence by choosing energy efficient MAC protocols we can increase the lifetime of wireless sensor networks [7] – [10].

When designing a WSN, the designer knows the different network parameters to implement such as radio to use, network diameter to apply, node density, traffic model to apply etc. The question now is, which MAC protocol will perform optimally under different packet generation rate (PGR) considering two performance metrics; energy consumption and packet delivery ratio (PDR)? There are other performance metrics but energy consumption and PDR are chosen in this work because they are very important metrics in WSNs. Energy consumption was considered because energy determines the lifetime of the WSN. Since the sensor node has limited energy (battery power), problems could arise when the energy is not efficiently utilized. Every WSN application is meant to perform a given service and such service can only be achieved when messages from sender are delivered or received by the intended nodes. This is why PDR is considered as a performance metrics in this work. The idea behind this work is to study the impact of packet generation rate on the performance of MAC protocols and to investigate the MAC protocol that will consume less energy and have a high packet delivery rate to the sink node, among all the considered MAC protocols in the WSN. How does the packet generation rate in sensor nodes affect the network lifetime and packet delivery ratio in WSN? It is a known fact that the transceiver component of the sensor node contributes heavily to the energy consumption in the nodes. The power consumption in the nodes directly influences the number of living nodes in the network and the network life time. When the number of living nodes in the network is reduced, the connectivity and the reliability of the WSN are threatened. To avoid this in Wireless Sensor Networks, there is need to study the effect of PGR on the performance of MAC protocols taking into account the different network parameters/ network environments. The main challenge with using MAC protocols is to find the optimal protocol considering different performance metrics.

II. MATERIAL AND METHODS

In carrying out this work, the following steps and methods were adopted. A thorough study and evaluation of the effect of the number of messages generated per given time was carried out based on the performance of all the considered MAC protocols, taking into account PDR. Furthermore, experiments were conducted to monitor the impact of the message generation rate on the performance of each MAC protocol looking at the network lifetime. This was achieved by using WSNet simulator to run the experiments using different network parameters. Finally, the performance of all the investigated MAC protocols using network lifetime/energy consumption and packet delivery ratio as our performance metrics were analyzed and compared. WSNet simulation results were used for evaluation and comparison of the considered MAC protocols. The simulations were based on these assumptions:

a. The link is not ideal, attenuation and interference are possible.
b. The nodes are static, no mobility.
c. Only the energy consumption of sensor nodes radio component was considered. (energy used by the nodes to sense activities was ignored)
d. The wireless sensor network is a homogenous one.

Table 1: Simulation parameters

S/N	Parameters	Status Value
1	Simulation Area	50 m x 50 m
2	Simulation Time	500, 3000, 6000, and 12000 seconds
3	Node Deployment	Random, except the Sink Node
4	Mobility Model	Static
5	Antenna Type	Omni Directional
6	Traffic Type	CBR
7	Traffic Period/ Inter-arrival Time	5, 30, 60, and 120 seconds
8	Number of nodes	10, 50, 100 and 200

For the study, a layout of 50 x 50 meters was used. Nodes are always static in the experiments therefore; Constant Bit Rate (CBR) was used as the type of application traffic. CBR is a traffic model used by different WSN applications such as vehicular traffic volume monitoring, health care applications etc. The simulation of CBR traffic was done with a packet generation interval of 5, 30, 60 and 120 seconds to monitor the impact of packet generation rate on the performance of each MAC protocol. In the experiments, Node ID 0 is designated as the sink in the wireless sensor network. Since the topology is not a complex one, it is enough to show the basic characteristics of the considered MAC protocols. The experiments considered the following four MAC protocols: DCF MAC protocol, B-MAC protocol, X-MAC protocol, and IEEE802.15.4 868 bpsk MAC protocols. Different simulation scenarios were studied using performance metrics: network lifetime (energy consumption at the node) and packet delivery ratio (PDR).

Each of the considered MAC protocols were from the three different classes of MAC Protocols, namely Schedule-based MAC protocol (DCF MAC protocol). Random access MAC protocol (B-MAC and X-MAC protocols) and Hybrid MAC protocols (IEEE802.15.4 868 bpsk MAC protocols).

Schedule-based MAC protocols for WSNs assume the existence of a schedule that regulates access to resources to avoid contention between nodes. Typical resources include time, a frequency band, or a CDMA code. The main objective of schedule-based MAC protocols is to achieve a high level of energy efficiency in order to prolong the network lifetime. The idea behind contention-free or schedule-based MAC protocols is to allow only one sensor node to access the channel at any given time, thereby avoiding collisions and message retransmissions.

Random access MAC-layer protocols, also known as contention-based protocols, require no coordination among the nodes accessing the channel. Colliding nodes back off for a random duration of time before again attempting to access the channel. Contention-based MAC protocols do not rely on transmission schedules, but instead on other mechanisms to resolve contention when it occurs. The enhancement of these protocols with collision avoidance, request-to-send (RTS) and clear-to-send (CTS) mechanisms improves their performance and makes them more robust to the hidden terminal problem. The main advantage of contention-based techniques is their simplicity compared to most schedule-based techniques [9].

Hybrid MAC protocols are proposed to have the benefits of both Scheduled and Contention based protocols. Every one of the given protocols separates the entrance channel in two separate sections. Control bundles are sent in channel of the random access, while data ones are transmitted using scheduled access channel. Hybrid protocols can get higher energy sparing and offer better adaptability [1].

III. CASE STUDY: LITERATURE REVIEW

The subject of MAC protocols in Wireless Sensor Network is an important one. The table1 shows a summary of authors work, the results obtained and the additions of this work. Though there are various efforts to compare some MAC protocols considering different performance metrics, areas like impact of packet generation rate/ traffic load on the MAC protocols performance lack behind. The performance evaluation of these MAC protocols considering packet generation rate/ traffic load is desired and vital. The research work focused on the impact of packet generation rate on MAC protocol performance in Wireless Sensor Networks.

Table 2: Summary reviewed literatures

Authors	Considered MAC Protocols	Network environment	Performance metric	Results	Additions of our Work
Arifuzzaman M. et al. [11]	EP-MAC, S-MAC, T-MAC, and Hybrid MAC	Single node density, Static nodes, Multi hop Network	Power consumption and Delay	EP-MAC consumed less power but had a higher delay.	Considered PDR. Impact of Node density on the performance of the MAC protocols
Agarwal S. et al.[12]	MACPE, S-MAC and T-MAC	Single node density, Static nodes, Multi hop Network	Power consumption	MACPE consumes less power	Considered PDR. Impact of Node density on the performance of the MAC protocols
Ramana Rao M. V. et al.[2]	B-MAC and X-MAC	Single node density, Static and Mobility nodes,	Average End-to-End delay, Average Packet Delivery Ratio, Average Number of hops and Jitter	B-MAC has higher Average PDR in Static node.	Considered Energy Consumption. Impact of Node density on the performance of the MAC protocols
Furat Al-Obaidy et al.[13]	S-MAC, T-MAC, B-MAC, L-MAC and Crankshaft	Single node density, Static nodes, Multi hop Network	Power consumption, PDR and Latency	Crankshaft consumes less power. BMAC has the highest PDR	Impact of Node density on the performance of the MAC protocols

IV. RESULTS

This section provides the results of the two performance metrics considered in this research; the network lifetime results and the packet delivery ration results, considering the packet generation rate. The results gotten from the experiments were discussed.

4.1 Network Lifetime Results

In the context of this study, network lifetime was taken to be the time at which the first sensor node in the WSN consumes all its energy. The network lifetime for each MAC protocol was compared considering different packet generation intervals. Figure 1. shows the results of network lifetime for packet generation interval of 5 seconds for different node densities (sparse, medium dense, dense and highly dense WSN) for each selected protocol

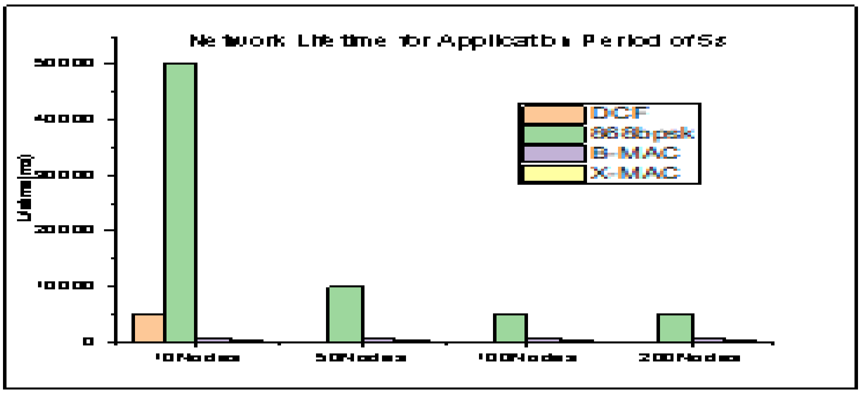

Figure1: Lifetime with PGR of 5s a function of network density

The results prove that IEEE802.15.4 868 bpsk MAC protocol has the highest network lifetime in all the experimented node densities when compared to other protocols in the experiments. The network lifetimes for 802.15.4 868 bpsk MAC protocol are (50004ms), (10034ms), (5065ms), and (5043ms), in sparse, medium dense, dense and highly dense networks, respectively. The IEEE802.15.4 868 bpsk MAC protocol performed the best among the entire considered MAC protocols because the protocol adopts a loosely synchronised sleep and wakeup cycle, sensor nodes can operate for extended periods of time with minimum energy consumption. This allows nodes to operate at low duty cycles while maintaining network-level connectivity to reduce the energy consumption in sensor nodes [14].

This result also shows that DCF MAC protocol performed better than B-MAC and X-MAC protocols only in sparse WSN with a lifetime of 5022ms and performed the worst among all compared protocols in medium dense, dense and highly dense WSN. DCF MAC protocol performed better in sparse WSN because the protocol has power-save (PS) mode that allows nodes to periodically sleep to conserve energy. The power-save mode works best in single-hop network as seen in the sparse WSN experiment in this study. In DCF MAC protocol, power-save mode tries to save energy by reducing the time of idle listening [15] – [16]. DCF MAC protocol performed poorly in medium dense, dense and highly dense WSN because power-save mode in DCF MAC protocol was designed for a single-hop network. When implemented on WSN with high node densities that resemble multi-hop networks, problems like clock synchronisation, neighbour discovery and network partitioning may arise. These problems cause an increase in energy consumption of the sensor nodes [15]. B-MAC and X-MAC protocols performed better than DCF MAC protocol in medium dense, dense and highly dense WSN in this experiment because they are low power listening MAC protocol that uses preamble [1, 17].

In Figure 2, the results prove that there is an increase in network life with the packet generation interval of 30 seconds when compared to result obtained with the packet generation interval of 5 seconds. The network lifetime increased from 5022ms to 10024ms for DCF MAC protocol and from 706ms to 760ms for B-MAC protocol and so on. This is because of decrease in messages generated and sent per given time. As the network traffic reduces, the energy spent by sensor node's radio to transmit and receive messages reduced, thereby increasing the network lifetime. The result also shows that IEEE868 bpsk MAC protocol has the highest network lifetime of 30002ms in sparse network and in all the experimented node densities with different lifetime values, when compared to other protocols in the experiments. This is so because the data transfer between the sensor nodes and the sink is always initiated by the sensor nodes, allowing a node to determine when data is transferred and to maximise its energy savings [18, 19].

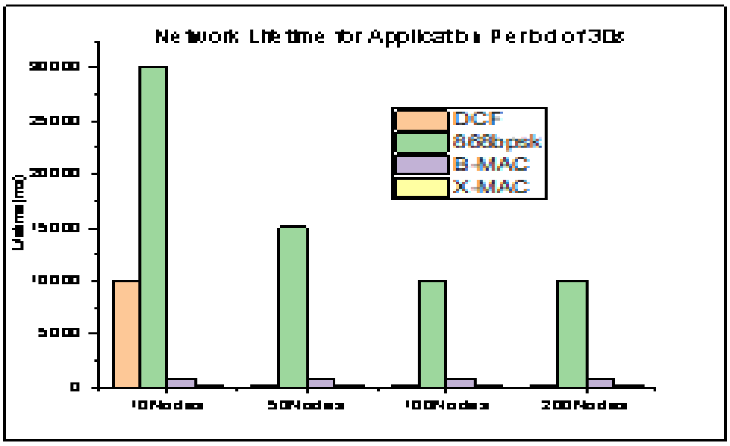

Figure2: Lifetime with PGR of 30s a function of network density

In Figure 3, the result shows that IEEE802.15.4 868 bpsk MAC protocol has the highest network lifetime in all node density when compared to other protocols in the experiments. This was so because the contention access period (CAP) feature of IEEE802.15.4 868 bpsk MAC protocol was designed to greatly reduce, when excess, the device duty cycle, especially in low-activity networks as presented in this experiment. The CAP access control protocol offers a battery life extension (BLE) mode of operation. The BLE mode allows sensor nodes to go into sleep mode in the presence of low activity [14]. Furthermore, the results from the experiments prove that there was an increase in network life with the packet generation interval of 60 seconds when compared to results obtained with the packet generation interval of 30 seconds. This was due to the reduction in the amount of messages generated per sensor node since the message generation rate was increased to 60 seconds.

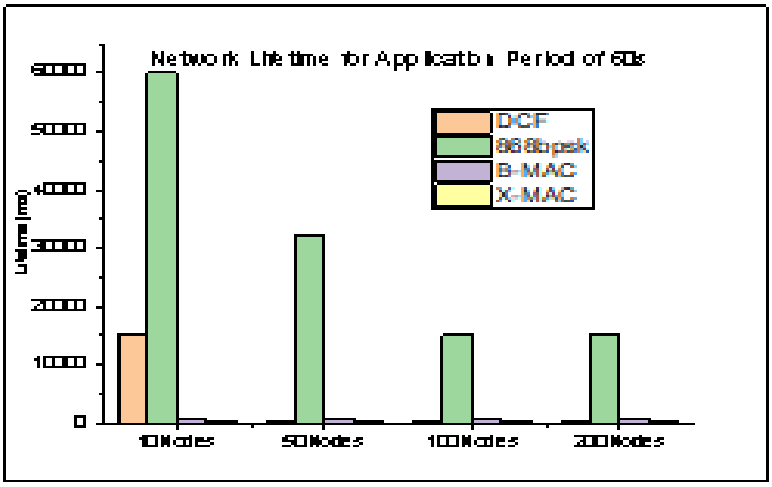

Figure3: Lifetime with PGR of 60s a function of network density

In Figure 4, the results from the experiments prove that there is an increase in network life with the packet generation interval of 120 seconds when compared to results obtained with the packet generation interval of 60 seconds. The network lifetime increased from 11024 ms to 12003 ms for DCF MAC protocol and from 60002ms to 92000ms for IEEE802.15.4 868 bpsk MAC protocol. This was due to the reduction in network traffic since fewer amounts of messages are generated per sensor node. When less energy was needed by the sensor nodes to transmit or receive, the network lifetime was extended.

The result also shows that IEEE802.15.4 868 bpsk MAC protocol has the highest network lifetime of 92000ms in sparse network and in all the experimented node densities when compared to other protocols in the experiments. B-MAC protocol has network lifetime of 803ms, DCF MAC protocol has 12003ms and X-MAC protocol has network lifetime of 202ms in sparse network experiment. This was so because the IEEE 802.15.4 standard can support network traffic like periodic data, intermittent data, and repetitive low-latency data. Also, the BLE mode of IEEE802.15.4 802.15.4 868 bpsk MAC protocol allows sensor nodes to go into sleep mode in the presence of low activity just like in this experiment [14].

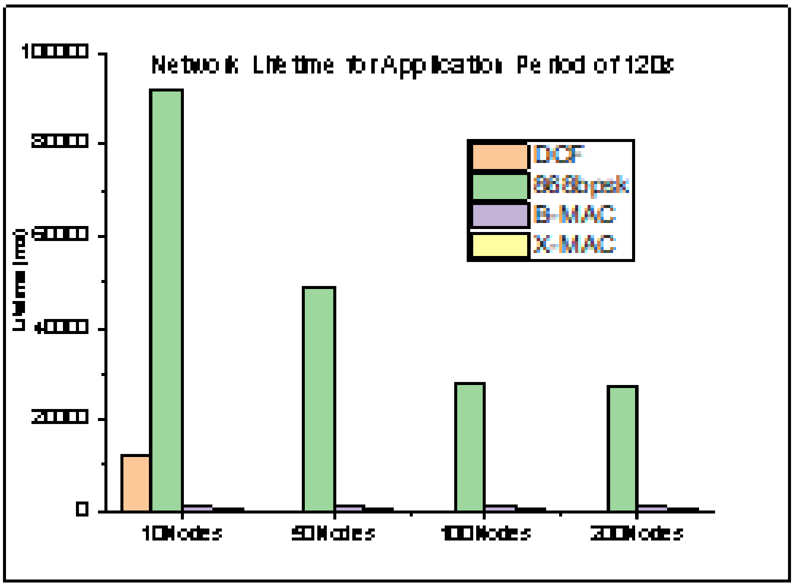

Figure4: Lifetime with PGR of 120s a function of network density

4.2 Packet Delivery Ratio Results

From the results obtained in the study (Figure 5 to Figure 8), these observations are noted: That when T_s (the time required to send a symbol) parameter was increased in the radio, the number of packets received by the sink reduced significantly.

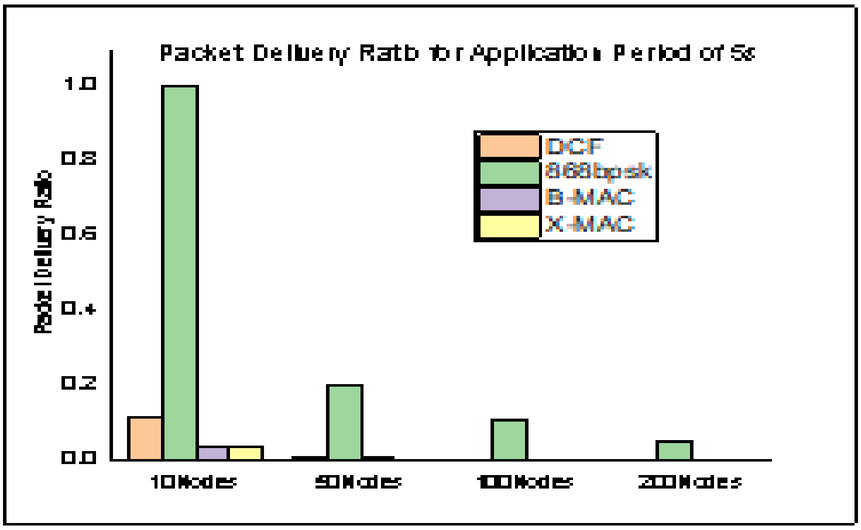

Figure5: PDR with PGR of 5s a function of network density

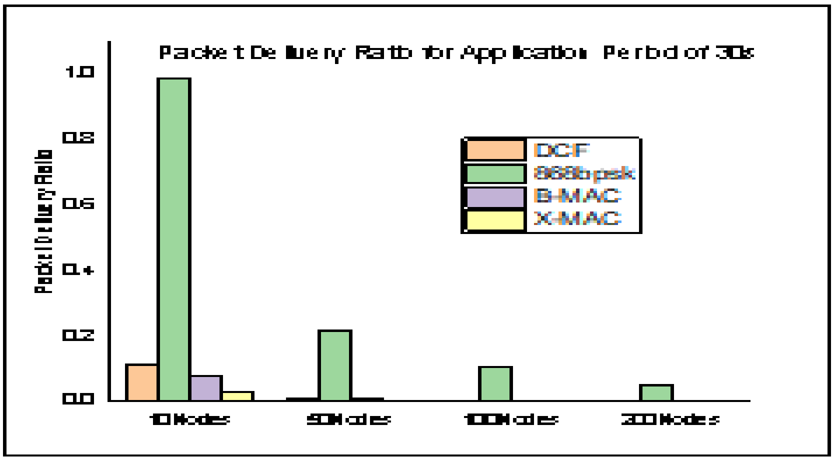

Figure6: PDR with PGR of 30s a function of network density

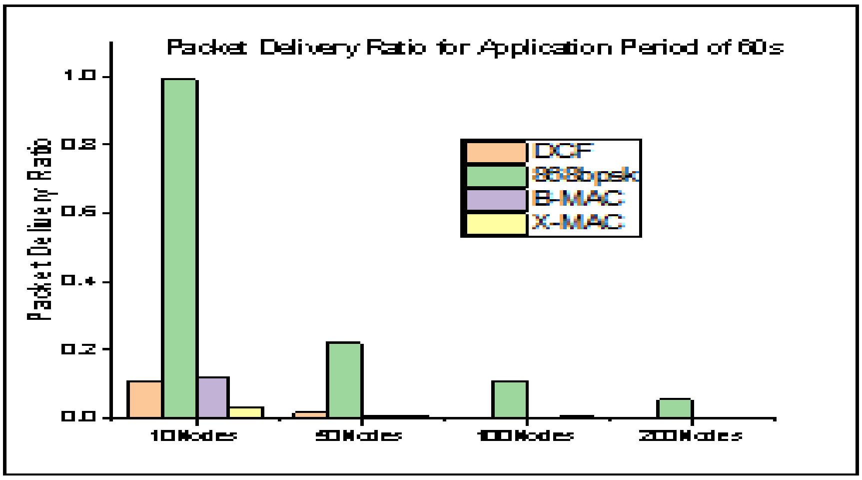

Figure7: PDR with PGR of 60s a function of network density

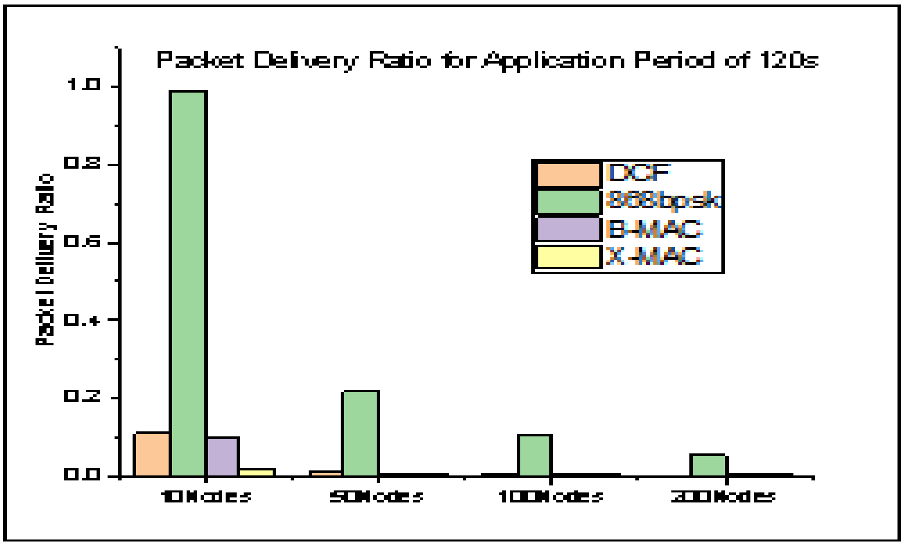

Figure8: PDR with PGR of 120s a function of network density

This was because the time required to send a packet to the sink will increase thereby reducing the number of data packets that the sensor nodes can send to the sink. That when the range of the radio's communication was decreased, the number of packets received by the sink reduced also. This was due to the number of sensor nodes that was within the communication range of the sink reduced, which means that the total packets received from those number of nodes reduced. Packets sent by any sensor node that was not within the range of the sink's communication range are lost. Also, as sensor nodes are in the carrier sensing range of each other, the probability of collisions due to the hidden node problem is eliminated.

The rate of packet delivery increases as the traffic load decreases. This was because as the traffic load decreases the number of collisions in the WSN decreases. The results show that IEEE802.15.4 868bpsk MAC protocol has the highest packet delivery ratio of 0.99 in sparse WSN as against 0.12 of DCF MAC protocol, 0.04 of B-MAC and X-MAC protocols, when considering application period of 5seconds. Also, IEEE802.15.4 868bpsk MAC protocol performed better than other considered MAC protocol, in all packet generation periods (5s, 30s, 60s and 120s) as can be seen in the column plot. This was so because to reduce the likelihood of collisions, the IEEE802.15.4 868bpsk MAC protocol uses random delays [14, 18]. Further, the data transfer between the sensor nodes and the sink that was always initiated by the sensor nodes contributed to the result that was obtained in the experiment [19, 20]. The results prove that there was a very slight increase in packet delivery ratio with as the application period was increased from 5seconds to 120seconds in the experiments (from 0.98 to 1.00). It was observed from the results that the PDR remained the same for some MAC protocols (B-MAC and X-MAC protocols). Since the network traffic reduced (the amount of messages generated per given time in the network), the amount of messages that the sink node will receive will equally decrease.

From the results obtained it can prove that DCF MAC protocol performed better than B-MAC and X-MAC protocols, in all packet generation periods (5s, 30s, 60s and 120s) this was because DCF made various enhancements such as virtual carrier sense, binary exponential back-off and fragmentation support to enhance packet delivery and to reduce energy consumption in sensor nodes [21].

The result also shows that B-MAC protocol performed better than X-MAC protocol in all packet generation periods (5s, 30s, 60s and 120s), in the number of packets delivered to the sink node. This was because B-MAC protocol employs an adaptive preamble sampling scheme to reduce duty cycle and minimize idle listening. B-MACs flexibility results in better packet delivery ratio and throughput [1]. This was because B-MAC protocol removes the need for, and the overhead introduced by synchronized wake/sleep schedules [14, 17]. As the number of transmitted packets increased, so did the control packets for schedules, which B-MAC protocol eliminated.

V. DISCUSSION AND CONCLUSION

The study investigated the performance of four MAC protocols in WSN with respect to the network lifetime and packet delivery ratio, considering the impact of different packet generation rate. The results obtained have proved that in each node density, the network lifetime increased as the packet generation rate/interval increases. In 10 Nodes network density experiment for example, when the packet generation rate was 5s, the network lifetime was 5022ms and 50004ms for DCF MAC and IEEE802.15.4 868bpsk MAC protocols respectively. When the packet generation rate was 60s for the same experiment, the network lifetime increased to 12003ms and 60002ms for DCF MAC and 868bpsk MAC protocols respectively. This was as a result of decrease in network traffic (messages sent per given time). As the messages sent and received in the network reduce, the energy spent by sensor nodes radio to transmit and receive message reduced, thereby increasing the network lifetime. More simulation results proved that in each node density, the PDR increased as the packet generation rate/interval decreases. This was due to the collision or contention at the MAC layer decreased.

It can be seen from the comparative results that IEEE802.15.4 868bpsk MAC protocol has the highest network lifetime and highest packet delivery ratio, at all the considered application periods. It was also proved that B-MAC protocol has a higher packet delivery rate than X-MAC protocols in all considered packet generation intervals. Furat Al-Obaidy et al, in table2 , observed the same results obtained here when they compared the performance of B-MAC protocol using packet delivery ratio as the performance metrics. This validates the results obtained here and gives confidence to this research work.

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