PERFORMANCE EVALUATION OF BROADCAST MAC AND ALOHA MAC PROTOCOL FOR UNDERWATER WIRELESS SENSOR NETWORKS

Jekishan K. Parmar[1], Mrudang Mehta[2]

[1]M. Tech Student, Department of Computer Engineering, Dharmsinh Desai University, Gujarat, India
[2]Associate Professor, Department of Computer Engineering, Dharmsinh Desai University, Gujarat, India

Abstract

Broadcast MAC (BMAC) is simple yet very efficient MAC protocol for Underwater Wireless Sensor Network (UWSN). BMAC senses the channel and if channel is free then data is transmitted. It is much desired protocol for some low traffic networks. Here we carry out its evaluation. We also evaluate ALOHA protocol which is also for UWSN. There are various versions of ALOHA protocol available but here we are considering the pure ALOHA where the sender just sends the data whenever it wants. BMAC and ALOHA, both possess simplicity in their implementation as well as in their working and hence we evaluate both of them together in similar simulation scenario. We compared the performance of these two Underwater MAC protocols on the basis of bit-rate and number of nodes participating in the network. On completing the evaluation process we found that B-MAC performed well in the simulation scenario that we had designed.

Keywords: *BMAC, ALOHA, UWSN, Underwater MAC, Performance Evaluation, Bit-rate.*

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1. INTRODUCTION

Recently Underwater Wireless Sensor Network (UWSN) has appeared as a very important and in demand networking aspect for various types of marine applications [1] such as military surveillance, mine reconnaissance, ocean sampling, and underwater navigation assistance. Various types of low cost, medium and large scale monitoring systems have emerged with the development of UWSN. As described in [1], solutions of terrestrial wireless sensor network cannot be applied to UWSN. This is due to specific challenges faced by the acoustic channel. Some of the issues faced with acoustic channel include low-bandwidth, propagation delay and frequent-dependent attenuation. These all issues effect protocol design at all layers of a network protocol stack [2].

The focus of our work is on MAC layer protocol. There are various MAC layer protocol available for UWSN. Among the various protocols available we describe and evaluate two protocols, namely BMAC [3] and ALOHA [4]. Former is based on broadcasting mechanism and the latter is based on ALOHA idea which is tailored specifically for underwater network environments. Both of these protocols contain backoff mechanism when they are not able to transmit the data successfully. Though, the manner in which they use this mechanism differs in some ways from each other. Moreover both protocols do not prevent collision [5]. The purpose of evaluating these two protocols is to identify a protocol that is suitable for a particular type of scenario as described in our simulation experiment.

As both of these protocols are very much primary and are expected to perform well in low traffic networks, we find which one is suitable at scenarios where the bit-rate is low and there are only few nodes participating in the network. Moreover we also evaluate optimum bit-rates for both of these nodes in a specifically designed simulation scenario. The optimum bit-rates that we consider are based on energy consumption which is an important factor for any type of UWSN [1]. We also evaluate these protocols for amount of delay caused in the network at various bit-rates.

The analysis of these protocols by considering shallow UWSN scenarios would be also very helpful as shallow UWSNs basically just receives the data from UWSNs that are very deeply stationed and sends them to the onshore stations wirelessly [11]. Moreover shallow UWSNs may remain unused or very less utilized for several periods [11] and so our simulation scenario is also applicable for shallow UWSN. As concluded in [11], there is severe bandwidth as well as power consumption limitations for a shallow UWSN and it is one more point due to which we will try to incorporate the same in our simulation design.

We evaluate the performance of the given protocols by varying the number of nodes in the network. By this we can also analyze how variation in nodes affects the performance of a low traffic network. The results of our evaluation shows at what value of bit-rate, there is lowest amount of energy consumption in the network and we also investigate the cause of it in the paper. The organization of paper is as follows. Section II gives the detailed description of both of these protocols. In Section III, we carry out the task of evaluating and discussing the obtained results of our protocols. Finally in Section IV, we conclude the paper.

2. DESCRIPTION OF THE PROTOCOLS

2.1 ALOHA

In literature, there are different versions of ALOHA protocol. The ALOHA protocol that is described in [4] resembles very much to the pure ALOHA described in [6], there are also two sub-types of ALOHA that are described in [2]. In [7] authors have described a classic optimized version of ALOHA protocol called slotted ALOHA for underwater networks. The ALOHA that we are considering is the one referred in [4].

In ALOHA, when the sender wants to transmit the data it directly sends out the data. After sending the data it starts a timer, this timer indicates the time since the packet was sent and then it waits for the response from the receiver. This response is nothing but the acknowledgment of receipt of frame by the receiver. If the frame is received correctly by the receiver then only it will send the response. If there is some problem with the frame and receiver doesn't receive it and hence doesn't acknowledge it then server will back off for some specific amount of time and then resends the same frame. If the frame is not having any problem and reaches to the receiver successfully without any issues then the sender will receive the response from the receiver before it goes for back off. This time, for which the sender waits to receive the response from receiver, is called timeout period. The value of timeout period for the classic ALOHA that we are describing over here is random but there is a specific timeout period for another version called carrier-sensing ALOHA.

The time for which the carrier-sensing version of ALOHA waits for receiving the response is described in [2]. Though, our main focus is to find how the simplest form of ALOHA protocol behave in the simulation scenario designed for a low traffic network. The working of classic ALOHA and the resulting collisions are shown in figure 1.

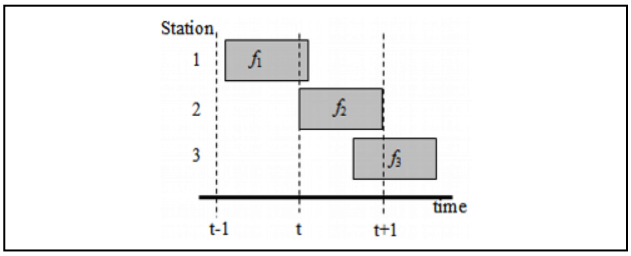

Fig-1: Working of ALOHA & Collisions

As given in [5], in ground communications, frame sent at time *t* will collide with the frame sent in time [t-1, t+1]. This is also shown in figure 1 where three stations have sent frames. The first has sent at *t*-1, second at *t* and the third at *t*+1. We can see that all the frames overlap each other at some point; hence no one was able to successfully transmit.

In UWSN, we can visualize ALOHA using similar approach but we have to consider propagation delay. Hence instead of looking at the time which frame was sent, we look at the arrival time on destination side. Thus, we say that transmission of frame is successful if it does not collide with other frames at destination side.

We can understand how differently propagation delay acts with ALOHA by considering an example given in figure 1. Let us consider that node 1 sends a message after time *t*-1. Also, node 2 sends message at time t. Now both these signals keep on propagating and meet eventually, which results into constructive and destructive waves. After this, the signals keep on propagating into that direction. At time *t*+1, signals of message sent by node 1 will reach to node 2 while signal of message sent by node 2 is still continuously propagating. Although, the message sent by node 1 is received at node 2 without any collision. Thus, we consider the transmission from node 1 to node 2, to be successful. It should be noted that, this won't be the case when you work with radio waves, if it were radio signals then they would get collided. Hence, we can say that working of ALOHA differs a lot compared to ground communications in UWSN.

2.2 Broadcast MAC

B-MAC is a simple yet efficient MAC protocol when we consider the low traffic networks [4]. B-MAC can take full advantages of the broadcast nature of Underwater Acoustics Channel. B-MAC also possesses a simple working mechanism which is completely dependent on the backoff mechanisms. Whenever a frame is to be transmitted, it will first sense the channel whether it is free or not, if it is free then it simply sends the data or else it will backoff. It continues to do so until a specific backoff limit is reached. When the backoff limit is reached it simply drops the frames. When the receiver receives the frame by B-MAC it does not send any ACK.

The only issue that rests with B-MAC is the number of collisions. The other problem that B-MAC faces is the "reply storm" problem [3]. It can be described by considering a situation where, CTS frames are broadcasted on network layer. When this broadcast of CTS is heard by all the nodes in the network, all of them will try and send RTS at the same time, this simultaneous issuing of large number of RTS frames is described as reply storm problem. This problem is due to the handshake nature of the MAC protocols. This reply storm problem is also the only reason for large number of collisions in B-MAC.

2.3 Comparison of B-MAC and ALOHA

There is very limited description of B-MAC found in literature but its capability to give optimum performance with geo-routing based protocol as well as its characteristic of working efficiently in low traffic networks [4] makes it our point of focus.

Moreover, one more important point to be noticed is that Broadcast MAC and ALOHA both use back off mechanisms and there is also a facility of acknowledgment from receiver in ALOHA which cannot be found in Broadcast MAC. Hence we consider ALOHA protocol for comparative evaluation with B-MAC.

We need to find whether the acknowledgment which is a part of ALOHA, consumes more bandwidth or not. If it would be consuming more bandwidth then it should have higher overall energy consumption as receiving node will also waste energy in generating acknowledgment as transmitting it back while it is expected that in B-MAC with various bit-rates the overall energy consumption of network should remain lower compared to ALOHA as there are no extra frames in the form of acknowledgment generated in it and so less energy would be consumed.

3. PERFORMANCE EVALUATION

We analysed few scenarios for evaluation of MAC protocols for UWSN before deciding parameters for the simulation scenario. We analysed scenarios that were configured in [2], [8] and [9] and then designed the simulation scenario for our low traffic network as described in following section.

3.1 Network Simulation Configurations

The simulation scenario that we have considered consists of five nodes, from which one acts as a sink node and other all are mobile wireless nodes participating in a UWSN as shown above in figure 2. The network configurations will be as that of a low traffic network. We will be also varying the number of nodes just by increasing by a number of one up to a total of eight nodes. Moreover, the sink node which is attached to the surface buoy will remain stationary throughout the simulation time.

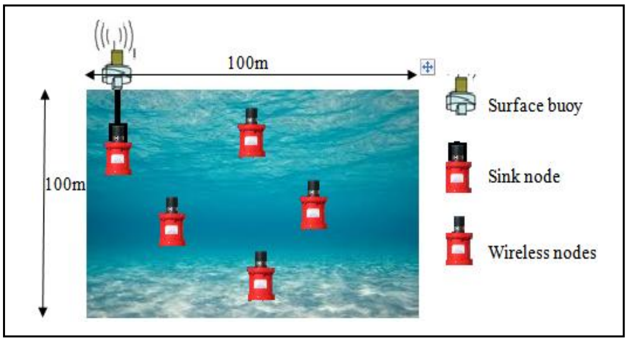

Fig-2: Visualization of Simulation Scenario

In our simulation we have considered our nodes to possess the physical properties like transmission power, receiving power, idle power, frequency and transmission range same as that of LinkQuest UWM1000 acoustic modem [10]. Also the dimensions of our network are 100m X 100m X 10m and so we have a shallow underwater acoustic network [11] with a depth of 100m. Bandwidth and energy consumption are also considered as impediments in this kind of shallow UWSN as described by [11]. Hence, we also get chance to understand the performance of B-MAC and ALOHA in this kind of network which has very high latency. Thus, if either B-MAC or ALOHA performs well in this kind of scenario we can expect them to work more efficiently in general UWSN.

To simulate the scenario that is being described we are using Aqua-Sim which is an NS2 based simulator [4]. The default value of sound propagation in the physical underwater acoustic channel is given as 1500 m/sec in Aqua-Sim. The mobility and wireless functionality are provided independently by Aqua-Sim which works in parallel with CMU-wireless package of NS2. Any changes that are made to Aqua-Sim are confined to itself and it is mentioned in [4] that it is an independent simulator, which is designed completely like NS2 in C++. The configuration of our simulation is summarized in table 1 below.

Table 1: Simulation Confgurations

Parameter	**Value**
Number of nodes	5
Transmission power	2 W
Receiving power	0.75 W
Transmission range	90 m
Data packet size	60 bytes
Control packet size	5 bytes
Speed of node	0.5 m/sec
Maximum speed of node	3 m/sec
Minimum speed of node	0 m/sec
Bit-rate	10 kbps (varying by 10 kbps up to 100 kbps)
Interval	10
Simulation time	600 sec

Most of the parameters that are given in the table 1 above have been discussed by us so far. But, the type of traffic generation has not been discussed so far. Hence, we describe the traffic generation over here.

The generation of traffic will be done using Poisson process with rate λ packets per second. The interval value supplied over here will be playing part in the generation of traffic. With this interval value as 10 we will have $\lambda = 0.1$ which can be considered as low traffic generation rate as given in [2].

3.2 Performance Metrics

The performance metrics that we have considered here are cumulative delay and overall energy consumption. Our entire focus while evaluating the performance of these protocols is on overall energy consumption. We aim to find the bit-rate at which there is the least consumption of energy by the network. We can then consider that bit-rate as an optimum bit-rate for that protocol in the context of overall energy consumption. At present, it is very difficult to get underwater acoustic modems with bit-rates greater than 35-40 kbps but we expect that in future there may be modems with higher bit-rates and good performance. Hence, we aim to evaluate the MAC protocols to find the bit-rate at which lowest overall energy consumption takes. Thus, we consider overall energy consumption and cumulative delay as our performance metrics.

- *Energy Consumption* [12]. We consider *energy consumption* during the communication period which depends on various factors like implementation of hardware, sleep control and MAC protocols [12], but we use *communication time* to evaluate energy consumption. The *communication time* is the total time spent in communication of sensor networks in the simulation including transmission time and receiving time of all nodes in networks.

- *Cumulative Delay*. The sum of the time taken by all the packets that are generated in the network to reach from source to destination is called *Cumulative Delay*.

3.3 Simulation Results

We carried out several simulations with scenario described above. In following figure 3, the results of simulations for cumulative delay by varying bit-rates are being shown for ALOHA.

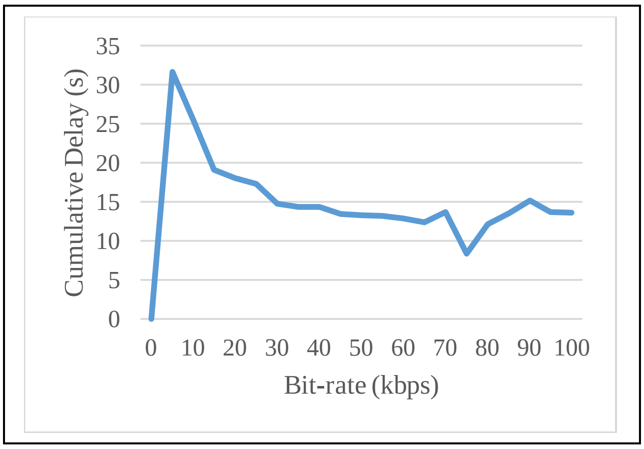

Fig-3: Bit-rate vs. Cumulative delay for ALOHA

The result shown above describes ALOHA simulation results for cumulative delay against various bit-rates. We can see that cumulative delay goes on decreasing continuously till 65 kbps of bit-rate value but it increases a little at 70 kbps, just before the least value is encountered around 75 kbps of bit-rate and after that it increases to become stable at the value of 13.68 sec at bit-rate of 95 kbps. Hence in the results we found that cumulative delay decreases rapidly till the bit-rate value of 65 kbps but after that it just keeps on hovering around 13 sec except at 75 kbps. Similarly for overall energy consumption simulation results are plotted in figure 4.

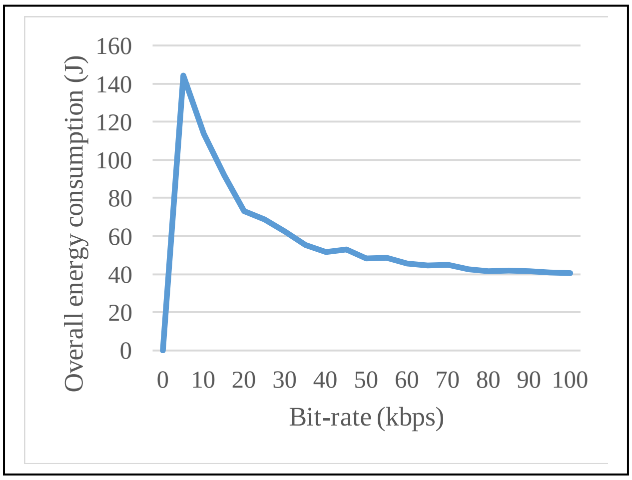

Fig-4: Bit-rate vs. Overall energy consumption for ALOHA

From the above figure 4, we see that overall energy consumption is decreasing either rapidly or slowly but only up to the bit-rate value of 70 kbps, after that it becomes nearly constant with value around 41 J. Also it should be noted that even between bit-rate values of 50 kbps and 70 kbps, the energy consumption is only around 44 J which is nearly half of what is found at 20 kbps. Hence, we can say that, with increase in bit-rate the energy consumption goes on decreasing but it gets stabilized at a point. Thus, increase of bit-rate does play a part when we consider overall energy consumption.

From the results of ALOHA against bit-rate as given in figure 3 and figure 4, we can say that, the cumulative delay becomes pretty much stable after 75 kbps and it also stops decreasing after 65 kbps. Also, we find that after 70 kbps, there is not any significant decrease in energy consumption.

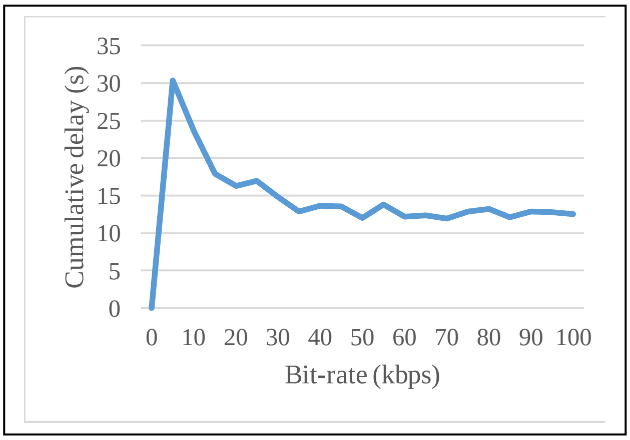

Fig-5: Bit-rate vs. cumulative delay for B-MAC

Figure 5, shows the cumulative delay caused in the network when B-MAC protocol is used. Here the continuous drop or continuous variation in values of cumulative delay is found up to bit-rate value of 50 kbps after which the cumulative delay is nearly constant at a value around 12 sec. In the following figure 6, overall energy consumption of network against varied bit-rate values is considered.

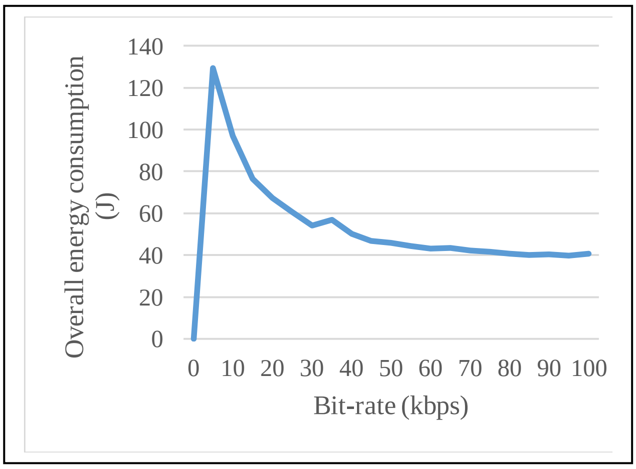

Fig-6: Bit-rate vs. Overall energy consumption for B-MAC

The overall energy consumption of network goes on decreasing rapidly till 50 kbps apart from a steep increase and decrease between 30 kbps and 40 kbps. Moreover, after 50 kbps the overall energy consumption of the network stabilizes with value of 40-42 J. Thus, we can say that after 50 kbps of bit-rate, the effect of increase in bandwidth doesn't affect the overall energy consumption.

From the results of B-MAC as given in figure 5 and figure 6 we can say that after 50 kbps there isn't any significant amount of change in cumulative delay as well as overall energy consumption.

Next, we analyse the behaviour of ALOHA and B-MAC protocols with increase in the number of network nodes in the scenario that is described in figure 2. The increase that we'll be doing would be only by one node at a time. We do the increase in this manner as we want to maintain the low traffic state of the network, if we increase the node rapidly then though we keep rates of traffic low, the overall traffic of the network will get increased. Thus, now the ALOHA and B-MAC protocols will be evaluated for same performance metrics but by varying number of nodes in the network.

Figure 7 shows, cumulative delay for ALOHA and figure 8 shows overall energy consumption for the same.

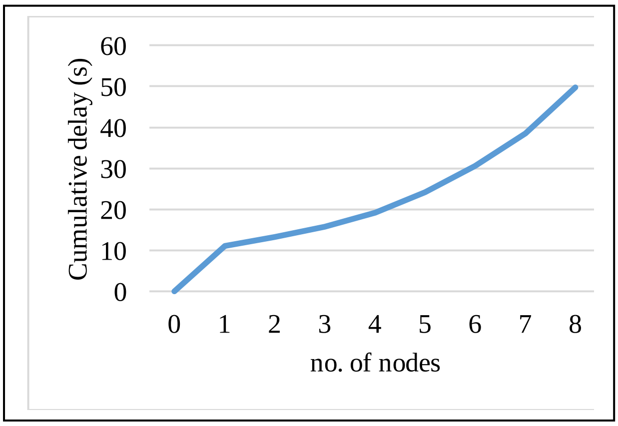

Fig-7: Number of nodes vs. cumulative delay for ALOHA

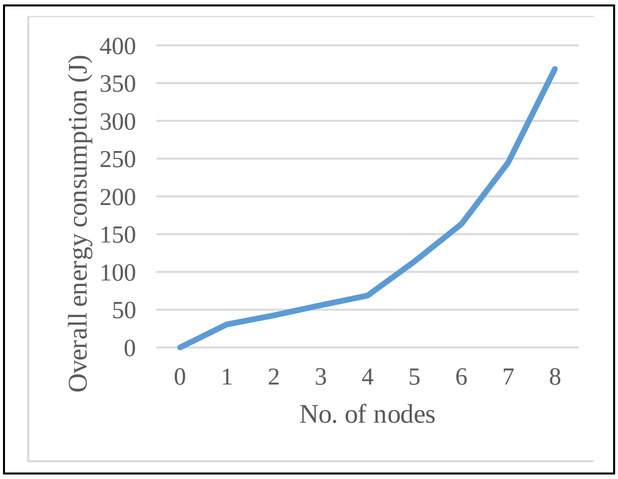

Fig-8: Number of nodes vs. Overall energy consumption for ALOHA

In this figure 7 and figure 8 for cumulative delay as well as overall energy consumption we find the results to be very much relatable. Both the energy consumption and cumulative delay are increasing with increase in number of nodes in ALOHA. But, the increase in energy consumption is not very rapid till the number of nodes are 4 but after increasing the number of nodes beyond 4; the increase is very sharp and rapid.

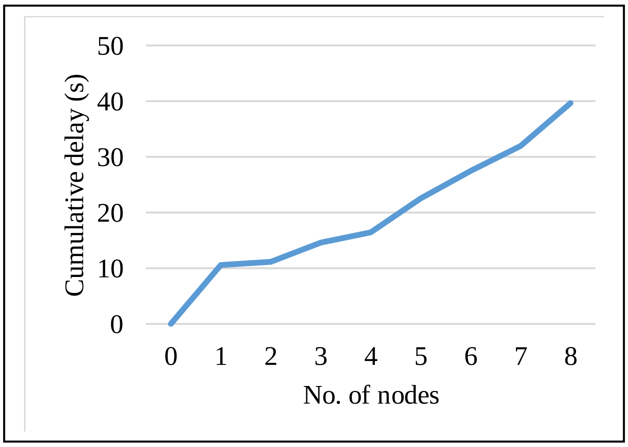

Fig-9: Number of nodes vs. Cumulative delay for B-MAC

In B-MAC, we see that cumulative delay is not increasing as regularly as it was in ALOHA. When there is only 1 node in the network the cumulative delay experienced by B-MAC is 10.6s and that of ALOHA is 11.1s. When number of nodes is increased to 2, cumulative delay for B-MAC is 11.1s and for ALOHA it is 13.3s. Thus there is not much difference in cumulative when number of nodes is 1 or 2. When number of nodes are 4, the cumulative delay for B-MAC is 16.1s and for ALOHA, it is 19.8s. Now, for amount of nodes we find more difference in cumulative delay of both. Thus, up to the point when number of nodes are 3 or 4, the increase in cumulative delay is less and then it increases rapidly.

Now in figure 10, the overall energy consumption of B-MAC protocol for various numbers of nodes is being shown. Here, also the rate of increase of energy consumption is very slow till the number of nodes is four but after that the increase is quick as well as steady till number of nodes are raised to 8. But, in the network when number of nodes is to its highest number i.e. 8, the energy consumption done by ALOHA is 379 J and by B-MAC it is 230 J. Hence B-MAC consumes 61% less energy when number of nodes are 8.

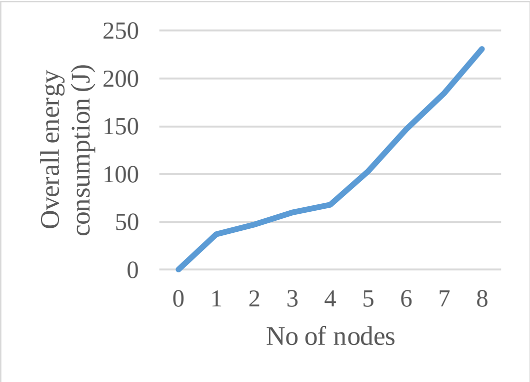

Fig-10: Number of nodes vs. Overall Energy consumption in B-MAC

Also the average energy consumption by B-MAC is 109 J, while for ALOHA it is 137 J which is 21% higher than B-MAC.

Both of the above protocols are giving similar kind of performance when we note their results against number of nodes. Hence, we observe similarity in their behaviour to tackle the increasing number of nodes, though B-MAC does consume (about 21%) less amount of energy than ALOHA in overall.

From the above observations, in the context of energy efficiency and latency, we can say that ALOHA performs well when bit-rate is around 65 kbps to 75 kbps and B-MAC performs well when bit-rate around 50 kbps. The reason for this is that with increase in bit-rate the amount of time that a node is spending for transmission will get reduced due to quick transmission of packet as with high bit-rates node transmits quickly and goes back to its idle state and hence the energy spent behind the task of transmission of packet is reduced, which in turn results into decrease in overall energy consumption of network.

4. CONCLUSIONS

In the performance evaluation of the two MAC protocols that we carried out, our main focus was on dependency of overall energy consumption and delay on the bit-rate of a network.

On carrying out simulations, we found that overall energy consumption as well as delay decreases with increase in bit-rate, but only up to a particular point, after which it becomes nearly constant. From the results, we can also say that if we want to devise an acoustic modem with higher bit-rate then the bit-rates at which B-MAC and ALOHA performed well can be considered. When we consider all performance criterions of bit-rate as well as overall energy consumption and delay in the network then we can say that B-MAC performed better than ALOHA. B-MAC consumed the least bit-rate and energy as well as caused much less delay in the network compared to ALOHA but again when number of nodes in the network were increased, both performed similarly. The difference in ALOHA and B-MAC when we consider the bit-rate vs. overall energy consumption in the network may be due to the methodology of providing responses i.e. acknowledgements by the receiver on receipt of packets which is not there in B-MAC. The generation of acknowledgments by the receiver in the network results extra number of generation of packets in the networks by the nodes which causes more energy as well as bit-rate to be consumed.

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BIOGRAPHIES

Jekishan K. Parmar just completed his M.Tech in Computer Engineering at Faculty of Technology, Dharmsinh Desai University, Nadiad, Gujarat, India in May, 2014. He received his B.E. in Information Technology from L. D. College Of Engineering, Ahmedabad in 2012. His research interests include Mobile Computing, Ad hoc Networks and Wireless Sensor Network.

Mrudang T. Mehta is an Associate Professor at Department of Computer Engineering, Faculty of Technology, Dharmsinh Desai University, Nadiad, Gujarat, India. He received his M.Tech. in Information Technology from Indian Institute of Technology, Roorkee in 2008 and B.E. in Computer Engineering from DDIT, Nadiad in 2001. His research interests include Wireless Sensor Network, Embedded System and Mobile Computing.