A Comparative Study on MAC Protocols of an Underwater Surveillance System from QoS Perspective

Reza Mohammadi and Reza Javidan
Department of Computer Engineering and Information Technology,
Shiraz University of Technology, Shiraz, Iran.
R.mohammadi@sutech.ac.ir

***Abstract*— Underwater wireless sensor networks can be employed in a vast range of applications such as the underwater surveillance systems. The adoption of underwater wireless sensor networks by underwater surveillance systems has brought forward a new challenge of fulfilling the quality of service (QoS) requirements. Providing QoS support is a challenging issue due to the highly resource constrained nature of underwater wireless sensor nodes and the harsh operation environments. In this paper, we focus on the analysis of QoS parameters for underwater surveillance system MAC protocols. In this paper, we analyze QOS parameters of four MAC protocols: RMAC, Slotted FAMA, UWALOHA and AQTUWMAC in terms of energy efficiency, packet delivery ratio and average end to end delay in two different nodes deployment strategies. To the best of our knowledge, this is the first paper that compares MAC protocols in randomly deployment strategy and Octahedron placement strategy for underwater surveillance system. We have used the underwater wireless sensor network simulator Aqua-Sim to simulate the MAC protocols.**

***Index Terms*— Underwater surveillance systems, Underwater MAC protocols, QoS in underwater surveillance systems.**

I. INTRODUCTION

The Earth is a water planet. Considering that over two thirds of the earth's surface is covered with water, it is justifiable to use underwater wireless sensor networks (UWSN) in aquatic applications [1][2]. UWSN consists of a number of underwater sensor nodes and underwater vehicles that communicate with each other using acoustic signal. During the past few years, a significant interest in monitoring aquatic environments such as underwater surveillance systems has emerged. Underwater surveillance system was made feasible by applying underwater communications among underwater devices [3][4][5].

UWSNs have many characteristics that make them different from packet radio networks. UWSNs use acoustic signals for communication. Due to the harsh underwater environment, UWSNs pose unique challenges such as high and variable propagation delays (approximately 1.5×10^3 m/s), temporary losses of connectivity, limited bandwidth and high bit error rates [6] [7] [8].

Underwater surveillance system (USS) that applies UWSNs performs monitoring task in underwater environment. The basic function of USS is to monitor underwater events such as contaminants, marine life, submarine rides and report sensed data via multi-hop acoustic routes to a distant command center or sink node. This critical aquatic application requires QoS parameters. In USS, QoS parameters are classified into two categories: topographical QoS parameters and application specific QoS parameters. Application specific QoS parameters depend on the quality demands of the specific task [9].

In USS, the most important application specific QoS parameters are high packet delivery ratio, low end to end delay, and high energy efficiency. Since monitoring task in USS must be in real time, low end to end delay is a vital QoS parameter. The mission time of USS is usually long, and therefore, the energy efficiency is QoS parameter in USS. Energy consumption causes to prolong the USS lifetime. High packet delivery ratio is another QoS parameter, which ensures that USS can continue its task in high network load.

The topographical QoS parameters in USS are the full coverage of the specified underwater environment and the connectivity of sensor nodes in the overall specified underwater environment. The most important issue in USS is the optimal placement strategy to achieve full coverage of environment and maintaining connectivity among sensor nodes.

To satisfy QoS requirements in USS, an efficient Medium Access Control (MAC) protocol is very important. Selecting a suitable MAC protocol is very important for acoustic channels with low quality and high latency since it has a great impact on the USS efficiency.

The MAC layer protocols operate directly on top of the physical layer. The main task of a MAC protocol is to decide when a node accesses a shared channel and to resolve any collisions between the sensor nodes. The MAC layer protocols perform tasks, such as correcting communication errors occurring at physical layer, framing the data packets and addressing flow control [10]. In this paper, we aim to analyze four MAC protocols for the underwater surveillance system in terms of QoS requirements.

The rest of this paper is organized as follows. In Section II, we present the underwater surveillance architecture. Section III describes the MAC protocols that we consider in this paper. After that, we evaluate the performance of four MAC protocols in Section IV. Finally, we give our conclusions in Section V.

II. UNDERWATER SURVEILLANCE SYSTEM ARCHITECTURE

In this section, we present the USS architecture. In our USS architecture, we have four different types of nodes: underwater sensor node, surface station, onshore station and surface buoy as shown in Figure 1.

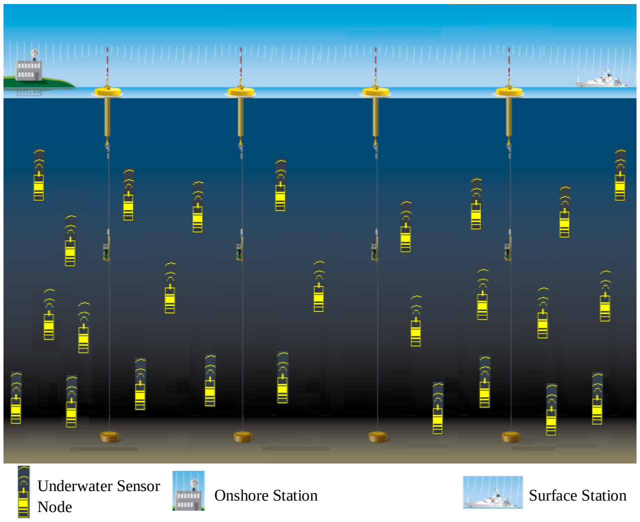

Figure 1: Underwater surveillance system architecture

The underwater sensor nodes have less battery energy than the surface buoy. The underwater sensor nodes are cheap sensor nodes, which cannot communicate directly with the surface station or the onshore station. Surface buoys are powerful nodes that can gather data from the ordinary sensor nodes and forward it to the surface station or the onshore station through radio signals. Surface station and onshore station are the command center: It gathers data from surface buoys and interprets them. According to Figure 1, our architecture multiple surface buoys are deployed on water surface.

Underwater sensor nodes can deploy in underwater environment in two different ways: randomly and structure based. The randomly deployment method is easier than the structure based deployment. In this method, hundreds of underwater sensor nodes are randomly deployed in a specific underwater environment. The randomly deployment method does not ensure full coverage of specific underwater environment or connectivity among sensor nodes.

Structure based method is more difficult to deploy. In [11], S. M. Nazrul Alam and Z. J. Haas proposed a structured based method to achieve full coverage and full connectivity among sensor nodes. Their structure based method is called the octahedron placement strategy. Octahedron placement strategy ensures full coverage and full connectivity, while minimizing the number of nodes required for surveillance.

III. RELATED WORKS

In this section, we review the related work on MAC protocols that we consider in this paper.

A. *Slotted FAMA*

Slotted FAMA (Floor Acquisition Multiple Access) is based on FAMA [12] and proposed by M. Molins and M. Stojanovic [12]. In FAMA, the sender and receiver use RTS/CTS packets for sending data. RTS and CTS transmission time length are determined based on the maximum propagation delay. In underwater environment, propagation delay is high. Thus, FAMA protocol is not suitable for underwater communications [13]. To overcome FAMA drawback, slotted FAMA divides the time into time intervals called “slots”. All control and data packets have to be sent at the beginning of one slot. Let γ be the transmission time of CTS and τ be the maximum propagation delay in underwater environment. If the length of the slot is set to $\tau + \gamma$, then it can be guaranteed that the packet collision will not occur. Slotted FAMA uses ACK for receiving data successfully and NACK for not receiving data successfully. To increase efficiency, a sender can perform one handshaking and send trains of packets. One of the main drawbacks of Slotted FAMA is that it is not an energy efficient protocol. Reducing collisions between transmitted packets is the main advantage of Slotted FAMA. Figure 2 illustrates a successful handshaking and data transmission in Slotted FAMA.

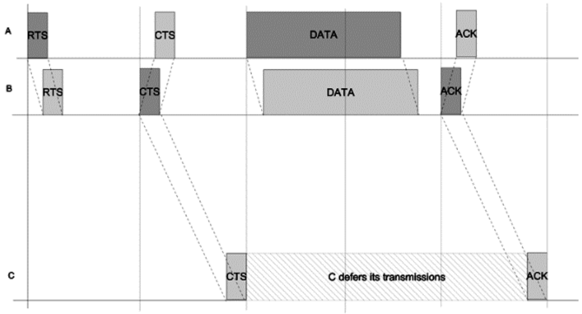

Figure 2: An example of successful data transmission in Slotted FAMA [2]

B. *UWALOHA*

UWAloha is based on the Aloha idea [14]. UWAloha is a very simple protocol and does not use control packets such as RTS/CTS before transmitting data packets. Peng Xie et al. tailored the UWAloha to underwater network environments in Aqua-Sim [14]. In UWAloha, when a node wants to send the data packet, it will send the packet immediately without sensing the channel. Then, the sender node starts a timer and waits for acknowledgment from the receiver node. If the receiver node receives the data packet correctly, it sends an ACK control packet back to the sender node. If the sender node receives an ACK before the timer is expired, the sender node knows that this packet has been successfully received and starts to send the next data packet. Otherwise, the sender node waits for the random time called back off time and sends the same packet again [14]. Since the propagation delay in underwater environment is high, we eliminate ACK control packet for UWAloha in our simulation scenarios in section IV. The main disadvantage of UWAloha is that it does not consider power control and energy consumption. Additionally, UWAloha does not use control packets and data packet collisions can occur in this protocol.

C. *AQTUWMAC*

AQTUWMAC is proposed by R. Mohammadi et al. in [15]. The major goals of designing AQTUWMAC are energy efficiency and low end to end delay. AQTUWMAC is based on carrier sensing, and RTS/CTS control packets are used to avoid data collisions. AQTUWMAC has two phases, namely, the delay detection and the operation. In the delay detection phase, all nodes are powered on and each node detects the propagation delay to all its neighbors. In this phase, each node randomly selects a time to broadcast a control packet denoted as RTN. Before sending the RTN, the sender node inserts a transmission time of RTN in RTN packet and sends it. Upon receiving the RTN from its neighbors, a receiver node calculates the propagation delay by subtracting the transmission time field in the RTN packet from its local time. In the second phase, when a node wants to send a data packet, it sends an RTS packet and sets its timer to 2TSR + T_{cts}. where T_{cts} is the CTS duration and TSR is the propagation delay between the sender node and the receiver node. When the receiver node receives the RTS packet, it returns the CTS to the source node and sets its timer to 2TSR +T_{data}, where T_{data} is the data packet duration and TSR is the propagation delay between the sender and the receiver. When the source sensor node receives CTS control packet, it transmits the data packet. In AQTUWMAC, to avoid packet collision, every neighboring node is required to stay in a QUIET state upon overhearing an xRTS or xCTS packet. AQTUWMAC uses adaptive quiet time method for this purpose. In AQTUWMAC, the QUIET state is equal to the sleep mode and when a node is in a QUIET state, it consumes a very low energy. AQTUWMAC is the energy and an end to end delay efficient protocol; hence, it is suitable for networks with stationary nodes.

D. *RMAC*

R-MAC is an energy efficient MAC protocol proposed by P. Xie and J. Cui in [16]. By scheduling the transmissions of packets, RMAC can avoid packet collisions. Scheduling process is performed at both the source and the destination nodes. To improve energy efficiency, each node is periodically switched between the listen and sleep modes. R-MAC uses three phases: the latency detection, period announcement and periodic operation.

In the latency detection phase, each sensor node tries to measure latency between itself and its neighbors. Each node broadcasts an ND (neighbor discovery) to its neighbors. Then, the neighbor nodes receive the ND packet and store the arrival time of packet. They then send the ACK-ND packet to the sender node. After receiving the ACK-ND, the sender node estimates the latency between itself and its neighbors.

In the second phase or the periodic announcement phase, each node broadcasts a SYN packet to its neighbors to announce its scheduling program for the listen and sleep periodic functions for the next phase. Once the SYN packet is received, the neighbor nodes first convert the received scheduling program to its own schedule, and then record it.

In the third phase, each node in the network periodically wakes up and sleeps. For a successful data transmission, the sender and the receiver use REV, ACK-REV, DATA, ACK-DATA packets. First, the sender node sends a REV packet to announce and reserve a time slot at the receiver node. If the receiver node is ready, it notifies its neighbor by sending ACK-REV packets and informs them about the reserved slot. Each neighbor that overhears the ACK-REV should be silent in its relevant time slots. Then, the sender node sends the data packet at the reserved time slot. Moreover, the data packet transmission can be performed in a burst. After receiving the data packets, the receiver node informs the sender node by sending the ACK-DATA packet.

As mentioned above, RMAC is energy efficient and does not require synchronization; but one of the main disadvantages of RMAC is that there is no technique when a new node wants to join to the network or a node decides to change its scheduling [17].

IV. PERFORMANCE EVALUATION

In order to analyze the mentioned MAC protocols QoS parameters, we conducted several experiments to test their performance under different operating conditions. To perform these experiments, we used the Aqua-Sim, and NS2 based underwater simulator [14]. First, we describe the details of the simulation settings.

A. *Simulation Settings*

Unless otherwise indicated for a certain experiment, the simulation parameters that we used are as follows. For the comparison of MAC protocols in equal conditions, we used 188 nodes in all scenarios. Based on the Octahedron placement strategy, considering 188 nodes in the 1000 x 1000 x 500 m^3 is enough. In our experiment, 9 source nodes placed at the bottom layer, and 9 at the surface buoys (surface sink) are deployed at the water surface. The maximum transmission range is 200 meters (spherical). The interference range is the same as the transmission range. In all our simulations, we set the parameters similar to UWM1000 [18]. The initial energy of each node is 10000 joule. We set the size of the data packets to 200 bytes. The bit rate is 17.8 Kbps. The power consumptions in receiving, sending and idling mode are 0.75w, 2w, and 10mw respectively.

B. *QoS Parameters*

We define three QoS parameters or performance metrics: energy efficiency, packet delivery ratio and average end to end delay. End to end delay is the average time interval from the source to the destination for each successfully delivered packet. The packet delivery ratio is defined as the ratio of the total number of distinct data packets successfully received at the sinks to the total number of packets generated at the source node. Energy efficiency is defined as the total packet delivered divided by the total energy consumption as follows:

$$Energy\ Efficiency = \frac{Total\ Delivered\ packet}{Total\ Energy\ Consumption} \qquad (1)$$

According to this formula, if a protocol delivers more data with low energy consumption, its energy efficiency metric is high. Therefore, high energy efficiency ratio means that the protocol is energy efficient. This metric is useful for comparing protocols against each other.

C. Simulation

In the first set of simulations, we studied how traffic rate affects the performance. In this set of simulation, we consider 188 numbers of sensors deployed in the 3D water with the volume of 1000 x 1000 x 500 m^3. In this scenario, we used Octahedron placement strategy for nodes deployment, which was mentioned in Section II. All nodes are stationary. This set of simulation lasts for 3600 seconds and all of the results are obtained from the average of 10 runs with a confidence interval of 99%. The packet interval time increases from 1 to 21 second.

The results of packet delivery ratio are shown in Figure 3, where it is observed that the packet delivery ratio increases as the packet interval time increases. It means that in this scenario, MAC protocols have high packet delivery ratio in low traffic rate because in low traffic rate the probability of collision decreases. From this figure, it can be concluded that RMAC has less packet delivery ratio than the other three protocols. This is because it is possible that two or more nodes want to reserve channel simultaneously in RMAC and it causes a reduced packet delivery ratio.

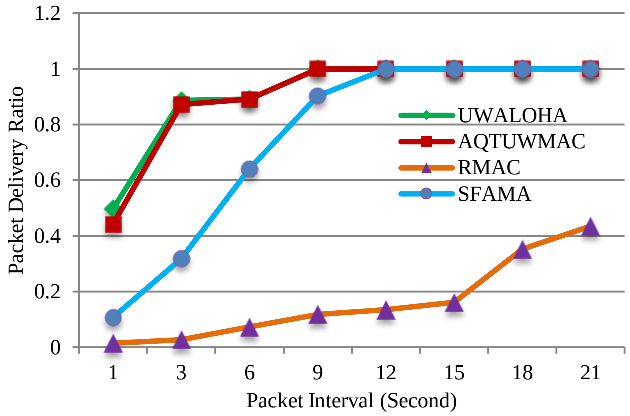

Figure 3: Packet delivery ratio vs. packet interval time in Octahedron placement strategy with stationary nodes

The results for energy efficiency are shown in Figure 4 where it can be concluded that the RMAC has better energy efficiency as compared to other MAC protocols in low traffic rate. This is mainly caused by two factors. First, RMAC has low packet delivery ratio as shown in Figure 3. Second, in RMAC, each node reserves a channel and goes to sleep mode before sending a packet. In this figure, UWALOHA has better energy efficiency after the RMAC. This is because UWALOHA has high packet delivery ratio (as shown in Figure 3) and consumes low energy for delivering a data packet to sink. Therefore, UWALOHA has better energy efficiency than AQTUWMAC and Slotted FAMA.

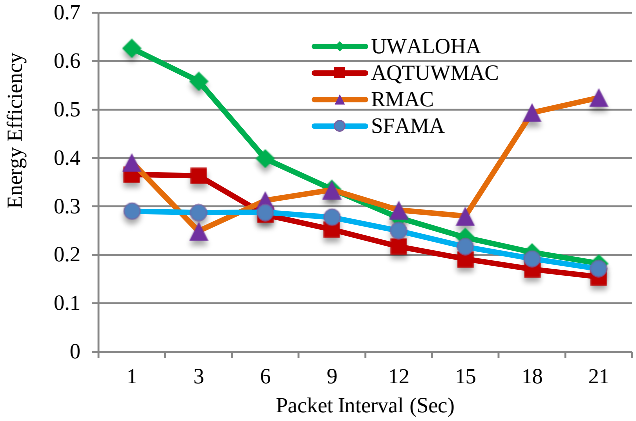

Figure 4: Energy efficiency vs. packet interval time in Octahedron placement strategy with stationary nodes

The results of average end to end delay are shown in Figure 5 and Figure 6. Because the Slotted FAMA and RMAC have high average end to end delay compared to AQTUWMAC and UWALOHA, the difference between AQTUWMAC and UWALOHA is not clear in Figure 5. Therefore, we use Figure 6 to show more details. From Figure 5 and Figure 6, we can conclude that UWALOHA and AQTUWMAC have very low average end to end delay in comparison to RMAC and Slotted FAMA. This is because Slotted FAMA uses slot times and the length of slot times are long. Further, RMAC tries to reserve a channel before sending a packet and this causes high average end to end delay. In contrast, AQTUWMAC and UWALOHA do not use slot time or channel reservation mechanism and they have low average end to end delay.

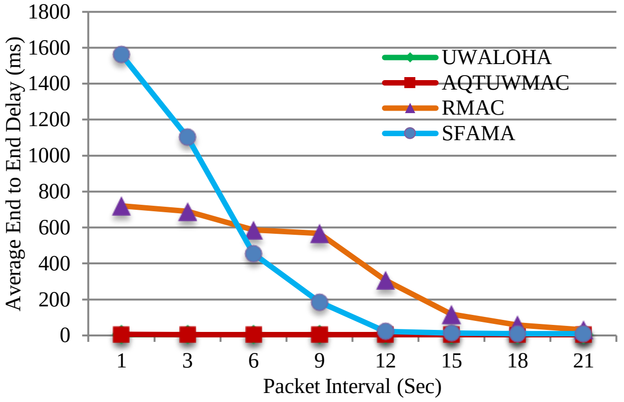

Figure 5: Average end to end delay vs. packet interval time in Octahedron placement strategy with stationary nodes

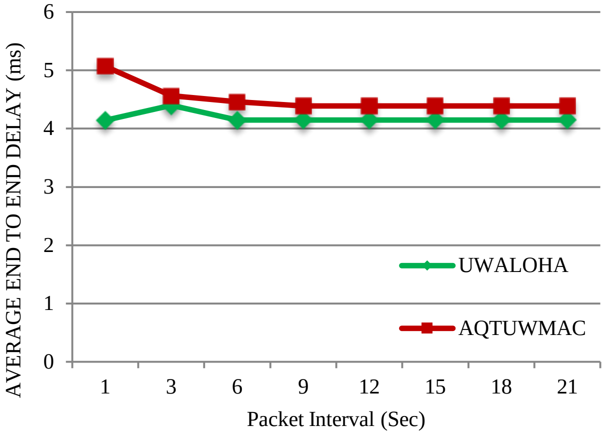

Figure 6: Average end to end delay vs. packet interval time in Octahedron placement strategy with stationary nodes for UWALOHA and AQTUWMAC

In the second set of simulations, we studied how the mobility of nodes affects the performance. In this set of simulation, we consider 188 numbers of sensors deployed in the 3D water with volume of 1000 x 1000 x 500 m^3. In this scenario, we used Octahedron placement strategy for nodes deployment, as mentioned in section II. We assume that the surface sinks and sender nodes are stationary and the other sensor nodes are mobile. Each sensor node randomly selects a direction and moves to the new position with a random speed between the minimum speed of 1 m/s and the maximum speeds, 1.5 m/s, 2 m/s and 3 m/s. Each sender node sends 1 packet per 10 seconds. This set of simulation lasts for 3600 seconds and all of the results are obtained from the average of 10 runs with a confidence interval of 99%.

The results of the packet delivery ratio are shown in Figure 7. From Figure 7, we observe that the AQTUWMAC and UWALOHA have high packet delivery ratio in different node speeds. From this figure, we can conclude that RMAC and Slotted FAMA have less packet delivery ratio than the other two protocols. This is because in RMAC, it is possible that the sensor nodes reserve a channel for sending packet, but the mobility of nodes causes a failure in the reservation. Further, due to lengthy slot times in Slotted FAMA, it is possible that the mobility of nodes affects the reception of the data packets.

The results for energy efficiency are shown in Figure 8. From this figure, we observe that the energy efficiency decreases as the speed of nodes increases. From Figure 8, we can conclude that RMAC has better energy efficiency compared to the other MAC protocols. As shown in Figure 7, RMAC has low packet delivery ratio and RMAC has sleep mode that causes low energy consumption. Therefore, each node can reserve channel and go to a sleep mode. Considering that UWALOHA has high packet delivery ratio and consumes low energy for delivering a data packet to sink (Refer to Figure 7), UWALOHA has better energy efficiency than the Slotted FAMA and the AQTUWMAC.

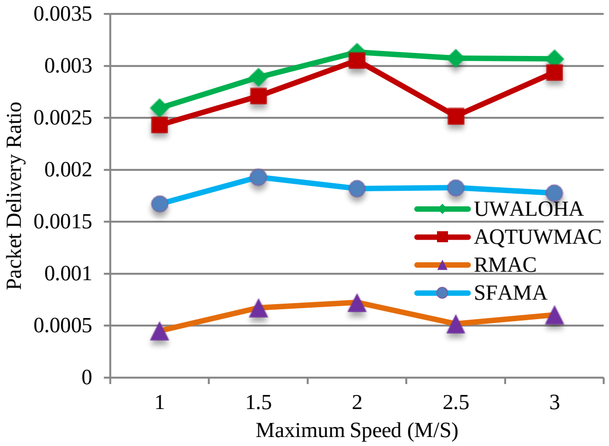

Figure 7: Packet delivery ratio vs. maximum speed of nodes in Octahedron placement strategy with mobile nodes

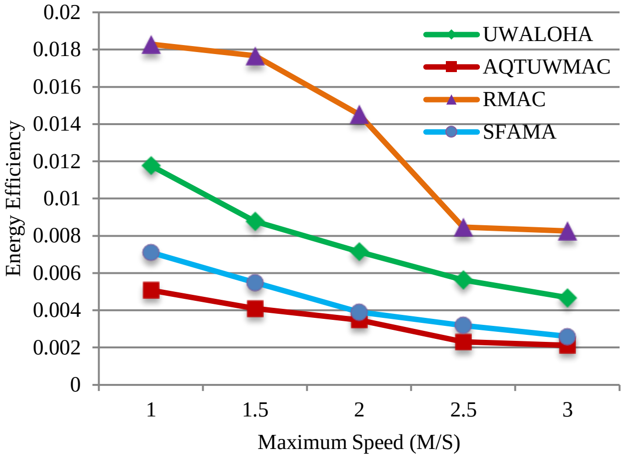

Figure 8: Energy efficiency vs. maximum speed of nodes in Octahedron placement strategy with mobile nodes

The results of average end to end delay are shown in Figure 9. From Figure 9 we can conclude that UWALOHA has very low average end to end delay compared to RMAC, AQTUWMAC and Slotted FAMA. In the case of mobility, AQTUWMAC could not calculate the propagation delay to calculating the QUIET time correctly and this causes high average end to end delay. Additionally, the lengthy slot times in Slotted FAMA causes the average end to end delay. Each node in RMAC tries to reserve a channel before sending a packet and this causes high average end to end delay.

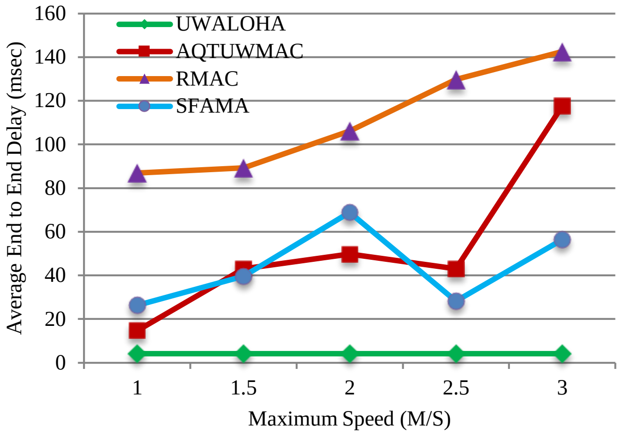

Figure 9: Average end to end delay vs. maximum speed of nodes in Octahedron placement strategy with mobile nodes

In the third set of simulations, we studied how the traffic rate affects the performance. In this set of simulation, we consider 188 numbers of sensors randomly deployed in the 3D water with volume of 1000 x 1000 x 500 m^3. All nodes are stationary. This set of simulation lasts for 3600 seconds and all of the results are obtained from the average of 10 runs with a confidence interval of 99%. The packet interval time increases from 1 to 21 second.

The results of packet delivery ratio are shown in Figure 10. From Figure 10, we observe that the packet delivery ratio increases as the packet interval time increases. It means that in this scenario, MAC protocols have high packet delivery ratio in low traffic rate. From this figure, we can conclude that RMAC has less packet delivery ratio than the other three protocols in high traffic rate. This is because in RMAC, it is possible that two or more nodes want to reserve channel simultaneously and caused reduce packet delivery ratio.

From Figure 10 and Figure 3, we can conclude that MAC protocols have high performance in terms of packet delivery ratio in the Octahedron placement strategy compared to the randomly deployment strategy.

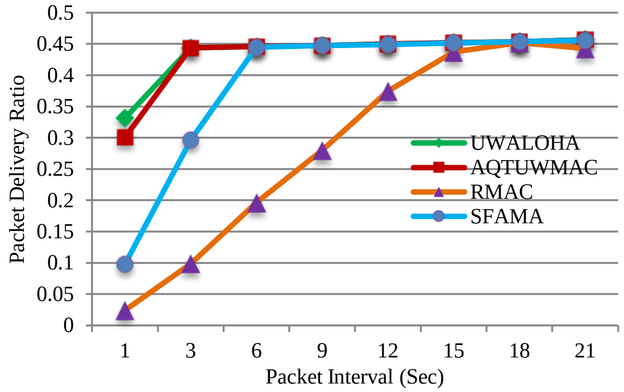

Figure 10: Packet delivery ratio vs. packet interval time in randomly deployment strategy with stationary nodes

The results for energy efficiency are shown in Figure 11. From this figure, we observe that the energy efficiency decreases as the packet interval time increases. From Figure 11, we can conclude that RMAC has better energy efficiency compared to the other MAC protocols under different packet interval times. This is because the RMAC has low packet delivery ratio as shown in Figure 10 in the randomly deployment strategy. Moreover, each node in RMAC reserves a channel and goes to sleep mode before sending a packet. In this figure, the other three protocols approximately have similar energy efficiency.

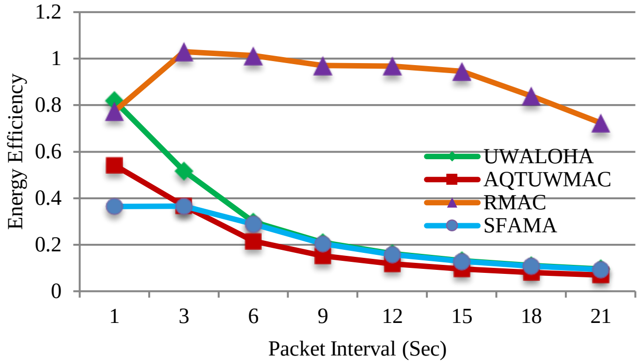

Figure 11: Energy efficiency vs. packet interval time in randomly deployment strategy with stationary nodes

The results of average end to end delay are shown in Figure 12. From Figure 12, we can conclude that UWALOHA and AQTUWMAC have very low average end to end delay compared to RMAC and Slotted FAMA. This is because RMAC tries to reserve a channel before sending a packet, and it causes a high average end to end delay. Further, Slotted FAMA uses slot times that have long duration. In contrast, AQTUWMAC and UWALOHA do not use slot time or channel reservation mechanism and they have low average end to end delay.

Based on Figure 5, 6 and 12, we can conclude that MAC protocols have high performance in terms of the average end to end delay in the Octahedron placement strategy compared to the randomly deployment strategy.

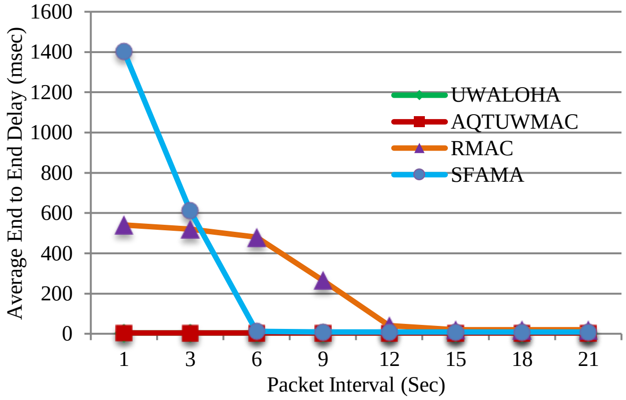

Figure 12: Average end to end delay vs. packet interval time in randomly deployment strategy with stationary nodes

In the fourth set of simulations, we studied how the mobility of nodes affects the performance. In this set of simulation, we considered 188 numbers of sensors randomly deployed in the 3D water with a volume of 1000 x 1000 x 500 m^3. We assumed that the surface sinks and the sender nodes are stationary and the other sensor nodes are mobile. Each sensor node randomly selects a direction and moves to the new position with a random speed between a minimum speed of1 m/s and maximum speeds of 1.5 m/s, 2 m/s and 3 m/s. Each sender node sends 1 packet per 10 seconds. This set of simulation lasts for 3600 seconds and all of the results are obtained from the average of 10 runs with a confidence interval of 99%.

The results of packet delivery ratio in randomly deployment strategy with mobile nodes are shown in Figure 13. From Figure 13, we observe that the AQTUWMAC and UWALOHA have high packet delivery ratio in different node speeds. From this figure, we can conclude that RMAC has less packet delivery ratio than the other three protocols. This is because in RMAC, it is possible that the sensor nodes reserve a channel for the sending packet, but the mobility of the nodes causes failure in the reservation. Further, it is possible that the mobility of nodes affects the reception of the data packets since the slot times in Slotted FAMA are lengthy.

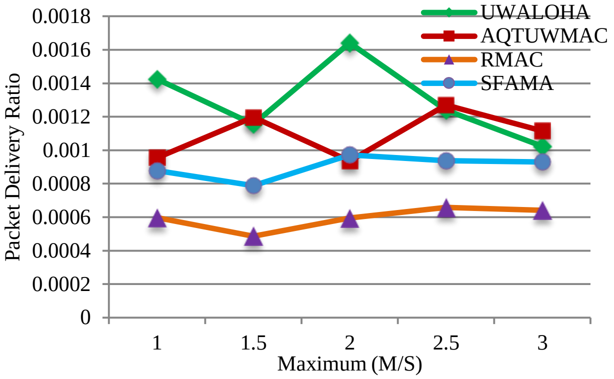

Figure 13: Packet delivery ratio vs. maximum speed of nodes in randomly deployment strategy with mobile nodes

The results for energy efficiency are shown in Figure 14. From this figure, we observe that the energy efficiency decreases as the speed of nodes increases. From Figure 14, we can conclude that RMAC has better energy efficiency compared to the other MAC protocols. As shown in Figure 13, RMAC has low packet delivery ratio and RMAC has sleep mode that causes low energy consumption. Therefore, each node can reserve a channel and goes to a sleep mode. Figure 13 also shows other MAC protocols have similar performance in terms of energy efficiency.

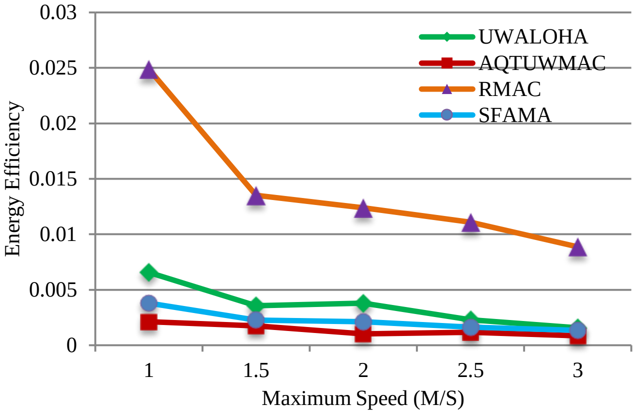

Figure 14: Energy efficiency vs. maximum speed of nodes in randomly deployment strategy with mobile nodes

The results of average end to end delay are shown in Figure 15. Based on Figure 15, we can conclude that UWALOHA has very low average end to end delay compared to RMAC, AQTUWMAC and Slotted FAMA. This is because in the case of mobility in randomly deployment strategy, the AQTUWMAC could not calculate the propagation delay to calculating QUIET time correctly, leading to a high average end to end delay. Further, the lengthy slot times in Slotted FAMA causes the average end to end delay. Each node in RMAC tries to reserve a channel before sending a packet, causing a high average end to end delay.

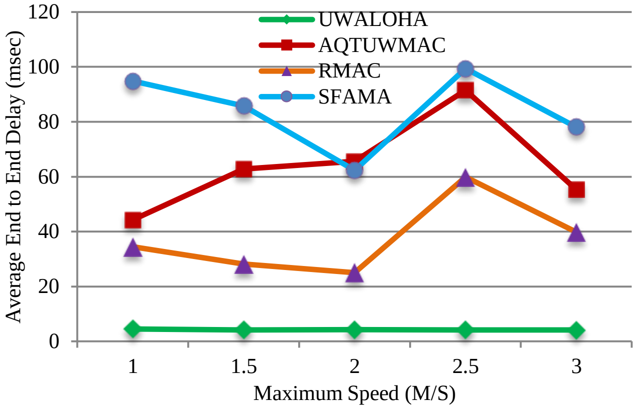

Figure 15: Average end to end delay vs. maximum speed of nodes in randomly deployment strategy with mobile nodes

V. CONCLUSION

In this paper, we analyzed QOS parameters of four MAC protocols: RMAC, Slotted FAMA, UWALOHA and AQTUWMAC in terms of energy efficiency, packet delivery ratio and average end to end delay for underwater surveillance systems. We have considered two different nodes deployment strategies named the randomly deployment and Octahedron placement strategy for analyzing QOS parameters. In an underwater surveillance system, average end to end delay and energy efficiency are necessary. Therefore, we showed that UWALOHA and AQTUWMAC in terms of these parameters are better than RMAC and Slotted FAMA. Although RMAC is an energy efficient protocol, it has very high average end to end delay. Hence, it is not suitable for an underwater surveillance system. Further, although the Slotted FAMA has relatively high packet delivery ratio, it has a very high average end to end delay; hence it is not suitable for an underwater surveillance system.

REFERENCES

[1] J. Partan, J. Kurose, and B. N. Levine, “A Survey of Practical Issues in Underwater Networks,” in *Proceedings of ACM WUWNet'06*, Los Angeles, CA, USA, 2006.

[2] I. F. Akyildiz, D. Pompili, and T. Melodia, “Underwater Acoustic SensorNetworks: Research Challenges,” *Ad Hoc Networks Journal* (Elsevier), vol. 3, no. 3, pp. 257–281, 2005.

[3] M. Chitre, S. Shahabudeen, and M. Stojanovic, “Underwater acoustic communicatin and networks: Recent advances and future challenges,” *Marine Technology Society Journal*, no. 1, pp. 103–116, 2008.

[4] J. Heidemann, W. Ye, J. Wills, A. Syed, and Y. Li, “Research Challengesand Applications for Underwater Sensor Networking,” in *Proceedings of IEEE Wireless Communications and Networking Conference*, Las Vegas, Nevada, USA, 2006, pp. 228–235.

[5] M. Keshtgari, R. Mohammadi , M. Mahmudi, M. Mansouri. “Energy Consumption Estimation in Cluster Based Underwater Wireless Sensor Networks Using M/M/١ Queuing Model”, *International Journal of Computer Applications*, Vol43, No.24, April 2012.

[6] M. Stojanovic, “Acoustic (Underwater) Communications," *Encyclopedia of Telecommunications*, J. G. Proakis, Ed. John Wiley and Sons, 2003.

[7] E. Sozer, M. Stojanovic, and J. Proakis, “Underwater acoustic networks," *IEEE J. Oceanic Engineering*, vol. 25, no. 1, pp. 72-83, Jan. 2000.

[8] J. Proakis, E. Sozer, J. Rice, and M. Stojanovic, “Shallow water acoustic networks," *IEEE Commun. Mag*., pp. 114–119, Nov. 2001.

[9] V. Jha,P. Gupta and U. Ahuja ,” QoS Issues In Underwater Sensor Networks” , *Computer Science & Information Technology*, pp. 45–51, 2012.

[10] M. Keshtgari, R. Javidan and R. Mohammadi .” Comparative Performance Evaluation of MAC Layer Protocols for Underwater Wireless Sensor Networks”, *Canadian Center of Science and Education*, Vol. 6, No. 3; March 2012.

[11] S. M. NazrulAlam and Z. J. Haas , “Coverage and Connectivity in Three-Dimensional Networks’ , *MobiCom'06*, Los Angeles, California, USA, September 23–29, 2006.

[12] C. L. Fullmer and J. Garcia-Luna-Aceves, “Floor acquisition multiple access (FAMA) for packet-radio networks,” In *ACM SIGCOMM’95*, Cambridge, MA, USA, August 1995.

[13] M. Molins and M. Stojanovic, “Slotted FAMA: a MAC protocol for underwater acoustic networks,” in *IEEE OCEANS’06*, Sigapore, May 2006.

[14] Peng X,et al. “Aqua-Sim: an NS-2 based simulator for underwater sensor networks.” In: Proceedings of the *OCEANS2009,MTS/IEEE Biloxi—marine technology for our future: global and local challenges* ; 2009.

[15] Mohammadi Reza, and Javidan Reza, " Adaptive Quiet Time Underwater Wireless MAC: AQT-UWMAC ", *International Journal on Communications Antenna and Propagation (IRECAP)*, Vol. 2, No. 4, August, 2012.

[16] P. Xie and J.-H. Cui, “R-MAC: An energy-efficient MAC protocol for underwater sensor networks,” in *Proceedings of International Conference on Wireless Algorithms, Systems, and Applications (WASA)*, Aug. 2007.

[17] F. Yunus, S Ariffin and Y. Zahedi, “A Survey of Existing Medium Access Control (MAC) for Underwater Wireless Sensor Network (UWSN),” *Fourth Asia International Conference on Mathematical/Analytical Modelling and Computer Simulation*, pp. 544-549, 2010.

[18] LinkQuest. http://www.link-quest.com/.