A Review and Classification of Energy Efficient MAC Protocols for Underwater Wireless Sensor Network

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Abstract: Underwater wireless sensor network is an emerging wireless networking technology (UWSN). UWSN has various applications for example it can be used for monitoring seismic activities, underwater animal, pipeline etc. UWSN face challenges in their MAC later operations. Different energy efficient MAC protocols have been proposed for underwater wireless sensor networks (UWSN) to overcome the problem of propagation delays which is inherent in underwater acoustic networks. In this paper, we study the energy efficient MAC protocols including EE-MACU, R-MAC and T-Lohi. We classify UWSN MAC protocols into two broad categories contention free and contention based and we further categorize contention based protocol. We analyze and compare key UWSN MAC protocols based on certain parameters and suggest their suitability in various scenarios.

Keywords: Underwater wireless sensor networks (UWSN), energy efficient MAC protocol, and performance analysis.

INTRODUCTION

Wireless sensor networks have become of increasing interest over the past decade. The main objective of a wireless sensor network (WSN) is to develop a network of sensors which gathers information from different kind of environment for long periods. WSNs have many practical applications: image based sensors can be used to study ecosystems; motion sensors can be used to detect enemies movement in the battlefield; temperature sensor to detect forest fire; monitoring for toxic chemicals; Tsunami alerts, structural health monitoring, healthcare, sports & fitness etc.

Many challenges and issues of WSN are extensively reviewed by various researchers in the last decade. Some of them are discussed in [1, 2]. Since, funneling effect problem and hidden node problem are relevant to our discussion here, will concentrate on these two issues.

Underwater wireless sensor networks cannot use electromagnetic waves because of their short range propagation due to high absorption rate. Alternatively sound waves are suggested to be used for underwater wireless communication which can travel several hundred meters underwater. Although acoustic waves solve the problem of long distance transmission they pose another problem of propagation delay. The speed of the sound waves underwater is 1500 m/s compare to electromagnetic waves speed which is $3x10^8$ m/s. The bandwidth available for UWSN is also limited to 9-14 kHz band using Multiple Frequency Shift Keying (MFSK) modulation techniques [3] and they suggested that the data rate is around 300-800 bits/s. UWSN has inherited many issues of WSN, being a special type of WSN. But the prominent problems in UWSN are built upon the errors emanating from propagation delays. Protocols designed for terrestrial WSN do not account for the propagation delay because of speed of electromagnetic waves. But when these protocols are applied in UWSN environment with propagation delay of 0.66 millisecond per meter they fail to produce the desired results.

In this paper, we review and classify the UWSN MAC protocols including a comparison of some of the key protocols. Some similar work exists in the literature for example; Manijeh *et al*. in [4] compared the performance of R-MAC, Slotted FAMA and UWAN-MAC. Catipovic (1990) in [5] discussed underwater performance limitations. Moreover, Performance of Slotted FAMA is claimed to be better than R-MAC and UWAN-MAC in terms of reliability. However, apparently performance of R-MAC is supposed to be better than Slotted FAMA because of channel reservation mechanism used by R-MAC before transmitting the data. Rohan *et al*. in [6] and Yunus *et al*. in [7] compared different energy efficient MAC protocols for UWSN. Protocols have been analyzed separately but no comparative analysis is done and eventually failed

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to conclude which protocol is better than the others. In contrast to the work in [4, 6], we classify the UWSN MAC protocols and provided an in depth analysis of key UWSN MAC protocols on the basis of energy efficiency.

The rest of the paper is organized as follows: Section 2 introduces UWSN major issues and proposed communication architectures. Section 3 we present our classification of UWSN MAC protocols and review some of the key MAC protocols in detail. Section 4 we analyze and compare the MAC protocols based on certain parameters. Finally, we summarize our work and highlight our future work.

2. UWSN ISSUES AND ARCHITECTURE

Propagation delay is a major issue in UWSN MAC communication. A simple case of collision due to propagation delay is shown in Figure **1**. There are three nodes A, B and C. Distance between nodes B and C is less than the distance between node A and B.

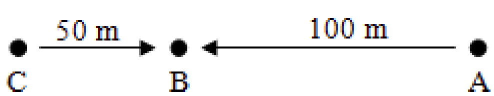

Figure 1: Nodes A, B and C Configuration.

Suppose distance AB is 100 m and BC is 50 m. A transmits a packet to B at time t = 0 which takes 0.066 sec to reach B. While the packet is travelling from A to B, C also sends a packet to B at time t = 0.033 sec. A collision will occur at node B because both the packets from A and C will reach at the same time. In order to overcome the problem of propagation delay in UWSN we need to define new protocols which consider the effect of propagation delay as well.

There are two kind of UWSN architecture known as 2 dimensional and 3 dimensional architectures. Nodes are fixed to the bottom of the sea in 2D architecture whereas they are suspended 3D architecture. Since nodes are not fixed in the 3D architecture, they keep moving around due to the water waves. This movement keeps changing the distance among the nodes which keeps changing the propagation delay between the nodes. We have considered only 2D architecture for this paper.

Usually the data collected from the sensing nodes is needed to be transmitted to some central data collection point where the received data is either analyzed or some action is taken according to the information sent by the sensor nodes. In case of UWSN such a data collection point is usually on shore. In order to accomplish this we need a node which collects the data from the sensor nodes in acoustic wave form and then convert it into electrical wave form then transmit through a wire or most likely a wireless system to the on shore central data collection node [8]. One such architecture is proposed by Akyildiz *et al*. [9] as shown in Figure **2**. It is considered a two dimensional architecture because the sensor nodes are anchored to the bottom of the network. This is cluster based architecture, however practically not all the deployments are necessarily to be cluster based. From cluster heads data is transmitted to surface station in acoustic wave form. Surface station transmits data to on shore sink or ship or to satellite through radio wave or microwave.

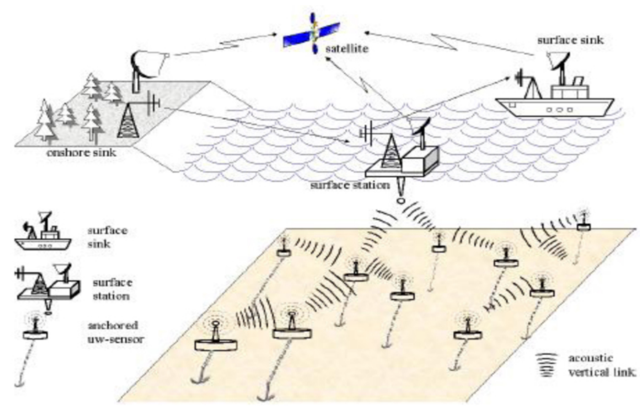

Figure 2: Two Dimensional Architecture.

A three dimensional architecture is also proposed by [9]. In this kind of architecture the sensor nodes are floated instead of fixed as in case of 2D architecture. That's why it is called 3D architecture. A 3D architecture is useful where activity to be detected is at different level of the oceans for example temperature of the sea at multiple levels.

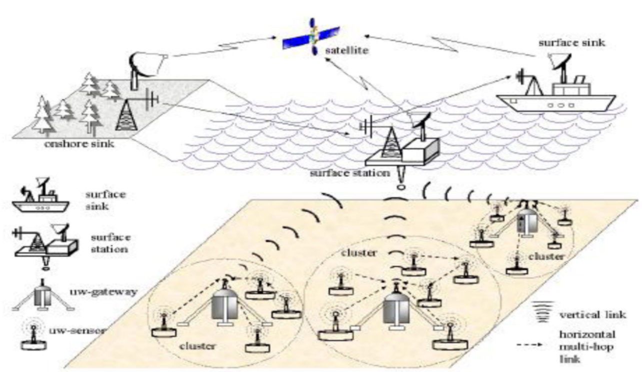

Figure 3: Three Dimensional Architecture.

There are three main issues related to UWSN MAC protocol namely, energy efficiency, hidden node and funneling effect. Although these issues exist in terrestrial WSN, they become worse in case of UWSN and need to propose new MAC protocols which address these issues. Let's describe hidden node effect and funneling effect briefly.

Hidden node is defined as a node that is within the range of the destination but out of range of the transmitting node as shown in Figure **4**. Suppose A wants to send data to B and, according to CSMA, it senses the channel and determines it is free and starts Tx to B. While data Tx from A to B is in process, C decides to send to B as well and senses the channel also. But since A is out of range of C, C will not be able to sense that B is busy in receiving data from A and will start sending data to B as well which will corrupt the data which B receives from A and C. More interestingly both A and C are unaware of this data collision because it happened at the receiving node B. In wireless communication any data collision which happens at the receiving node is not detected by the transmitting node.

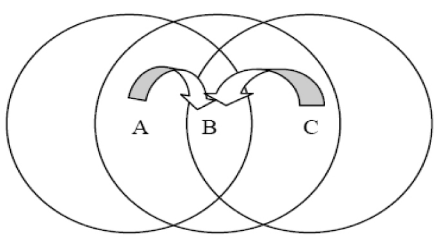

Figure 4: Three Nodes Configuration for Hidden Node [10].

Wireless sensor networks exhibit a unique funneling effect where events generated in the sensor field travel hop-by-hop in a many-to-one traffic pattern toward one or more sink points, as illustrated in the Figure **5**. The sensors nearest to the sink have not just to send their own data to the sink but also the data of the other nodes, which are away from the sink. This causes more data congestion and energy loss at the nodes near the sink than nodes further away from the sink, hence, shortening the operational lifetime of the overall network [11].

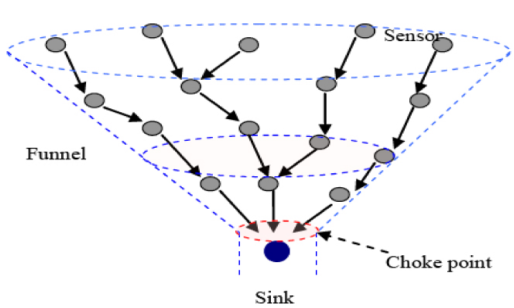

Figure 5: Funneling Effect Scenario [12].

Receiver Initiated Packet Train (RIPT) has been proposed by Nitthita [13] to address the issue of hidden node for UWSN. Similarly FMAC-U is proposed by Gahng [11] to resolve the issue of funneling effect in UWSN. Protocols like TDMA and CDMA are contention free protocols. CDMA has shown some potential to be a future UWSN MAC but due to limited available bandwidth it is also not a preferred MAC protocol for UWSN [14].

3. CLASSIFICATON AND REVIEW OF MAC PROTOCOLS

UWSN MAC protocols can be classified on the basis of access method that is either contention based or contention free. We further categorize MAC protocols according to the issues and challenges in UWSN. The three main MAC layer challenges discuss in this paper are energy efficiency, funneling effect and hidden node problem [15]. Figure **6** show our classification of UWSN MAC protocols. We focus on categorizing contention based protocols as they are most commonly used.

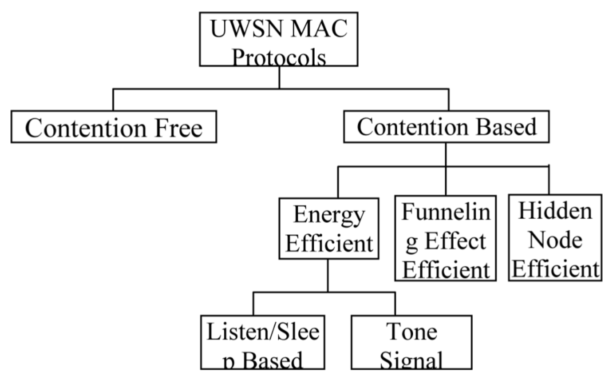

Figure 6: UWSN MAC Classification.

1) Contention Free (e.g. TDMA, CDMA)

Further classification is not done here because we are analyzing contention based protocols which are more efficient.

2) Contention Based (e.g. CSMA/CA)

i) Energy Efficient

a) Listen/Sleep Scheduled

b) Tone signaling

ii) Funneling Effect

iii) Hidden Node

We reviewed and compared three major UWSN energy efficient MAC protocols, namely, Energy Efficient MAC Protocol for UWSN (EE-MACU) [16], R-MAC [17] and T-Lohi [18].

3.1. EE-MACU

The focus of the EE-MACU protocol is on the energy efficiency and is different from ALOHA, MACA, MACAW as they are designed for efficient bandwidth utilization. Nodes spacing is kept short in order to keep the required transmission power to low. This protocol also capitalizes the idea of turning off the receiver periodically when no data is to be transmitted as almost all the energy efficiency protocols do.

Node A transmits its cycle periods and node B wakes up at exactly correct time in the next cycle without any knowledge of the propagation delay. This process assumes that the propagation delay remains constant for each transmission period. However, in real scenario this is not always true because of the movement of the waves which change the density of the medium. This change of density changes the speed of the sound wave which results in variable propagation delay. To address this issue the listen time is chosen to be longer than the maximum propagation time for each node.

Another problem is, there is no time synchronization mechanism among the nodes and each node uses its own pulse timing. In case of clock drift the timing for listen and wake up will change. One more major issue is not clear that how the random time will be chosen by each node initially. What will happen if the chosen time by the two nodes is the same?

In case of node failure the neighboring nodes remove the wake-up schedule for that node. When a new node is added up, initially it transmits its wake-up schedule at randomly chosen time. There is chance of receive-receive and transmit-receive collision due to this new node because initially its transmission period cycle is not scheduled with the existing network. It is shown that this scheme provides 95% energy efficiency for single hop network of 7 nodes. However, there no comparison was made with any other similar protocol to show that this scheme is more robust than the others.

E-MACU is published again in 2007 and gives bit more detail view of the proposed algorithm. When a node transmits its SYNC packet, it stamps the starting time of the transmission in it. The receiving node decodes the transmission length with help of stamped time in the SYNC packet. This way the propagation delay is not known to either node but both the sending and receiving nodes know when to wake-up from the sleep mode to transmit and listen SYNC packet, respectively.

Initially all the nodes in the network transmit SYNC packets at different randomly selected time. However it is not clear how to ensure that two nodes do not choose the same time or overlapping time to transmit the SYNC packets. In such case collision is sure to happen. How the collision will be detected because there is no acknowledgment mechanism used. One answer to the problem may be that the initialization process will keep repeating until the wake-up schedule is not fully synchronized among the nodes. But question is that will the SYNC packet transmission time will be different next time? If the initially chosen random time for each node remains the same then collision will keep occurring again and again. If it keeps changing after every round then may be initialization will never end.

After transmitting SYNC packet the nodes remain awaken in order to receive SYNC packet from the other nodes. The SYNC packet informs neighboring nodes that it will transmit data after time period *T.* Initially this time period is same for all the nodes. Suppose node A transmits the SYNC packet first after choosing the transmission time randomly. The neighboring nodes B, C, and D receive A's SYNC packet and schedule their wake-up times accordingly. A will also schedule it's wake-up time for B, C and D. *T* is the cycle period for transmitting data of each node. For example if $T = 1$ sec for a node A, then it means it will transmit data after every 1 sec. During 1 second cycle it will keep sleeping and waking up at scheduled time to receive data from all the other nodes. So for node A, the period T must be long enough so it may receive data packets from all the other nodes within its transmission range before it transmits its data again.

If we take the example of network configuration given in [16] (shown in Figure **7**), although node E has only one neighboring node B, it may not have cycle period such that it transmits the data twice during the cycle period of B or such that its data packet collides with the data packet of other nodes which are hidden for node E.

The node which has the maximum number of neighboring nodes will have the maximum cycle period

T because it has to receive data packets from all of its neighbor nodes during that time period. In the above example it is node B. So E has to choose such a cycle period that it transmit its data packet only once during the cycle period of B.

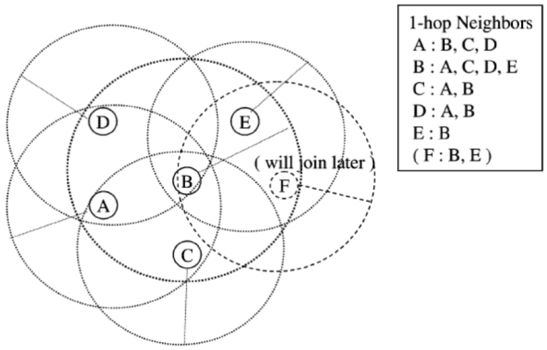

Figure 7: Network Configuration Example [16].

Keeping all these constraints in view, it is not mentioned how initial cycle period T_0 will be chosen. The initial cycle period T_0 depends on the maximum number of neighboring nodes for any node in the network. Initially there is no procedure for a node to know the neighboring nodes within its transmission range. Suppose the value T_0 is such that during that time period B cannot receive packets from all of its neighboring nodes. During data communication nodes list is exchanged between the nodes to compare it with the node list maintained by each node and identify the missing node. This way node B can learn about the node from which it cannot receive data due to shorter cycle period and adjust its cycle period accordingly.

Is there any chance that two nodes may transmit SYNC packets simultaneously? Node E is hidden node for all the nodes other than node B. It is possible that node E and D both choose same time of start to send SYNC packet. When the packets reach to node B they will collide and the packet will be lost. In the second round when the list of nodes is exchanged B will receive list of nodes from A or C and will learn that node D is missing. But if the data transmitting time of E and D are still unchanged then they will keep colliding. Apparently there is no reason for D and E to change their data transmission time according to the proposed protocol. During performance evaluation of the proposed protocol it is assumed that initially a localized neighbor search method is used but which method is used and how it integrates with initial synchronization process needs to be defined. This MAC protocol neither addresses the issues of hidden node nor congestion control in case of large number of nodes and data volume.

3.2 R-MAC

R-MAC protocol is very much similar to [16] energy efficient protocol. Like [16], it is based on listen/sleep cycle and broadcast its listen/sleep schedule as well. Unlike [16] the listen and sleep cycle of each node is independent to its neighboring nodes transmitting time. A Network Discovery (ND) control packet is broadcast at the selected random time by all the nodes to determine propagation latency among the nodes.

Propagation latency consists of transmission delay and propagation delay. Suppose a node A transmits a ND packet to node B (see Fi. 8). Node A will record the time at which the first bit of the ND packet was transmitted and the received node records the time at which the last bit of the ND packet was received. When node B transmits the acknowledgment of the ND packet, ACK-ND, it contains the duration I_B from the arrival of the last bit of to the start of the transmission the first bit of ACK-ND packet. Upon receiving the last bit of ACK-ND packet from B, node A records the time of arrival and calculate the time I_A from the recorded time of transmission of first bit of ND and the recorded time of receiving last bit of ACK-ND. Propagation latency is calculated as $L_{AB} = I_A - I_B / 2$. This way each node records the propagation latency for all of its neighboring nodes.

Once the propagation latencies are calculated each node randomly selects its own start time of the listen/sleep periodic operation and broadcast their schedule to each other. Each node adjusts its listen/sleep period according to the received schedule information. This may take more than one round to adjust all the conflicts of the timing among the nodes (see Figure **8**).

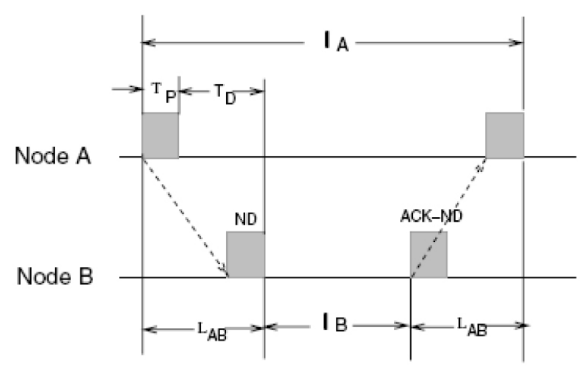

Figure 8: Latency measurement [17].

Suppose node A transmits its listen/sleep cycle period to node B by a packet called SYN. SYN packet contains node A ID and time interval I_A which specifies the time period form node A's transmission of SYN packet to the start time of periodic operation of listen and sleep. When node B receives the SYN packet it records the arrival time. I_B is calculated by $I_B = I_A - L_{AB}$.

Once listen/sleep schedule is established the data transfer among the nodes begins. There are three control packets for data transfer. Reservation packet (REV) is used to reserve a time slot at the receiver. If the receiver is ready then it sends acknowledgment (ACK-REV) packet back to the requesting node and all the other nodes. This ensures that during that time slot only the node which sent the REV packet will transmit the data and rest of the nodes will refrain from transmitting their data to the receiving node. If some other node wants to send the data to the same receiving at the same time then it has to buffer its data in the queue. The data is sent in the form of burst and next node can send data only when the previous node finishes sending the data. This makes R-MAC unsuitable for mission critical operations where delay in data transmission cannot be to be tolerated.

There is another important issue in R-MAC protocol, that is, it uses R-window (a time slot) for the nodes to receive ACK-REV packet. When a node needs to transmit data to the intended receiver it has to make sure that REV packet is sent in the listen mode of the other nodes but not in the R-window of the listen mode which is reserved for ACK-REV packets only. REV packet defines data transmission time required duration and the time slot beginning from its current time period. When calculating the transmission time period for the data to be sent, R-window of the neighboring nodes must be taken into account. Since the ACK-REV can only be received in R-window, the receiver node schedules the time slot to send ACK-REV packet.

It is possible that two nodes transmit ACK-REV on the channel one after the other with very small time difference. To address this issue an additional one-way latency is added in the time schedule for ACK-REV. Still the chances of R-window overlap are present which can be eliminated after few rounds of listen/sleep announcement.

It is obvious that R-MAC protocol may be energy efficient in terms of less data collision but it requires excessive control packets to avoid data collision. We need to analyze the amount of energy required for control packets transmission and reception against the data retransmission in case of collision.

3.3. T-Lohi

The primary objective of T-Lohi is to provide a MAC protocol that has efficient channel utilization, stable throughput, and low energy consumption [18]. Tone-Lohi protocol is also contention based and employs carrier sensing prior to sending the data. Problem of spatial fairness is also addressed in this protocol. A tone signal is used to reserve the channel by transmitting short wake-up tone signals. This means that it also employs the concept of listen/sleep algorithm as most of the energy efficient protocols do like EECDC-MAC [19] and PW-MAC [20]. We know that wireless sensor networks are half-duplex and cannot receive signals while transmitting. A separate low power tone receiver is suggested to receive tones. This may create three different situations as shown in the Figure **9**.

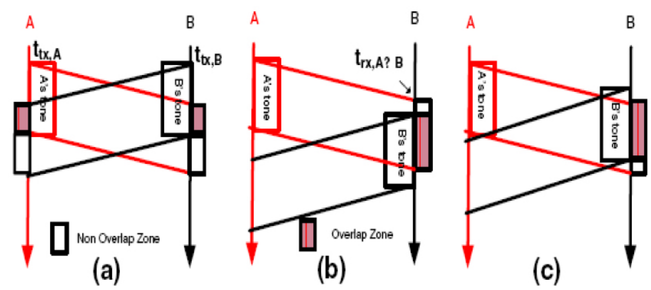

Figure 9: (**a**) Bidirectional deafness (**b**) Unidirectional deafness before B starts transmitting (**c**) Unidirectional deafness after B starts transmitting [18].

The node intended to send data transmits short tone to reserve the channel. After sending the tone the node listens to receive contention tone from the other nodes for the duration of contention round. If no tone is received then the sending node assumes that no other node is intended to send the data and reserves the channel to transmit its data. To save the energy data receiver and node processor remain off until the node receives a wake-up tone by the low-power wake up receiver. The energy consumed by tone receiver is $1/100^{th}$ of the data receiver. The low power tones may be mixed up with large amount of noise. This will lead to false tone detection. In case of long period of large amount of noise the efficiency of T-Lohi may decrease significantly by long period of back-offs of the nodes and no data transfer occurs due to false tone detection by the nodes.

T-Lohi is implemented in three different ways. First it is assumed that all the nodes are time synchronized and called *synchronized T-Lohi* (ST-Lohi). If two nodes transmit tone signal simultaneously in the contention round than the both will receive tone during the contention period. They both will back-off for random time period and after that the node with earlier time will transmit the tone signal again. If it receives no tone signal during the contention period it will start transmitting the data.

Time synchronization causes overhead and implementation complexity. Unsynch-ronized T-Lohi is used to avoid the disadvantages of ST-Lohi. In unsynchronized T-Lohi the can start contending to send data in if the channel is not busy. Propagation time and tone detection time are twice in UT-Lohi compare to ST-Lohi to avoid collision. Aggressive UT-Lohi is used to avoid long contention time problem of UT-Lohi. aUT-Lohi implies same contention time as ST-Lohi does, assuming that the conditions in which the collision may occur are quite unlikely to happen.

There are two situations described in which the collision may happen. First is tone-data collision. This may happen if node B is far from node A so that the contention round at A ends before A can detect the tone sent by B. Second is data-data collision. It occurs when two nodes assume that they have successfully reserved the channel for data transmission. In ST-Lohi data-data collision happens because of bidirectional deafness. It is shown that T-Lohi throughput performance is 34-50% which is better than slotted floor acquisition multiple access (FAMA) and B.

Peleato and M. Stojanovic proposed MAC protocol for ad-hoc underwater. Energy efficiency is compared by Volkan Rodoplu and Min Kyoung Park proposed MAC protocol. Maximum energy efficiency achieved by T-Lohi is 9% over the optimal energy cost.

4. COMPARISONS AND ANALYSIS

We have analyze and compare the three major MAC layer contention based protocols based on parameters shown in the left of Table **1**. Both EE-MAC and R-MAC use listen / sleep cycle to conserve the energy by avoiding idle listening.

Idle listening is one of the major sources of energy waste for energy limited nodes. Listen and sleep period of each node is required to be known to all the other nodes in the network. For this purpose each node in the network is needed to record the schedule of listen and sleep of all the other nodes. R-MAC protocol has more overheads compare to EE-MAC because it uses channel reservation mechanism which requires sending back acknowledgment packet to the requested node. T-Lohi causes false tone detection problem due to low power tone signals used to wake up a receiving node from the sleep mode. This false detection causes waste of energy and low data rate because the node shifts to normal receiving node from low power receiving mode and keeps waiting to receive data. On the other hand if that node needs to transmit data it will hold its data transmission assuming that it is about receive data from some other node. However there is no data to be received because of false tone detection and the node will not only waste energy but also will not send data which will decrease the throughput as well. This situation may long from minutes to hours.

EE-MAC and R-MAC are batter solution then T-Lohi. T-Lohi requires full duplex communication to listen tones signal which make it unsuitable for energy limited sensor networks. Compare to EE-MAC, R-MAC needs multiple rounds of broadcast packets by each node to fully synchronize and store the timing of listen sleep period which makes it unsuitable for UWSN networks having large number of nodes. Hence compare to these three protocols EE-MAC appears to be more suitable for a UWSN network despite of the fact that it has some issue of time synchronization among the nodes.

Table 1: Comparison of MAC Layer Protocols of UWSN

Parameter	EE-MAC	R-MAC	T-Lohi
Contention Based	Yes	Yes	Yes
Listen/sleep method	Yes	Yes	Yes
Non-Idle Listening	Yes	Yes	Yes
Non-overhearing	No	No	No
Packet Overhead	Yes	Yes	No
Time Synchronization	Yes	Yes	No
Tone Signal	No	No	Yes
Funneling Effect	Yes	Yes	Yes
Hidden Node Problem	Yes	Yes	Yes

5. CONCLUSIONS & FUTURE WORK

Under water wireless sensor networks are an emerging wireless networking technology, which has various applications. MAC layer communication in UWSN has additional challenges as compare to WSN. In this paper, we highlighted the major challenges in MAC layer protocols. We then review and classify MAC layer protocols for UWSN. We have reviewed mainly two different methods of energy savings. One is periodic listen sleep cycle and another is tone based wake up method. The purpose is to understand the pros and cons of these two methods. We analyzed the methods of energy saving and the conclusions given in their respective papers. Our conclusion is that none of these protocols are tested for large number of nodes which is the real test for these protocols to know their efficiency under heavy traffic condition. EE-MAC looks more promising than the others mainly because of its simplicity in operations. In future considering the applications of underwater wireless sensor network, we will first aim to implement the energy efficient MAC protocol using MATLab and validate its working using the proposed architecture in this paper. We will also consider the more complex application scenario by performing a simulation based case study of the protocols to understand their behavior for heavy traffic load.

REFERENCES

[1] Rajkumar VBA, Jadhav K, Vidya S. Wireless Sensor Networks Issues and Applications. International Journal Computer Technology & Applications 3(5): 1667-1673

[2] Willig A. Wireless sensor networks: concept, challenges and approaches. e & i Elektrotechnik und Informationstechnik 2006; 123(6): 224-231.

[3] Rice J. Seaweb Acoustic Communication and Navigation Networks. SSC San Diego, c/o Naval Postgraduate School, Physics Department Monterey, CA 93943, United States.

[4] Keshtgary M, Javidan R, Mohammadi R. Comparative Performance Evaluation of MAC Layer Protocols for Underwater Wireless Sensor Networks. Modern Applied Science 2012; 6(3).

[5] Catipovic JA. Performance limitations in underwater acoustic telemetry. IEEE Journal of Oceanic Engineering 1990; 205-216.

[6] Parmar R, Poonia RC. A Literature Survey on Energy Efficient MAC Protocols for WSN. International Journal of Computer Science and Information Technologies 2014; 5(3).

[7] Yunus F, Ariffin S, Zahedi Y. A Survey of Existing Medium Access Control (MAC) for Underwater Wireless Sensor Network (UWSN). In Proceeding of 4th Asia International Conference on Mathematical/Analytical Modelling and Computer Simulation, 2010.

[8] Manjula R, Manvi S. Issues in underwater acoustic sensor networks. International Journal of Computer and Electrical Engineering, 2011.

[9] Akyildiz IF, Pompili D, Melodia T. State of the Art in Protocol Research for Underwater Acoustic Sensor Networks. Broadband & Wireless Networking Laboratory School of Electrical & Computer Engineering Georgia Institute of Technology Atlanta, GA, USA.

[10] Zohra MF, Zoulikha MM, Said K. Techniques Of Detection Of The Hidden Node In Wireless Ad Hoc Network. Proceedings of the World Congress on Engineering London, UK 2011; II.

[11] Ahn G-S, Miluzzo E, Campbell AT, Hong SG, Cuomo F. Funneling-MAC: A Localized, Sink-Oriented MAC For Boosting Fidelity in Sensor Networks. SenSys'06, 2006.

[12] Chen H, Fan G, Xie L, Cui J-H. A Hybrid Path-Oriented Code Assignment CDMA-Based MAC Protocol for Underwater Acoustic Sensor Networks. Sensors, November 2013.

[13] Chirdchoo N, Soh W-S, Chua KC. RIPT: A Receiver-initiated Reservation-based Protocol for Underwater Acoustic Networks.

[14] Heidemann J, Stojanovic M, Zorzi M. Underwater sensor networks: applications, advances and challenges. Phil Trans. R Soc A 2012; 370.

[15] Lin P, Qiao C, Wang X. Medium access control with a dynamic duty cycle for sensor networks. IEEE Wireless Communications and Networking Conference, 2004; 3: 1534-1539.

[16] Rodoplu V, Park MK. An Energy-Efficient MAC Protocol for Underwater Wireless Acoustic Networks, Department of Electrical and Computer Engineering, University of California.

[17] Xie P, Cui J-H. R-MAC: An Energy-Efficient MAC Protocol for Underwater Sensor Networks, International Conference on Wireless Algorithms, Systems and Applications, IEEE Computer Society, 2007.

[18] Syed AA, Heidemann WYJ. T-Lohi: A New Class of MAC Protocols for Underwater Acoustic Sensor Networks, Information Sciences Institute / USC.

[19] Guntupalli L, Li FY, Ge X. EECDC-MAC: Energy Efficient Cooperative Duty Cycle MAC Protocol. 978-1-4673-4404-3/12 ©2012 IEEE.

[20] Tang L, Sun Y, Gurewitz O, Johnson DB. PW-MAC: An Energy-Efficient Predictive-Wakeup MAC Protocol for Wireless Sensor Networks. technical program at IEEE INFOCOM 2011.

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