A Survey on Medium Access Control in Underwater Acoustic Sensor Networks

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***Abstract*—A medium access control (MAC) protocol permits the nodes to access the shared medium by providing contention resolution mechanism. The design of MAC protocol in ad hoc networks becomes a more challenging task due to the interruptible energy source or limited battery life of nodes. This brings energy efficiency as the preliminary goal of the MAC protocol. MAC protocol for Underwater Acoustic Sensor Networks (UWASN) has to face even more challenges; many of them are due to the harsh underwater channel. Recently, a number of MAC protocols have been proposed for UWASN and selection of a suitable protocol has a great impact on the system efficiency. In this paper, we first highlight the unique aspects of acoustic channel and the problems associated with the MAC layer in UWASN. Existing MAC solutions for UWASN and open research issues are investigated and the summary of the protocols is provided to see the performance against different parameters considered in UWASN applications for selection of protocol.**

***Index Terms*—Acoustic Channel, Underwater Acoustic Sensor Networks, Medium Access Control**

I. INTRODUCTION

Recently, there has been a growing interest in monitoring the marine environment for scientific exploration, commercial exploitation and coastline protection [1]. Underwater Acoustic Sensor Network (UWASN) has emerged to be an ideal system for efficiently exploring and observing the ocean. UWASN are helpful in the applications of oceanographic data collection, pollution monitoring, undersea exploration, disaster prevention, assisted navigation, tactical surveillance applications, mine reconnaissance [2], seismic monitoring of underwater oil fields, pipeline and leak monitoring, assistance during underwater construction [3] and ecological monitoring [6]. However, the characteristics of the physical medium in ocean pose some challenges such as time synchronization, power limitation, long and variable propagation delay [12], limited bandwidth [13], high bit error rates, temporary loss of connectivity caused by multipath and fading effects [14], frequency dependent attenuation, asymmetric links [11] and even completely failure of nodes [15]. These challenges require suitable architecture for underwater sensor network, particularly the design of medium access control (MAC) protocol needs much more attention.

A MAC protocol allows the nodes in a network to share the common broadcast channel. The main task of a MAC protocol is to resolve data packet collision and to prevent simultaneous transmissions while providing energy efficiency, low channel access delays and fairness among competing nodes. MAC layer in UWASN has much importance on the network utilization in the presence of harsh underwater acoustic channel. Recently, many new MAC protocols for UWASN have been proposed. Selection of a suitable MAC protocol has a great impact on the system efficiency and is especially important for channels with low quality and high latency.

In this paper, we survey the state-of-the-art in MAC protocol for UWASN. The physical layer has great impact on the design of MAC protocol since it has direct coordination with MAC. The potential problems due to the characteristics of acoustic channel for underwater communication are identified and their impact on the design of MAC protocol is discussed. On the other hand, we discuss the issues related to the requirement of MAC protocol as well as posed by the environment which might not present in terrestrial wireless sensor networks. Such an understanding help us in reviewing the performance of existing MAC solutions. We then provide an overview of the existing MAC protocols and summarize their performance.

The remainder of the paper is organized as follows. In Section II, we discuss the problems of MAC protocol for UWASN in great detail. We provide survey on the existing MAC protocols in Section III. Finally, we summarize the open issues and features of existing works as well as future direction in Section IV.

II. MEDIUM ACCESS CONTROL IN UWASN

Medium Access Control protocol is the core of any communication protocols stack whose performance provides basis for achieving QoS in any wireless network. Therefore, a detailed analysis on different aspects of the design of MAC protocol is mandatory in order to evaluate the performance of existing MAC protocols. In this section, we discuss the challenges posed by an acoustic channel on the operations of MAC and the problems associated in MAC protocol.

A. Challenges posed by Acoustic Channel

This section highlights the challenges posed by an acoustic channel that may affect the design of MAC protocol.

1) Acoustic Wave Propagation: In underwater, radio waves propagate at long distances through conductive sea water only at extra low frequencies ($30 - 300$ Hz) [2] that requires large antennae and high transmission power, which is not possible

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for cost effective and energy constrained sensor nodes. On the other hand, optical waves do not suffer from high attenuation but are affected by scattering and also require line of sight. Hence, the only possible way of communication is to use acoustic waves as a mean of communication in underwater channel.

2) Low Propagation Speed: The propagation speed of sound in underwater is about $1500 m/s$. Therefore, propagation delay in underwater is five orders of magnitude higher than in radio frequency (RF) terrestrial channels, and extremely variable that depends on temperature, salinity and depth. While propagation delay is negligible for short-range RF, it is a central fact of underwater wireless. This has profound implications on localization and time synchronization.

3) High and Variable Propagation Delay: The low propagation speed results in a high propagation delay even for communication between two neighbors. The variable propagation delay is due to formation of shadow zones, surface scattering, bubbles and noise due to breaking waves, biological sources and rain [18]. Collision detection/avoidance is the primary function of any MAC protocol, which is closely bound to the propagation delay. The high and variable delay is the major hurdle in immediate collision detection or avoidance mechanism and thereby results in reduced throughput of the acoustic channel.

4) High Bit Error Rates: The underwater channel is severely impaired, especially due to multi-path and fading. Multi-path propagation may be responsible for severe degradation of the acoustic communication signal, since it generates InterSymbol Interference (ISI). Higher value of ISI may result in higher bit error rates. Fading is caused by absorption due to conversion of acoustic energy into heat and also depends on scattering and reverberation, refraction, dispersion, bubbles, spherical and geometrical spreading. The attenuation increases with distance and frequency. Moreover, some external noise such as shipping noise, thermal noise, wind noise or turbulence noise may reduce the signal-to-noise ratio. Eventually temporary losses of connectivity (shadow zones) can be experienced in addition to high bit error rates. This would be a big challenge for a MAC protocol to provide certain reliability and maintain connectivity by hiding harsh propagation conditions.

5) Limited Bandwidth: The available bandwidth/data rate is severely limited and is highly dependent on distance between two communicating nodes. For a range (distance between two communicating nodes) of 1000Km, the available bandwidth is less than 1KHz, for a range of 10-100Km, the available bandwidth is 2-5KHz, for a range of 1-10Km, the available bandwidth is approximately 10KHz, for a range of 100m-1Km the available bandwidth is 20-50 KHz and for a range of less than 100m the available bandwidth is greater than 100 KHz [15]. Along with the range, the bandwidth/data rate also depends on available power [15]. Hence, a MAC protocol should provide spectral efficiency, i.e., higher bits/hz.

6) Low Battery Power: Sensor nodes are generally powered through small batteries of limited power, which can not be usually recharged. Replacement of these low cost batteries in underwater is a challenging task and uneconomical too. Therefore, life of a sensor node corresponds to its battery power. MAC can play a role in conserving battery power since it has control over the transceivers by applying some duty cycling approach and thus extend the life of nodes.

B. Problems Associated with MAC Protocol of UWASN

In this section, we identify the problems which have to be addressed in designing UWASN MAC protocol.

1) Network Topology and Deployment in UWASN: The MAC protocol for UWASN is highly dependable on the deployment of underwater nodes which might be sparse or dense. Event readings of sparsely deployed nodes would be highly uncorrelated because the sensors nodes can monitor as well as communicate at long distance due to availability of long range acoustic modems[16], [17]. Designing MAC protocol for sparse deployment would require higher reliability since a loss of single packet may result in lack of event information. On the other hand, densely deployed scenarios are also possible in which a low power short-range multi-hop underwater acoustic network is implemented that eventually result in redundant event reports. Redundancy may relax the reliability requirements of MAC protocol but on the other hand it would consume more energy that needs to be controlled to prolong the life of low power sensor nodes. We do not advocate for a deployment specific MAC protocol rather it must be adaptive to the deployment scenarios for changing needs of applications.

2) Energy Consumption: In many MAC protocols design, a receiver has to listen to the medium for sake of its potential packets. This is known as idle listening, which contributes to its energy consumption more than its transmission and reception. Likewise overhearing (receiving packets not destined for the receiver) and collision are also the processes which unnecessarily waste the energy of nodes. These problems are much more associated in handshaking based protocols, where the control traffic is excessive. A MAC protocol designed without taking care of these factors would not be acceptable for UWASN. Hence, a primary objective of MAC protocol must be energy efficiency without compromising throughput.

3) Synchronization: Synchronization is an important challenge in the design of MAC protocol since the duty cycling approach is generally based on time synchronization of nodes. This is due to the fact that the propagation delay is much higher and particularly variable. Hence, the MAC protocol operations like implementing time division multiple access or implying duty cycling can not be performed accurately.

4) Hidden Node and exposed Node Problem: Hidden node and exposed node problems arise more specifically in contention-based collision avoidance MAC protocols. A situation of a hidden node occurs when one node cannot sense one or more nodes that can interfere with its transmission. A situation of an exposed terminal occurs when a station delays transmission because of another overheard transmission that would not collide with it. In the former case, there will be collision and nodes have to keep attempting for successful transmission. This causes not only waste of energy but also reduced throughput. While in the later case, nodes underutilize the channel that result in low throughput. Thus a MAC protocol should overcome these problems to efficiently utilize the resources.

5) High Delay Associated in Handshaking: The conventional handshaking schemes guarantee collision avoidance but a lot of time and energy is wasted during exchange of control packets. So handshaking-based algorithms are efficient only when the network is fully connected and the propagation delay is small compared to the packet duration. However, handshaking becomes unattractive if the connection failure is higher or there are frequent changes in the topology.

6) Power Waste in Collision: It is observed that a node consumes more power on transmission than on reception, which is typically a 1:125 receive:transmit ratio [10]. Furthermore, this ratio becomes worst if collision is frequently due to the lack of an appropriate collision avoidance mechanism. So, the main focus of MAC protocol should be on avoiding or minimizing collision.

7) Near-Far Effect: The transmission power should be selected at the transmitter such that signal transmitted from the transmitter to the intended receiver should be correctly received at the desired SNR value neither lesser nor higher. The near-far effect occurs when the signal received by a receiver from a sender near the receiver is stronger than the signal received from another sender located farther [11]. This problem is more important if MAC is based on CDMA technique.

8) Centralized Networking: Centralized solutions are not possible in underwater communication using acoustic channel. This is due to higher propagation delay and narrow bandwidth available in acoustic.

III. Existing MAC Protocols

In this section, we provide an overview of the existing MAC protocols and discuss their advantages and disadvantages. Performance of MAC protocol is characterized by the medium access technique and how well they can perform in underwater medium. Generally the MAC protocols are classified into two categories: contention-free protocols and contention-based protocols. Contention-free protocols include Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA) where communication channels are separated in time, frequency or code domains. In Contention-based protocols the nodes compete for a shared channel resulting in probabilistic coordination. Contention-based protocols include random access protocols and collision avoidance protocols.

A. Slotted FAMA

Slotted FAMA, proposed in [4], is based on a channel access discipline called floor acquisition multiple access (FAMA). FAMA protocol combines time slotting, carrier sensing and handshaking techniques. The main principle of Slotted FAMA algorithm is similar to CSMA algorithm but the important difference is that channel access is divided into time slots and it is mandatory for every node to send packet (RTS, CTS, DATA or ACK) at the beginning of the time slot. If a node wants to send a packet, it will have to wait until the start of the next slot to run its CSMA algorithm. The slot length must be equal to the sum of maximum propagation time, transmission time of RTS/CTS packet and a guard time that should be inserted to account for any clock drift. This technique basically integrates CSMA with Slotted Aloha protocol in order to achieve high throughput.

Advantages: First, the time slotting technique as proved in Slotted Aloha minimizes the chances of collision and hence increases throughput. Moreover, it eliminates the need of long excessive control packets. Second, receiver of a frame can immediately forwards packet to next hop without going into back-off state unlike FAMA in which a node hears a transmission, waits to prevent a collision and, after that, if it has a packet ready to transmit it goes to the Backoff state. Third, it has improved backoff algorithm.

Disadvantages: The algorithm is suitable for small amount of users (throughput decreases as no. of users increases). Second, it is suitable for the optimal transmission range of 2Km, neither less nor more. Third, handshaking mechanism may lead to low system throughput in the presence of high propagation delay in underwater acoustic channel. Fourth, idle listening increases energy waste and therefore is not energy efficient approach. Fifth, guard time inserted in the slot duration to cater for the system clock drift would result in underutilization of channel. Sixth, due to high propagation delay of underwater acoustic channel, the carrier sensing may sense the channel idle while a transmission is going on [11]. Last, it requires clock synchronization of nodes which is a challenging task in UWASN.

B. MAC Protocol based on control packets

This MAC protocol [5], is an extension of Slotted FAMA[4] that does not require clock synchronization and allows nodes to use different handshake lengths for different receivers. The handshake control packets length is determined by the distance between two nodes. The length between closer nodes can be made shorter and far-apart nodes need longer handshake. Upon receiving an RTS, a receiver immediately replies with a CTS and listens to the channel waiting for the data packet. If during this listening period it hears an RTS meant for some other node, it sends a very short warning packet to its partner. Upon receiving CTS, a node waits some time before transmitting the data packet. If it hears another CTS or a warning from its partner during this time, the node aborts transmission. The length of the waiting period will depend upon the distance between the nodes, which the sender can learn by measuring the RTS/CTS round-trip time.

Advantages: It inherits the advantages from slotted FAMA except that the slot lengths are variable and determined by using the distance between the two partners. This would eliminate the need of clock synchronization of nodes. Second, it would less likely suffer in delayed sensing causing unpredicted behavior of the protocol as in FAMA.

Disadvantages: It assumes that the nodes are localized which itself is an important issue in UWASN. It also does not apply any duty cycling technique that causes idle listening and increases energy consumption.

C. Distributed Energy-Efficient MAC Protocol

A distributed CSMA-based energy-efficient MAC protocol [6] is based on the assumption that nodes follow sleep periods and is aimed at efficiently organizing the sleep schedules. In order to synchronize the sleep schedule, each node decides its own transmission start time initially and is awake for the whole first cycle. It broadcasts its SYNC packet (the beacon signal) for its initialization of MAC protocol. The beacon signal contains a fixed Walsh/m-sequence as a preamble to its data transmission and its next transmission cycle. As a result of this coordination, nodes determine their sleep schedules by decoding SYNC packets and schedule the wake-up time for their own transmission. Thus, the network is locally synchronized by the transmission/listen schedules among nodes. After the transmission of data packet, the nodes do not go to sleep mode immediately rather keep listening for certain period. This idle listening helps to know if any new node joins the network.

Advantages: Ratio of transmission duration to the time period T (duty cycle) is very low. Intuitively, the chances of collisions are very low and also energy is saved due to low duty cycle. Second, it does not require centralized clock synchronization of nodes rather the distributed frame synchronization is applied that makes it attractive for UWASN.

Disadvantages: The protocol only works well for low and uniformly distributed traffic. Second, low duty cycle saves energy but reduces throughput.

D. R-MAC: A Reservation Based MAC Protocol

In Reservation based MAC protocol (R-MAC) [7], each node operates in listen and sleep modes periodically for same length of periods. However, all the nodes select their listen/sleep schedule randomly and announce this schedule by broadcasting a synchronization packet (SYNC). Sender puts the starting time of its data transmission in SYNC packet. Upon receiving SYNC packet, the receiving node calculates the time interval based on the arrival time of this SYNC packet to the starting time of sender transmission and infers its own schedule. When a node has data to send, it first sends a REV (reservation packet) to reserve a time slot at the receiver. If the receiver is ready to receive data, it notifies all its neighbors as well as the sender by sending ACK-REV acknowledgment packet. Upon receiving ACK-REV packet, all the nodes other than the sender keep silent in their corresponding time slots, and the sender can send data in a burst at the reserved time slot. The receiver sends back an ACK-DATA to the sender at the end of the burst transmission notifying about its release of medium.

Advantages: Transmission of control and data packets is scheduled at both sender and receiver that avoids data packet collision and increases fairness. Second, no centralized scheduling and synchronization is required. Third, burst based acknowledgment technique is provided that increases throughput and efficiency. Fourth, the distributed scheduling algorithm solves the exposed terminal problem.

Disadvantages: First, this protocol works fine when all nodes are static and no new node joins the network i.e. it can not adopt to dynamic topology. Second, there is no technique proposed when, in the third phase, a new node joins or a node failure occurs or a node wants to change its transmission schedule. Third, variations in the transmission delay due to channel fluctuations and system clock drifts have not been incorporated in the algorithm. Finally, the protocol has higher overheads in the form of control packets that makes it inefficient in terms of bandwidth and energy.

E. Aloha Based MAC Protocol

In [8], two Aloha based distributed random access MAC protocols are proposed; namely, Aloha with Collision Avoidance (Aloha-CA), and Aloha with Advance Notification (Aloha-AN). In these protocols, each node tries to make use of the sender-receiver information that it picks up from those packets that it overhears, so as to help avoid collisions and lead to better throughput performance. In Aloha-CA, each packet is differentiated into two distinct segments, namely, a header segment, and a data segment. Nodes calculate the busy duration of medium from the ongoing transmissions along with indications of whether these busy states are caused by transmitting, receiving, or overhearing a packet. The collision would be possible only during the short header segment. When a node has a packet to transmit, it checks its database table to ensure that its transmission at this instant does not result in a collision at any other node besides making sure that it is not currently a receiver of any packet. If it deduces any transmission from its table, the packet transmission will be postponed using random backoff technique.

In Aloha-AN, node first transmits its header segment as a small advance notification packet (NTF). The sender will then wait for a period of time, called the lag time, before sending out the actual DATA packet. As the lag time will be set as a network parameter, every node in the network that hears the NTF segment will know when to expect the associated DATA segment. The receiver of NTF packet checks whether the associated DATA packet will cause any conflict with its own scheduled DATA packet transmission or reception and calculates the expected transmission time of the associated DATA packet. If there is any conflict either with its transmission or nearby nodes, a resolution mechanism will be invoked. The conflict-resolution mechanism grants the medium access to the node that will transmit first.

Advantages: The algorithms are much simpler and no handshaking or control packets are involved and no synchronization is required. This reduces the protocol overheads. Second, the transmission of small size of NTF packets to inform about data transmission results in low overheads in case of collision that would have been much higher if complete data packet is transmitted.

Disadvantages: The algorithms are suitable for stationary nodes but they incur higher overheads in managing transmission database for mobile nodes or in the case of AUVs network. This will degrade the performance of the algorithms. Second, it is not a trivial task to get propagation delays of all the nodes in a mobile network under varying propagation conditions [2]. Particularly, the propagation delay is highly variable in underwater environment. Third, the protocol will not provide fairness because a node sending NTF packets will keep capturing channel as long as it has data. Finally, it does not define any sleep intervals making it energy inefficient.

F. Tone-Lohi: Reservation based MAC protocol

In T-Lohi [9], [10] reservation based MAC protocol, nodes contend to reserve the channel for the right to transmit data. Each frame consists of a series of contention rounds (CRs)and contention-free data transmission period. The contention procedure requires nodes to send a short tone during CR duration and listen to decide if reservation is successful. If only one node competes in a CR, it wins and can transmit data in the corresponding data period. If multiple nodes complete in one CR, then each detect contention, applies backoff and try again in some later CR. The contention round is long enough to allow to detect and count contenders.

Both the data channel receiver and CPU remain off until a tone is detected by the low-power wakeup receiver. After receiving a wake-up tone, each node needs to scan the data channel for a possible preamble, even during a reservation period. If no preamble is found, the tone is considered a contention indicator. Otherwise, nodes decode the data header and go back to sleep unless they are the destination. T-Lohi is proposed in three flavors; Synchronized T-Lohi (ST-Lohi), Conservative Unsynchronized T-Lohi (cUTLohi) and Conservative Unsynchronized T-Lohi (cUTLohi).

ST-Lohi synchronizes all communication (contention and data) into slots and duration of each slot is equal to the contention round. The duration of contention round is $CR_{ST} = t_{max} + T_{tone}$, where t_{max} is the worst case one-way propagation time and T_{tone} is the tone detection time. In unsynchronized T-Lohi, nodes can start contending any time they know the channel is not busy. Each T-Lohi CR requires a node to determine who else is contending. So with cUT-Lohi, the channel must be observed for $CR_{cUT} = 2t_{max} + 2T_{tone}$ i.e. twice the period in synchronization to account for worst-case timing of tones. Although cUT-Lohi avoids the complexity of synchronization, its long contention time reduces throughput. Aggressive unsynchronized T-Lohi (aUT-Lohi) follows cUTLohi, but cuts the duration of its contention round to $CR_{aUT} = t_{max} + T_{tone}$. It is based on the assumption that there is low probability of tones collision since there are few packet losses for aUT-Lohi.

Advantages: In Tone-Lohi an innovative method of reservation is used instead of conventional RTS/CTS based reservation techniques that has an excellent performance in the underwater channel. Second, the tone enabled wakeup receiver in T-Lohi algorithm reduces a much amount of energy. The T-Lohi algorithm is basically for dense network deployment but it gives excellent performance in almost all scenarios. Third, among the three versions of T-Lohi, ST-Lohi is most energy efficient, cUT-Lohi provides packet delivery with almost no packet loss and aUT-Lohi combines the best features of ST-Lohi and cUT-Lohi i.e. minimum collisions with energy efficiency.

Disadvantages: There are some cases of data-data collision in ST-Lohi due to bidirectional deafness and also some cases of tone-data and data-data collisions in aUT-Lohi protocols because contenders only listen for t_{max} but there is only a minor probability of such situations. Second, if the receiver is the hidden node with respect to transmitter or if any data packet is lost due to channel noises, there is no mechanism to identify this loss. So, this protocol is excellent for the deployment scenarios where there is no hidden node problem i.e. dense deployment.

G. UW-MAC: A CDMA Based MAC Protocol for UWASN

In UW-MAC [11] nodes randomly access the channel transmitting a short header called the Extended Header (EH). The EH is sent using a common chaotic code c_{EH} known by all devices at the maximum rate (minimum code length). The EH contains information about the final destination i.e. the surface station, the next hop and the parameters that sender will use to generate the chaotic spreading code for the actual data packet. Following EH, the sender transmits the data packet on the channel using the optimal transmit power and code length set by the power and code self assignment algorithm. If no collision occurs during the reception of the EH, the receiver will be synchronized with the sender. It despreads the EH using the common code, and acquire the carried information. As a result, the receiver will be able to locally generate the chaotic code and thereafter decode the data packet. It then acknowledges the successful reception of data packet by sending an ACK packet using separate code c_A. If the sender does not receive ACK within timeout period T_{out}, it is allowed to make N^T_{max} maximum number of attempts. The value of T_{out} must be set long enough to consider the long propagation and transmission delays.

Advantages: The dynamic power control algorithm solves the exposed terminal problem. Second, the dynamic code length control algorithm helps in controlling the data bandwidth according to channel environment. The DS-CDMA scheme in UW-MAC, increases the spectrum efficiency i.e. bandwidth/data rate is higher. This increase in data rate reduces the error rate and provides security of the information but also increases the transmission latency.

Disadvantages: DS-CDMA based approach is not suitable for densely deployed sensor nodes. Second, although it provides power control algorithm, but the near-far problem can not be avoided for mobile nodes. Most importantly, for the limited acoustic band, data can not be widely spread to achieve the full benefits of noise immunity and security.

Protocol	Basic Approach	Time Synch.	Duty Cycling	Throughput	Overheads	Complexity
Slotted FAMA [4]	CSMA & TDMA	Required	No	Low	High	Medium
Extension of Slotted FAMA [5]	CSMA	Not required	No	Low	High	Medium
Distributed Energy efficient MAC [6]	Adaptive TDMA	Not required	Yes	Medium	Medium	Medium
Reservation based MAC [7]	Dynamic reservation with CSMA	Not required	Yes	Low	High	High
ALOHA based MAC [8]	Random Access (ALOHA)	Not required	No	Low	Low	Low
Tone-Lohi: Reservation based MAC [9]	Reservation based on separate tone (CSMA like)	With and Without	Yes	High	Low	Medium
CDMA Based MAC [11]	CDMA	Not required	No	Medium	Low	High

TABLE I
COMPARISON OF EXISTING MAC PROTOCOLS FOR UWASN

IV. OPEN ISSUES AND CONCLUSIONS

This paper presents different issues for designing MAC protocol for underwater acoustic sensor networks and the existing techniques in the literature. In UWASN, deployment of sensor nodes, which is application specific, plays a critical role in the performance of protocol. Therefore, a single protocol can not be considered as a solution for all the applications. Table I shows the comparison of all the protocols investigated in this paper. We also highlight the issues inherited from physical layer that one must need to consider in the design of MAC protocol. Particularly varying propagation environment, high error rates, limited bandwidth, 3D mobility and limited resources of sensor nodes are very important.

In addition, there are certain requirements which the MAC protocol must meet in order to function efficiently for UWASN. The protocol should minimize the idle listening as well as avoid overhearing and should not depend on time synchronization of nodes which is quite a challenging task in underwater environment. Moreover, it should efficiently utilize the limited acoustic bandwidth by avoiding control packets, minimizing redundancy and retransmissions and control the hidden and exposed node scenarios. Table I includes the parameters *time synchronization*, *duty cycling*, *throughput* and *overheads* to report the performance in light of these requirements.

In the existing MAC protocols, mainly there is emphasis on data acknowledgment rather than some adaptive Forward Error Correction (FEC) techniques. Data acknowledgment packets make the channel busy and may increase the chances of collisions with other data packets. An adaptive FEC technique incorporated in MAC can be the potential solution for UWASN. In addition, the existing MAC techniques do not address the QoS issues in frame scheduling. Heterogeneous UWASN are possible which might require to prioritize traffic. A priority based reservation can be explored to provide QoS based MAC protocol. The reservation should not be based on CSMA like technique rather some efficient technique as provided in Tone-Lohi should be incorporated to provide energy and bandwidth efficient solution. Our future work is to design such a QoS aware MAC protocol based on adaptive FECs and prioritized reservation techniques.

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