ARPN Journal of Engineering and Applied Sciences

A HYBRID BASED MAC PROTOCOL FOR UNDERWATER ACOUSTIC SENSOR NETWORKS

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ABSTRACT

Underwater acoustic sensor networks (UASN) have fascinated in recent years and grown rapidly with the longing to monitor the enormous portion of the world, wrapped up by the oceans. The acoustic wave has been used as a physical layer technology for monitoring the long-range applications in underwater with a few drawbacks. These networks deal with variable propagation delay, energy constraints and limited bandwidth that is strenuous for designing a substantial Medium Access Control (MAC) protocol for underwater sensor networks. In this paper, we have illustrated the applications of UASN and deliberately pointed out the advantages of using sensor technologies in deep oceans. On another fold, we have developed a hybrid based MAC protocol for time-critical applications. The proposed MAC is a cluster based protocol which helps to increase the lifetime of sensor nodes. To reinforce the channel efficiency, the multilevel scheduling in data phase is initiated with two queues depending on the priorities fixed by the cluster head. With this promising scheduling, we could eliminate the waiting time of the sensor nodes and achieves the higher throughput. The simulation results indicate that hybrid based MAC protocol increases network throughput, and reduces the end to end delay.

Keywords: underwater acoustic sensor networks (UASN), medium access control (MAC), multilevel scheduling MAC protocol (MS-MAC), round Robin, FCFS.

INTRODUCTION

"Every Ocean is kind of different from the other ocean & different from itself at different times". The term 'different' portrays the temperature, pressure, salinity, gases and composite minerals. These parameters have to be carefully measured in the deep ocean in order to preserve the biological environment. The role of monitoring the ocean can be achieved through advance man-made technology. The researchers have strived on developing the energy efficient sensors and compact underwater vehicles to fit in the underwater surface for montoring the deep sea applications.

The underwater sensors differ from terrestrial sensors by means of cost, and communication methods. Since underwater has its unique characteristics, sensor devices are prudently built to prevent saltwater corrosion. The medium of propagation in water is contradicts from air. From sensible observation, the radio frequency waves, optical fiber and electromagnetic waves do not propagate well for underwater communication. In 1826, scientists adjudicated the sound of speed in water to be 1435 m/s was explored on Lake Geneva at 8 degree C. Therefore, Acoustics communication is realistically suitable for underwater and eventually applied for many test-bed experiments. The communication takes place between the sensors through sound waves by an acoustic transmitter in underwater. This kind of acoustic topology is called as Underwater Acoustic Sensor Networks (UASNs) as shown in figure 1. Researchers tend to choose radio frequency communication or optical fiber for shallow water applications and they prefer acoustic communication for deep water monitoring.

By virtue of long propagation delay, limited BW and high bit error rates [1], the terrestrial Medium Access Control (MAC) protocol is not appropriate for acoustics communication. The underwater sensors node is an eminently paramount since it ensures consignment of miscellaneous data packets which used for pivotal applications. The poor packet scheduling and steep transmission delay cut-down the performances of the unabridged network.

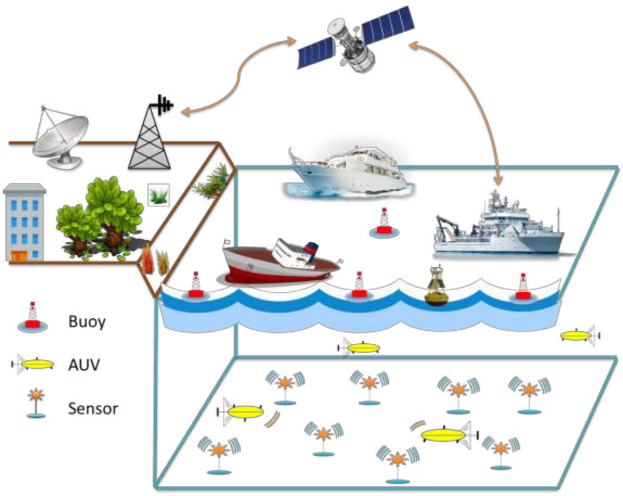

Figure-1. Underwater acoustic sensor networks.

In the last few years, the hybrid based MAC protocols have grown by adding advantages of contention-based and scheduled-based MAC protocols. The hybrid based MAC protocols for underwater sensor networks integrate various medium access techniques on demand or in a traffic adaptive fashion to accomplish better performance. In this paper, we have proposed a cluster-based MAC protocol for UASN with the combination of hybrid schemes. The protocol consists of two slots namely as, cluster head selection and beacon frame. The Cluster Head (CH) node is responsible for data transmission between cluster members in order to enhance the network coverage and node's lifetime. In order to achieve network performance, we introduced a multilevel scheduling in the data phase, which contains a high and low priority queue. The high priority queue works under the mechanism of round robin (RR) scheduling while the low priority queue performs first come first serve (FCFS). Both the queues run concurrently in the network for different applications. Hence, the proposed MAC protocol achieves higher throughput compared to the existing MAC protocols of underwater.

RELATED WORK

In this section, we have discussed about existing MAC protocols in the underwater networks.

CDMA is the promising scheduled based MAC protocols over TDMA and FDMA in underwater networks. It has a collision free property and resilient to Doppler's effect, which is ubiquitous in UASN. Inherently, it is robust in opposition to narrow-band jammers and necessitates governing the transmission power at all terminals, in concerning to counter the 'near-far' problem. To solve that issue, pompili [2] discussed CDMA based hybrid MAC protocol and developed a closed-loop distributed algorithm to jointly set the code length and optimal transmit power.

In conventional TDMA, each node synchronized by time slots with neighbors and schedules transmission in a different time at reception. The features of long propagation delay in underwater channel and particularly long range networks, a traditional TDMA is inefficient for the long time guards and leading to channel into under utilization. For overcoming the inefficiency problem, I-TDMA [3] is proposed for UASNs by interleaving data packets in empty time axis to improve the channel utilization and work well for statically deployed of few nodes. In [4] ST-MAC, a conflict graph (ST-CG) and traffic-based One-step Trial Approach (TOTA) has constructed to solve the issues of spatial-temporal uncertainty and vertex-coloring problem in ST-CG. The ST-MAC is energy saving and not suitable for mobile networks.

The FDMA techniques are intrinsically inefficient, due to the lack of flexibility in BW assignment and found incompatible in UW channel. To effectively exploit the limited BW and overcome multipath fading effects, the OFDMA protocol has been focused on [5]. It works on multicarrier modulation (MCM) in which several nodes concurrently transmit, by using various subcarriers with overlapping frequency bands that are mutually orthogonal. To drag out the work of [6], an adaptive OFDMA protocol has three modes of operations and converts a selective fading into parallel independent sub-channels that undergo flat fading.

In the absence of synchronization and to exploit the full BW utilization in the network, random access protocol has been benefited for underwater networks, which concentrated mainly on design metrics. However, lack of coordination may lead to recurrent interference from collisions, and results in loss of data. This is the main problem of ALOHA in the presence of high traffic [7]. Soh, chua [8] focused on long propagation delay and deliberated two methods called Aloha with Advance Notification (AN) and Aloha with Collision Avoidance (CA), but the protocols do not address the problem of hidden and exposed terminal nodes.

Carrier sense multiple access is a sub-part of the random access protocols have also been investigated in underwater. Chen and Wang proposed Ordered CSMA [9] that makes use of round robin scheduling and the scheme permits multiple carriers from multiple sources to communicate at the same time. The protocol designed for a single hop network and degrade the performances in a multi-hop network. . Chirdchoo [10] proposed a receiver-initiated based protocol called RIPT, which is a four-way handshake approach, where the data packets are transmitted in the form of a train and hence achieves the stable throughput with considerable collision rate.

In the last few years, the hybrid based MAC protocols have grown by adding advantages of contention-based and scheduled-based MAC protocols. In this paper [11], the authors point out the issues occurs in TDMA and handshaking techniques. The long transmission time of the packets during scheduled-based protocols results in low channel efficiency. The unavoidable rate of collision in contention based protocols decreases the network throughput gradually when the traffic load increases. In order to solve the issues, the authors proposed a reservation based MAC protocol namely HRMAC (Hybrid reservation). It's a cluster based MAC protocol and the cluster members (sensor nodes) reserve the channel at the initial phase. Each sensor nodes are assigned to a pseudo number by using spectrum spreading technology in order to avoid collisions. The reserved sensor nodes transmit their data packets in a given order via round robin scheduling. The HRMAC protocol achieves a good trade-off compared with traditional MAC protocols.

In [12], the author proposes a CHARQ protocol that blends the cooperative ARQ with incremental redundancy-hybrid ARQ. It uses multiple relays to improve the throughput, but it is still ineffectual because of reduplicative check packets and does not achieve optimal performance. To improve this, Haowang [13] proposes NCHARQ protocol based on a hybrid selective-repeat ARQ and network coding. They designed an adaptive window length estimation algorithm which adaptively alters the code rate with the respect to the environment change. The protocol achieved low reliability when less number of sensor nodes was deployed.

APPLICATIONS OF UNDERWATER SENSOR NETWORKS

There are plenty of applications in the field of scientific research, monitoring and disaster prevention. The paper focuses on disaster prevention, monitoring applications, and military applications.

Disaster prevention

The classification of disaster prevention is shown in Figure-2.

VOL. 13, NO. 17, SEPTEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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While there are numerous cataclysmic disasters shaken the world and millions of people were lost their beautiful lives. The deadliest catastrophic disaster is 1931 china floods, most extreme 3-4 million people are biting the dust due to devastating of floods.

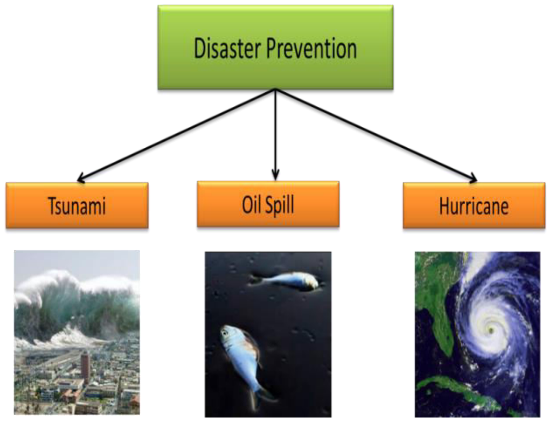

Figure-2. Disaster prevention.

In 2004, an undersea seismic tremor happened in the Indian Ocean (Tsunami) is an unforgettable history in India and the people of south side have been loaded with grieves, where hundreds of corpse has been dumped in the pits. From the statistics, the overall death of human beings by the tsunami is 2, 28, 000 and about 4 million individuals lost their homes.

Ocean electronics group has developed an ocean observation system for monitoring the tsunami in the Indian Ocean is shown in Figure-3.

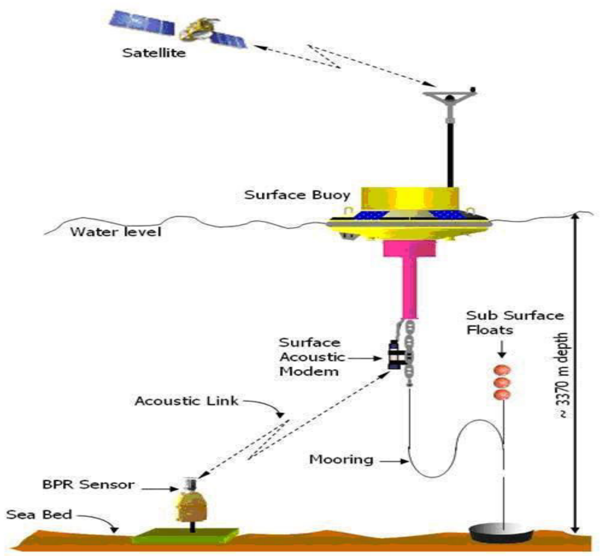

Figure-3. Tsunami observation system.

The system consists of a surface buoy and deep ocean bottom pressure recorder (DOPR). The DOPR pressure sensor is anchored to the seabed, and it contains an acoustic transmitter and central processing unit. If an earthquake occurs in the ocean bed, the waves create distinctive pressure changes which are recorded by the pressure sensor. The pressure sensor communicates with the buoy acoustically and the buoy acts as a data relay between the DOPR and satellite (INSAT). The surface buoy is made with an LDPE material at low cost. The buoy measures atmospheric pressure, surface sea temperature, humidity, wind speed, and direction.

Another important disaster occurs for the warm-blooded creatures in the seven seas are oil & chemical spill. The oil spill could happen accidentally or intentionally by terrorists. In a recent survey, NOAA responds more than 100 oil spills in US waters and exceeds one million metric tons of oil-based commodities (crude oil) spilled from oil tankers ever year which blends into the seas.

Why oil spills occur in the ocean

The petroleum products from hydrocarbon material originate under the sea. As shown in figure 4, to extract the product from 6000 feet's depth, the countries like Russia and USA drills the ocean core and extracts the oil which temporarily stores in the offshore. If a hurricane occurs or oil leakage from the pipe, the risk of tons of oil leak and thick oil slicks will be formed on the ocean.

Causes of oil spills

a) Natural Disasters
b) Illegal dumping by industries
c) Sinking or leakage of oil-carrying vessels or oil pipelines
d) Countries at war
e) Terrorist activities

Effects of oil spills

a) The leakage of oil from the pipelines causes perilous substance that discharges into the waters, shutting fisheries and shorelines, contaminating valuable wetlands and expanding the dredging cost for government.
b) Blocks entrance of oxygen in sea water.
c) The natural recovery process may involve up to 10 years.

Major oil spills in the world

a) Arabian Gulf Spills (1991)

Cause: Terminals and Oil tankers destroyed
Quantity of oil spilled: 6 - 8 million barrels

b) Deep water Horizon 2010

Cause: The cement at the base of the borehole did not create a seal, and oil and gas started to spill through it into the pipe leading to the surface.
Quantity of oil spilled: 210 million gallons

How to prevent oil spill

The oil spill can be controlled at initial stages. Mostly, the oil spill can be caused by human errors. Due to negligence, billion amounts are paid out every year to clean up the sea that is a very huge loss to the government.

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Oil spills take place in many ways like natural disaster (hurricane), pipe leakage etc.

Natural disaster cannot be controlled but inhibition can be made for oil spill from pipe leakage and oil tankers, for which a proper monitoring system control is needed. Nigeria is considered to have the worst oil spillage and environmental pollution resulting from such activities in the world [14]. According to society for One Nigeria, the country has lost more than 7 billion dollars in revenue due to pipeline vandalisation and crude oil theft [15]. Nweke and Ogbu [16] have discussed the security issues in Niger-Delta Oil and Gas Sector and has outlined the benefits of using wireless sensor network in oil and gas sector in Nigeria.

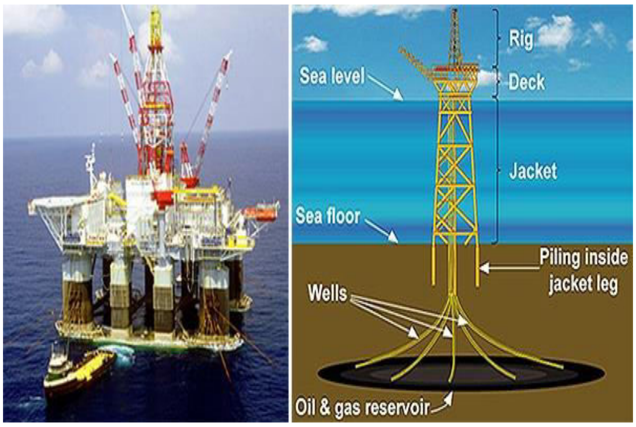

Figure-4. An oil rig in the sea.

Generally, oil slicks spread rapidly in the surface and cannot be taken out once they turn out to be very thin. Studies have shown that knowledge of the oil slick thickness at different locations, minutes after an oil spill occurs, reduces the clean-up costs since it helps in guiding the clean-up operation by indicating the real-time path for the most efficient treatment. In this paper [17], the authors develop a low cost sensor device for measuring the oil thickness. Just after an oil spill occurs, the sensors are thrown out into the slicks; the devices do sensing, processing and transmitting information about the oil spill. The network is created between the sensors which produce a map of the current state of the oil spill, including its thickness level at different locations in a short amount of time, guiding a fast and efficient treatment of the spill. The authors additionally used Light Sensor and Conductivity arrays in the device which are responsible for measuring the oil thickness.

Monitoring application

Underwater sensor network plays a major role in monitoring the sea waters such as pollution and biological monitoring. The Figure-5 shows the classification of monitoring applications in underwater.

Pollution monitoring

Since, our planet covers 71% of water surface and 2.5% fresh water found in it, whereas 1% is accessible and remaining water is trapped in glaciers and snowfields. Million gallons of water is consumed by agricultural and industries sector every year. Besides, discharging industrial and agricultural wastes into sea water in turn causes water pollution. Domestic sewage causes pathogens in surface water result in depletion of oxygen in water bodies and also a main source of waterborne diseases. Sewage, along with industrial effluents and agricultural run-off also contributes a large amount of nutrients in surface water causing eutrophication.

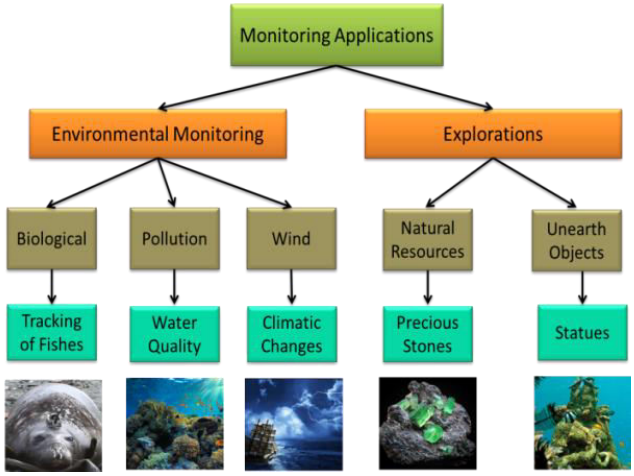

Figure-5. Monitoring Application.

Common issues of sea waters

a) Salinity – fresh water (<0.5%), Sea water (3% - 5%)
b) Toxicity (micro pollutants & industrial pollutants)
c) Pathogenic (Bacteriological) pollution
d) Depletion of Oxygen

These are the typical problems identified in sea waters. To overcome the problems, the government has been using several sensors to monitor the issues such as chemical leakage detection in rivers, hydroponics, and the pollution levels in the sea.

Several companies in the market manufacture the sensors for water monitoring purpose. The sensor measures conductivity (salinity), temperature, optical dissolved oxygen, pH and pressure in sea waters. Libelium world manufactures smart water sensors for river water applications and the sensors measures toxic substances like nitrate, fluoride, and arsenic. Recently in San Francisco Bay, 2000 leopard sharks are mysteriously died in the seashore due to pathogens. The deadly pathogen sneaks in through the shark's nose and slowly eats away at the brain. Since many organisms die in the deep waters because of lack of oxygen and algae bloom toxic, monitoring the pollution in sea waters is very important for preserving the living organisms in the ocean. Thus, it conserves the ecosystem.

Biological monitoring - Tracking of fishes

Scientist monitor the fish's behaviour in underwater through sensors such as fish's movement and the depth. The Global positional system (GPS) cannot find

VOL. 13, NO. 17, SEPTEMBER 2018 ISSN 1819-6608
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a fish location in sea waters because radio signals cannot penetrate into deep oceans. Scientists use acoustic telemetry to estimate an individual fish's location by attaching an acoustic transmitter to a fish. When a fish swims close to a receiver, its snap is heard, and its individual code number is recorded. The user can monitor the snap sound and go for fishing in that location.

Military applications

The Navy is a maritime force and has been involved in countless battles come wars in the struggle to bring peace and security to the people. It is a country's armed forces chiefly assigned to amphibious warfare. It's raised as a never-ending deterrent against international aggression.

The Navy use surface ships, submarines vessels and naval avigation for protecting the seaports, ferry troops, sea lanes and shore installations. On the other hand, the navy also incorporates nuclear deterrence by use of submarine-launched ballistic missiles. The US Navy utilizes Unmanned Underwater Vehicle (UUV) for mission activities and develops low-cost vehicles for increasing commercial growth in sea waters. At initial stages, the Navy operates UUV from a submarine and launched a Long Term Mine Reconnaissance System (LMRS). The LMRS is a torpedo tube-shaped underwater vehicle, capable of performing autonomous minefield reconnaissance as much as 120 miles and equips synthetic aperture sonar.

Another way of detecting a hidden mine in underwater is achieved by sensors. A sensor can sense the physical parameters like metals. Usually, the mine is made up of ferrous material and it could be differentiated by using metal detecting sensor. Hence, its help the military ships in a trouble-free voyage.

Therefore, the USNs are immensely used in military application that takes the help of UUV and sensors.

Some of the applications are,

a) Navigation Network node
b) Inspection or Identification a weapon
c) Mine countermeasures
d) Intelligence, surveillance and reconnaissance.

A HYBRID BASED MAC PROTOCOL

We have discussed the important applications of UASN in previous section. In this section, we have explained our proposed MAC protocol for underwater sensor networks.

Although the handshake technique is widely deployed in terrestrial multi-hop networks to resolve the hidden and exposed terminal problems. These mechanisms when adapts on underwater, it introduces the latency along with an extensible vulnerable period which leads to channel under-utilization and low throughput. On the other hand, schedule-based protocol such as TDMA, FDMA, and CDMA are not incorporated into the underwater environment that troubles in channel efficiency. Having these drawbacks, designing a substantial MAC (Medium Access Control) protocol is confronted since MAC plays a data communication between networks to the physical layer. A conventional MAC protocol does not suitable for underwater pivotal applications. The underwater sensor nodes are an eminently paramount since it ensures consignment of miscellaneous data packets. The poor packet scheduling and steep transmission delay curtail the performances of the unabridged network. In contemplation of the above mentioned problems and for a real time application, a hybrid based MAC protocol is proposed for UASNs in the paper.

How the protocol works

The proposed protocol works well for a static network with limited mobility. The protocol requires every cluster member to know their propagation delay between itself and neighboring nodes. In the initialization phase, a few Cluster Head's (CH) are chosen by adapting "LEACH Algorithm" [18] and the remaining nodes are actively as their cluster members. After calculating the position of their members, the CH's works out an order of transmission and broadcasts the initial order. There is an abundant beacon period has prevailed in the frame structure of the HSMAC protocol. In solitary beacon period, assorted circle periods are continued with a beacon broadcast by the CH's. A circle period resides of four slots namely HEED, SEQUENCE, SCHEDULING and ACKNOWLEDGEMENT.

In the HEED slot, when an idle node wishes to send the data to its neighboring nodes, it generates a HEED packet to CH and box up the information of sender's ID, receiver's ID, size of the data packet, time flag and tasks as shown in figure 6. The task describes about the high or low priority data. The CH receives 'n' packets of HEED from the cluster members and arranges the sequence into the new order for transmissions.

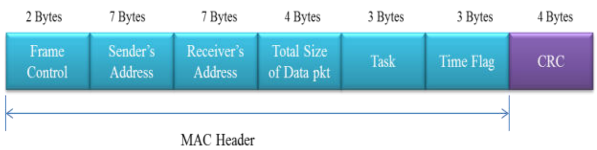

Figure-6. The HEED packet.

In the SEQUENCE slot, the CH broadcasts the SEQUENCE message to its members which consists of sender's address, receiver's address, total size of data packet and the queue as shown in Figure-7. The queue represents the high or low priority data. The queue technique is elucidated in the scheduling slot.

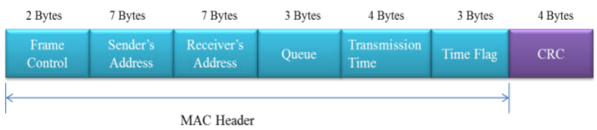

Figure-7. The SEQUENCE packet.

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The next slot is called “SCHEDULING slot” is a crucial part in the proposed protocol for data communication. The data transmission has carried over by MULTILEVEL SCHEDULING following the sequence order.

In the ACKNOWLEDGEMENT Slot, the receiver's come back with an ACK packet to sender's which encompass off - the number of received data packets, the packet list and the state of receiving data packets (correct or error) as shown in Figure-8. If the data packets do not receive correctly, the corresponding sender does have to contend the channel for retransmission in the next slot.

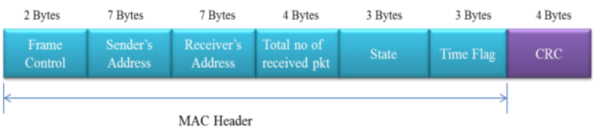

Figure-8. An ACKNOWLEDGEMENT packet.

The Multi-Level scheduling in data period

In the SCHEDULING slot, data transmission has carried over by Multilevel Scheduling in the network. It accomplishes a pair of processes called foreground and background queues. The packet scheduling pattern can also be lineup based on the number of levels in the accessible queue of a sensor node. These are follows.

Single queue

Each sensor node has a single ready queue for data transmission. All sorts of data packets arrive in the ready queue and are scheduled placed on offbeat criteria: priority, size, type, etc. Single queue has a steep starvation rate.

Multi-level queue

Each node has two or more queues. Data packets are settled into the various queues conforming to their types and priorities. Thus, scheduling has dual phases: (1) Allocating tasks among divergent queues, (2) Scheduling packets in each queue.

Working principle of multi-level scheduling

After receiving a SEQUENCE message from CH, the members are assigned in the sequence order based on the priority level (high and low). The purpose of the proposed protocol is to deliver the data based on the priority queue fixed by the CH. Existing WSN protocols works well for data transmission without any priority criteria, hence they focus only on successful transmission to attain high throughput. In proposed protocol, the sensor node has two types of queues such as high priority and low priority queue. The high priority queue is assigned for emergency applications, Eg. Tsunami detection. The low priority queue is fixed for secondary applications. The high priority task (P1) is achieved in the foreground process by Round Robin (RR) scheduling.

Therefore, RR has the convenience of time sharing and fairness. Since, every nodes grabs uniform contribution for transmission and miniature average waiting time is the colossal asset for aquatic communication. The RR mechanism makes a sensor node to wait less than the propagation of the network for their transmission, which is advantageous to improving the channel efficiency. The second priority task (P2) is carried out at background process by First Come First Served (FCFS) scheduling. The adverse of FCFS, waiting time can be extensive if terse request behind the longest ones and not suited for time sharing applications. Indeed, most existing WSN applications use FCFS schedulers that process data in the sequence of their arrival times at the ready queue. Fitly, these are the added advantages to the low priority task schedule for acoustics communication. The emergency data goes to high priority queue (P1) are processed using RR and secondary data packets that arrive at low priority queue (P2) are processed by FCFS. Queue size is contingent on the application necessity and high priority event is barely crop ups.

PERFORMANCE EVALUATION

The simulation model is implemented using the Aquasim tool [19] (specifically built for underwater environment). It is used to evaluate the performance of the proposed protocol scheme, comparing it against the HRMAC, RIPT and ALOHA protocol. The comparison is made in terms of network throughput and end-to-end transmission delay

We randomly deployed 20 nodes in a 4*4 km area in the network and the transmission range is set to be 5 km such that each sensor node can receive the packets from all the nodes in the network. The acoustic propagation speed is 1500 m/s. The length of the data packet is 512 bytes and control packet is 30 bytes, respectively. All sensor nodes are equipped with a half-duplex, Omni-directional transceiver with the fixed data rate of 1kbps.

Performance comparison in terms of network throughput

The comparison of the network throughput of four MAC protocols for UASNs is shown in Figure-9. The proposed protocol outperforms all of three protocols significantly as the load increases. The reason behind is that the data transmission is carried through multilevel scheduling. The packets are scheduled properly based on the priority levels and it improves channel utilization. The throughput is calculated based on successful transmission and overall transmission time. In proposed scheme, we use two different queues and various scheduling mechanism, the packets are successfully transmitted with a unit time.

Therefore, there is no delay occurs. The HRMAC protocol works under Round Robin (RR) mechanism for data transmission. The disadvantage of RR is larger waiting time and response time which takes a bit more time for data transmission. The throughput of HRMAC is higher than both RIPT and ALOHA. The RIPT is a receiver initiated and four-way handshake protocol. The data packets are transmitted in the form of packet train at the receiver from various one-hop neighbors. The

VOL. 13, NO. 17, SEPTEMBER 2018 ISSN 1819-6608
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throughput of RIPT is higher than that of ALOHA because receiver has accurate information on its own current state. The ALOHA protocol does not address the hidden terminal problem, which becomes worse when the load is high.

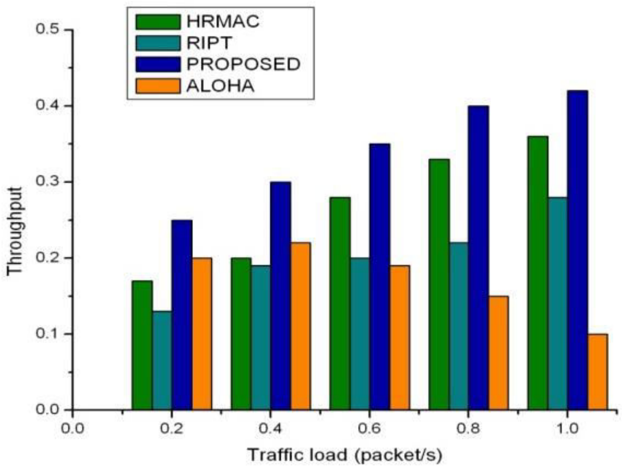

Figure-9. Throughput Vs Traffic Load.

Performance comparison in terms of end-to-end delay

Figure-10 shows the end-to-end transmission delay of the four MAC protocols. We proposed hybrid based MAC protocol for emergency and secondary application events.

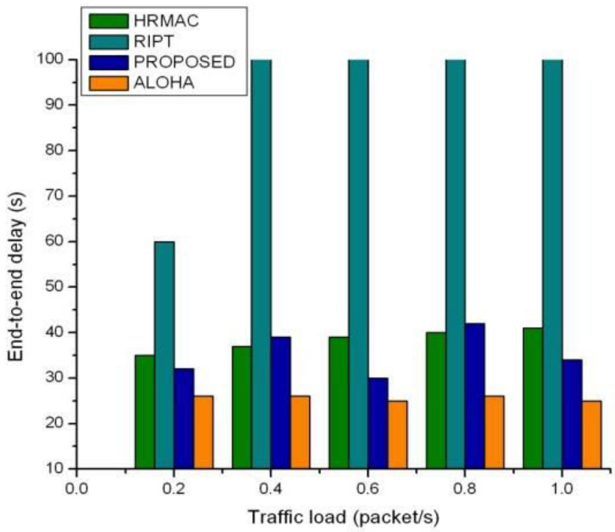

Figure-10. Delay vs traffic load.

High priority event is rarely occurs and cannot predict the size of the data queue. If two events occur simultaneously, the queue gets processed and arise the constant delay. The delay is slightly fluctuating due to switching of two queues used for data transmission. The proposed MAC is partly higher than the HRMAC, and marginally lesser than RIPT. The HRMAC adapts round robin technique for data transmission. The RR runs in a circular manner and size of the data packets are equally get processed, hence it results a quite constant delay in the network. The RIPT obtained the highest delay of all three MAC protocols because it is a receiver initiated approach in which a sender cannot transmit the data packets until a handshake is initiated by the receiver. The ALOHA protocol is seen to have the best transmission delay performance among the four schemes. The reason behind that it only uses a one-way notification mechanism.

CONCLUSIONS

In this paper, we illustrated the applications of underwater acoustic sensor networks in deep oceans and proposed a hybrid based MAC protocol. The proposed protocol adopted energy efficient Clustering algorithm for the cluster head (CH) selection. The Cluster head is responsible for packet transmissions in the network and aids to inflate the lifetime of sensor nodes. To enhance the channel efficiency, we come out with multilevel scheduling in the data phase, which contains two queues rest on the priorities fixed by the cluster head. These two queues run concurrently in the network to transmit the multiple data packets. The simulation results show that the proposed protocol achieves higher throughput comparing it with existing MAC protocols.

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