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Delay Aware Opportunistic Transmission Scheduling Technique for Efficient Channel Utilization in under Water Sensor Networks

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Abstract: Mobile underwater networks with acoustic communications are faced with several unique challenges such as high transmission power utilization, large propagation delay and node mobility. The delay-aware opportunistic transmission scheduling algorithm has been mainly designed for underwater mobile sensor networks. It uses passively obtained local information to enhance the chances of concurrent transmissions while reducing collisions. Along with that, a simple performance enhancement mechanism that permits multiple outstanding packets at the sender side, enabling multiple transmission sessions has been proposed which in turn significantly improves the overall throughput. Each node learns neighboring node 's propagation delay information and their expected transmission schedules by passively overhearing packet transmissions through the establishment of the newly developed MAC protocol called DOTS. This protocol mainly aspires to achieve better channel utilization by harnessing both temporal and spatial reuse. The simulation results exemplify that DOTS provides fair, medium access even with node mobility. Hence, this protocol also saves transmission energy by avoiding collisions while maximizing throughput. It also achieves a throughput several times higher than that of the slotted FAMA while offering related savings in energy.

Key words: CSMA, DOTS, medium access control, opportunistic transmission, mobile sensor networks

INTRODUCTION

Under Water Acoustic Sensor Networks (UW-ASNs) have recently been emerged as a way to explore and analyze the ocean which covers two-thirds of the Earth's surface, to consider a SEA Swarm (Sensor Equipped Aquatic Swarm) architecture illustrated in Fig. 1 for short-term ad hoc real-time aquatic exploration such as chemical spill monitoring, oil, submarine detection and surveillance. A swarm of traveling sensor nodes such as UCSD drogues is mainly deployed to the venue of interest and moves as a cluster with the ocean current. Each sensor inspects local underwater activities and reports critical events using acoustic multi-hop routing to a distant data collection hub, e.g., Surface buoys or Autonomous Underwater Vehicles (AUVs).

Despite, the blooming technological advances of acoustic communications, there are still confronted with limitations that need to be addressed in order for UW-ASNs to be put into practical use such as severely limited bandwidth, long propagation delays and relatively high transmission energy cost. Moreover, the unreliable nature of underwater wireless channels due to their complex multipath fading and surface scattering it further aggravates the smooth data communications. Figure 1 shows the schematic scenario of under water and surface vehicles.

Under these circumstances, Medium Access Control (MAC) protocols specially designed for terrestrial packet radio networks in which that cannot be directly used because the propagation delay of acoustic signals is much greater than the packet transmission time, for example 0.5 vs 0.04 sec to transmit a 256 byte data packet with the data rate of 50 kbps over a 750 m range carrier sensing in Carrier Sense Multiple Access (CSMA) may not prevent packet collisions.

This outstanding unique situation however permits several packets to concurrently propagate in an (Syed and Heidemann, 2006) underwater channel which must be subjugated in order to recover the channel throughput. Hence, this phenomenon is also exactly observed in transatlantic wire lines or wireless satellite relations. The main departure is that these are point-to-point links without any contention and that the large Bandwidth-Delay Product (BDP) is exploited at an upper layer such as in TCP connection. In general, the long

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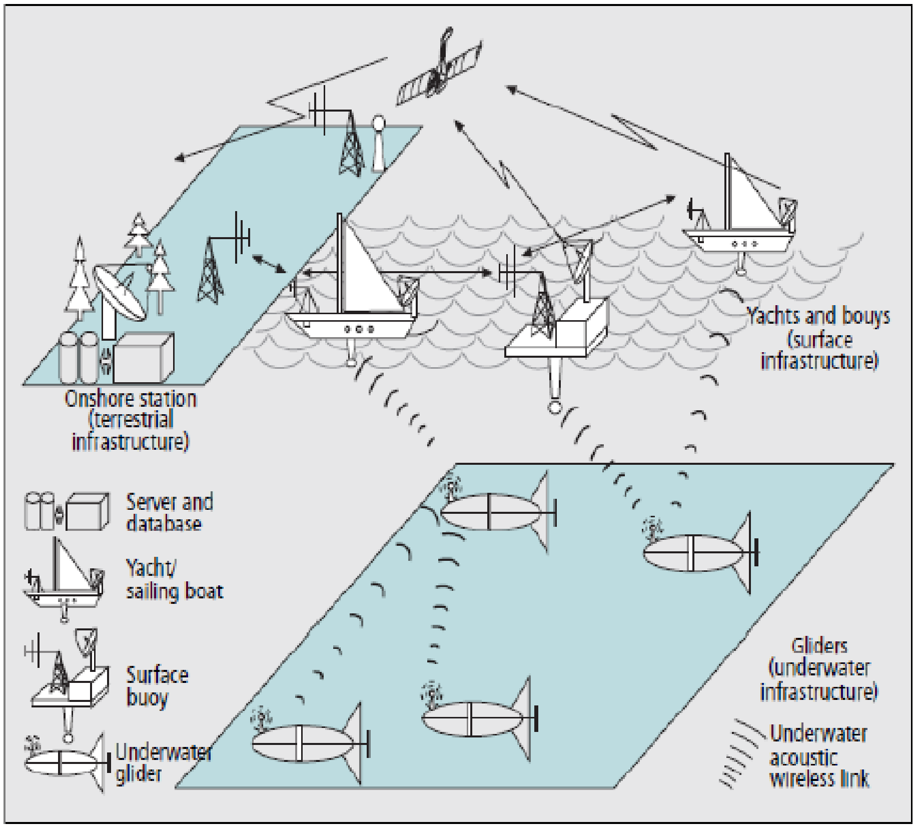

Fig. 1: Scenario of UW-ASN composed of under water and surface vehiclesin

propagation latency in an underwater wireless network produces a unique opportunity for temporal reuse which turn allows for multiple concurrent packets propagating within the same contention area. Added to that the temporal reuse is an additional opportunity on top of well established spatial reuse in wireless networks which allows simultaneous, non-colliding transmissions to various destinations if they are sufficiently removed from one another, to solve the exposed terminal problem.

In this study, by considering this issue the Delay aware Opportunistic Transmission Scheduling (DOTS) algorithm has been newly designed for underwater mobile sensor networks. The following are the key contributions of the study:

- DOTS can effectively utilize the temporal and spatial reuse by using local information
- In DOTS, each node learns its corresponding neighboring node 's propagation delay information and their expected transmission schedules by passively overhearing packet transmission
- It can also compensate for the long propagation latencies by increasing the chances of simultaneous transmissions while sinking the likelihood of collisions

The proposed extensive simulation result confirms that DOTS can significantly enhance the overall throughput. It also exemplifies that such opportunistic scheduling can efficiently handle the spatial unfairness caused by physical location and propagation latency such that closer the distance between a pair of nodes, the higher the chance of detecting the channel.

Literature review: The UW-FLASHR is a variant TDMA based MAC protocol (Yackoski and Shen, 2008) that can attain higher channel utilization than the maximum utilization possible in existing TDMA protocols. The main potential solution for enhancing CSMA in UW-ASNs is to utilize temporal reuse that abuses the long propagation latencies of acoustic waves.ST-MAC is an underwater TDMA protocol (Hsu *et al*., 2009) that highly operates by developing Spatial-Temporal Conflict Graph (STCG) to expose the conflict delays among transmission links and decreases the ST-CS model to a new vertex coloring issue.

A heuristic called the Traffic-based One-step Trial Approach (TOTA) has been designed to solve the coloring problem. STUMP a TDMA-like protocol (Kredo *et al*., 2009) that uses propagation delay information and prioritizes conflicting packet transmissions based on certain metrics in which it includes random ordering and uplink delay ordering. Moreover, TDMA scheduling is specifically performed in a centralized way which is not resilient to failure. Hence, discovering a reasonable TDMA schedule using distributed algorithms for optimized transmission scheduling entails a network-wide consensus. TDMA-like protocols are not appropriate for resource constrained mobile sensor networks.

A receiver initiated reservation protocol called Receiver-Initiated Packet Train (RIPT) has been designed for initiating packet transfers, the receiver accepts the packet transmission requests from its neighboring nodes and develops a transmission schedule (Kredo *et al*., 2011) for its neighboring nodes by recognizing the propagation delay to its neighbors. In RIPT, the receivers need to sometimes initiate packet transfer which are very expensive and under unreliable traffic demands, it is non-trivial to examine when to initiate packet transmissions. Despite to traditional underwater CSMA solutions, DOTS neither need an additional phase for reservation scheduling nor limit transmission schedules to an exact order.

The MACA-P is a MAC protocol (Acharya *et al*., 2003) mainly designed to detect an expose terminal from Request-To Send/Clear-To-Send (RTS/CTS) exchanges (Syed and Heidemann, 2008) such that a node eavesdrop an RTS without overhearing the corresponding CTS. MACA-P introduces a control gap (or delay) between RTS/CTS and DATA/ACK to allow neighboring nodes to schedule their transmissions through explicit RTS/CTS.

The Multi hop enabled energy efficient MAC protocol (Shazzad *et al*., 2015) is mainly preferred for overcoming the packet collisions happened and also the proposed protocol efficiently produces the multi hop networking by splitting the single phase contention resolution methodology into two phases. In this approach, the first phase illustrates the elimination of local nodes from the contention by the way in the later phase the undesirable effects of hidden nodes are diminished. Hence, this methodology of providing two phased contention resolution technique mainly improves the throughput, energy efficiency and shorter end to end delay.

In this proposed protocol, the data transmission (Shazzad *et al*., 2015) entails that data is efficiently received by the determined receiver. After that the data transmission has been visualized by the three parts of logical time frame such as, Local link reservation, Hidden link control and Data transmission. In Local link reservation, the time slots play a major role in determining the contention round. For efficient usage of the process, short duration tones are highly preferred for resolving the contention happened among the nodes. In order to consume the energy loss two types of receivers such as data receiver and low power wake up tone receiver are used. After the process of local link reservation, the hidden link control phase proceeds in such a way that it is carried out by the substituting two distinct control packets prior to the transmission of data. These additional features will enhance the process by ensuring the nodes in the hidden links by rescheduling the receiving data packets towards the destination.

Geographic routing protocols (Pompili *et al*., 2006) are very familiar for limited required signaling and scalability. Global positioning system are highly used for terrestrial systems for accurately plotting the geographical location of several sensor nodes in which some among them are not working properly in underwater environment. Apart from these routing protocols, certain sensors, UAVs, UUVs, etc., are used to recognize the exact position irrespective of other approaches.

In vector based forwarding routing (Xie *et al*., 2006), a small fraction of the nodes in routing is involved such that it does not require any state information on the sensors. In a distributed geographical routing, the nodes work in either greedy mode or recovery mode for efficient delay insensitive applications. In greedy mode, the nodes that currently holding the messages will be forward to the destination. The recovery mode is activated in the case of node failure to forward a message to the next feasible neighbor node.

In Cascading Multi hop Reservation and Transmission (CMRT), (Lee and Cho, 2014) most of the intermediate nodes start their handshaking process between the source and destination. Due to this relaying, cascade and makes the data to be deliver down to the destination. Apart from the above, CMRT also improves the channel utilization in a very efficient manner through the process of adopting a packet train method in which multiple data packets are aggregate together by handshaking. It subsequently reduces the time taken for exchanging the control packet and thus it increases the throughput.

In CMRT, intermediate node (Lee and Cho, 2014) process its shifts between six different states such as Wait_Resp, Idle, Delay_Data, Wait_Data, Data_Rx and Silence. Wait_Resp is mainly enhances the state of making the node to wait for the proper response from the receiver to the control packet. Delay_Data mainly helps the hidden nodes in avoiding the possible collisions by making the sender to delay the data transmission. Wait_Data is the state in which it makes the receiver to wait for few time to get the reliable data from the sender. In Data_Rx state the receiver receives the data packets from the sender. In order to avoid collisions between the neighbor nodes, silence node helps in making the channel reservation to remain silent when there is a cause for neighbor node to overheard the swapping the control packets. The remaining states which was not included in the above comes under the idle state.

A Protocol named Segmented Data Reliable Transport (SDRT) (Xie *et al*., 2006) has been developed to attain the reliable data transfer in under water sensor circumstances. It mainly adopts high efficient random forward error correction codes, erasure codes, in order to transfer the encoded packets hop by hop or block by block. It gradually reduces the total number of transmitted packets thereby improving the channel utilization and also shortening the protocol management. Basically, it is a hybrid approach of both Forward Error Correcting (FEC) (Petrioli *et al*., 2008) and Automatic Repeat request (ARQ). The data packets are mainly delivered to the destination from the source either by block by block or hop by hop. Apart from the data packets, an intermediate node will be encoding each data block using process of random forward error correction codes (Liao and Huang, 2012) and also it pumps the encoded data packets into the channels. As soon as the receiver gets the encoded packet, immediately decoding process will be done to extract the original data blocks. The receiver then again encodes the block and relays the block to the next hop. Until receiving the positive feedback from next hop, the sender keep on sends the encoded packets.

MATERIALS AND METHODS

Dots prerequisities: It has been explicitly observed that information obtained from passively overhearing neighboring transmissions can be useful in estimating collisions at the intended receivers. DOTS mainly use the passively obtained information by constructing a delay map to attain both temporal and spatial reuse by making intelligent transmission scheduling decisions. DOTS therefore has the ability to compensate for the long propagation latencies and severely limited bandwidth of the acoustic medium by using passively observed information to increase the chances of concurrent transmissions while decreasing the likelihood of collisions. Figure 2 and 3 shows the front view and Internal view of UANT system, respectively.

Fig. 2: Front view of UANT system

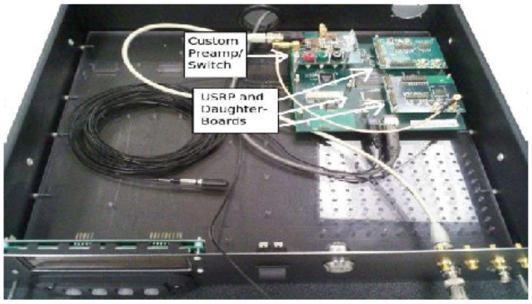

Fig. 3: Internal view of UANT system

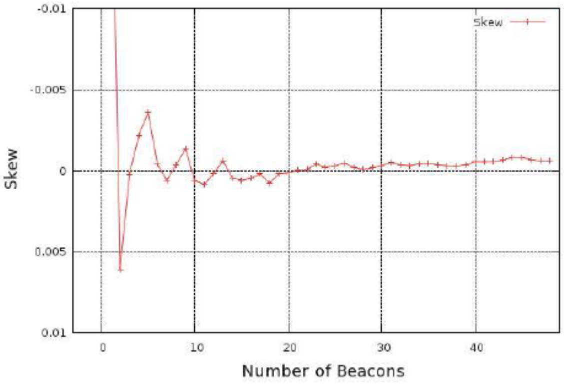

Fig. 4: No. of Beacons used in TSHL vs Skew estimate

Even though, the lack of clock synchronization might make it tough for an overhearing node of a transmission to evaluate the propagation delay between itself and its transmitting node. Using this protocol a leading transmitter will send out multiple time-stamped beacons. All receiving nodes will compute the difference between the received timestamp and the local time, in which it compute a linear regression over all these values and detect the slope of the line. Henceforth in the second phase, offset is found using the skew compensated time. By implementing this protocol on the UANT platform, it uses a software defined radio and a mix of custom and commercially available hardware for the transmitter and receiver.

Figure 4 shows that after the beacons are sent the skew between nodes converges and the nodes share the

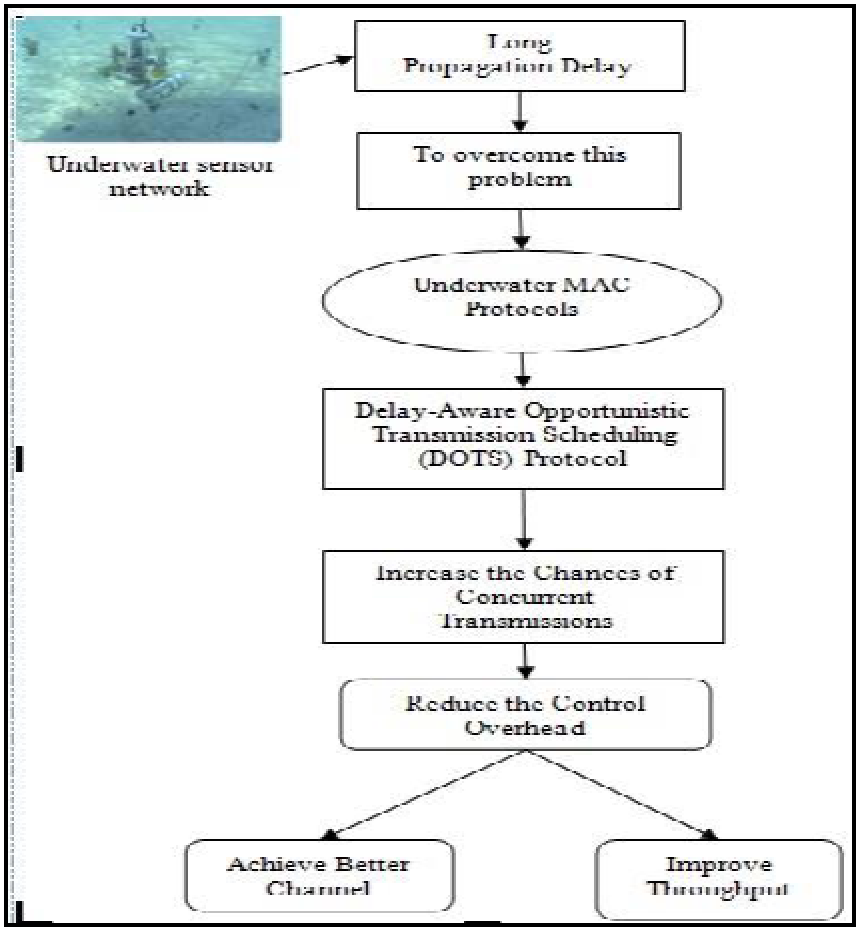

Fig. 5: DOTS framework

same idea of time. Note that to reduce overhead of resynchronization, timestamp information of beacons can be piggybacked in the header of a data packet from the node with the reference clock. In this process, when a node is receiving data it can also perform the linear regression and update the values of skew and offset. Since phase two of TSHL needs one packet from the receiving node to be sent back to the transmitter, this information can be appended to the acknowledgement that is sent after each data transfer.

Dots design: To enhance the underwater transmission scheduling alg1orithm, DOTS have been developed. It exploits long propagation delays by using passively observed one-hop neighboring nodes' transmissions to enhance channel consumption. The systematic process of DOTS is based on MACA-like random channel access with RTS/CTS. Due to this design option, it is confronted with the challenge that data transmission between two nearby nodes after RTS/CTS handshaking can be collided with RTS control frames of a distant node due to relatively long propagation delays. The general outline of the DOTS framework has been illustrated in Fig. 5. Recall that this will happen more frequently and be more expensive in underwater acoustic networks than in terrestrial radio networks due to the high latency and transmission expenses.

In order to identify the problem the following two conditions for collision free transmission are provided. They are RTS wait time in which it should be larger than the maximum propagation delay that is the propagation delay for a transmitted frame to reach its maximum transmission range. Then CTS wait time it should be greater than the RTS transmission time plus twice the maximum propagation delay and the hardware transmit-to-receive transition time. Therefore, these two conditions are the basis of DOTS protocol in order to avoid frame collision. By means of the supposition of synchronization, DOTS can able locally calculate the dispersed transmission and reception schedules to perform concurrent transmissions when viable by promiscuously overhearing neighboring transmissions. Added to that it can also maintains minimal internal states in a delay map database to keep track of observed neighboring transmission and reception schedules. This database is updated based on each observed frame's MAC header. In addition to standard source, frame size, destination, sequence number and Cyclic Redundancy Check (CRC) checksums in the MAC header, DOTS protocol require two added fields in the MAC header such as an accurate clock synchronized timestamp and an estimate of the propagation delay between the source and destination.

This approximation of the propagation delay between the source and destination of the overheard frame can be performed during the clock synchronization process (Zhou *et al*., 2011) by scrutinizing the time of departure information during the frame exchanges and soon after updated through further communications between the nodes. Furthermore, the interruption map database entries can terminate and be removed over time with the knowledge of data size of each entry and the maximum propagation delay for each overheard frame in order to keep the number of database entries small.

Delay map management: The following are the information contained in the delay map of each node, examined while observing neighboring transmissions:

- Source: The dispatcher of the observed MAC frame
- Destination: It denotes anticipated destination of the experiential MAC frame
- Timestamp: The time in which the experiential MAC frame has been sent
- Delay: The probable propagation delay between the source and the destination for the MAC frame.

Transmission scheduling: Based on the delay chart, a node decides whether it has the ability to transmit without interfering with a neighbor's reception. Figure 6 shows the transmission scheduling decision procedure. Node x sends an RTS to Node y. When Node u receives this RTS and has data to send, it can begin its own transmission to Node v concurrently if the following two conditions are tends to be held.

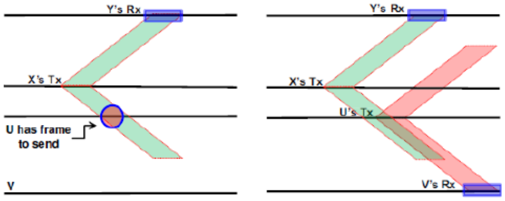

Fig. 6: Sample transmission decision

- Neighboring non-interference: This denotes that its current transmission (RTS) and future transmission (DATA) must not interfere with neighbors continuing and potential receptions
- Prospective non-interference: This denotes its prospect reception (CTS and ACK) must not be interfered with by neighbor's prospective transmissions

Schedule recovery: Collisions may occur during the period of successive transmissions.A node may leave its neighbor 's RTS/CTS due to the half-duplex nature of the acoustic modem or the lossy nature of the acoustic channel and gets started on its transmission sequence causing a frame collision. Since, every transmission decision is made locally, there is no way to provide collision-free scheduling. Hence, DOTS provide a schedule recovery scheme to minimize the damage caused by a collision or a lost frame and it will further avoid the condition of deadlocks.

Guard time: DOTS protocol uses a guard time to support node mobility caused by the ocean currents. Every node computes this guard time as 2*(average movement distance/speed of sound) when it checks the transmission scheduling algorithm. The multiplier 2 is used since both the sender and the receiver may move in opposite directions from each other. This guard time is then added to the guard time in the frame reception duration in which it results in a smaller range of allowable concurrent transmissions.

RESULTS AND DISCUSSION

The following are the several validity measures in which they are performed in order to inspect the efficiency of the proposed DOTS protocol.

Throughput: The throughput of the four protocols with different data sizes in the line topology has been illustrated in the following Fig. 7. Through that analysis it

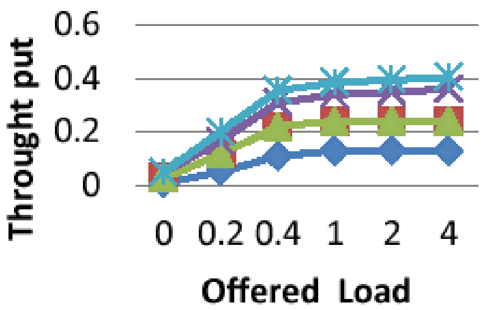

Fig. 7: Line topology: throughput as a function of offered load with fixed data size (512 bytes)

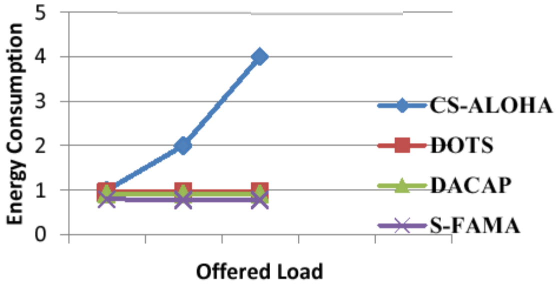

Fig. 8: Star topology: Energy consumption in the star topology with fixed data size (512 bytes)

Fig. 9: Guard time sensitivity to a MCM mobility speed (3 m sec)

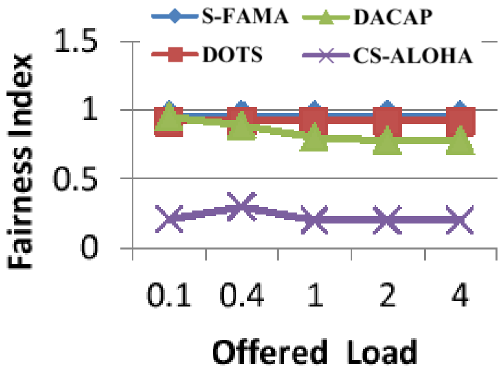

Fig. 10: Jain 's fairness index for the four protocols

is confirmed that DOTS outperforms S-FAMA by a factor of two and DACAP and CS-ALOHA by around 15% for a 750 m transmission range with both 512 and 1024 byte data frame sizes.

It is a highly remarkable feature that DACAP outperforms S-FAMA by two times because, DACAP allows for concurrent transmissions of the two sender-receiver pairs. While a sender-receiver pair (A and B) is undergoing data transmission in the line topology, the other pair (C and D) can also perform parallel data transmission because the two collision avoidance conditions of DACAP cannot suppress the transmissions of the two sender nodes (B and C). Subsequently, this allows DACAP to perform concurrent transmissions possibly with collisions. Henceforth it is the result of avoiding these minor collisions which greatly explains the utilization gain of DOTS over that of DACAP.

Energy consumption: The average power consumption of the four protocols in the star topology with a 750m transmission range and 1024byte data frame size has been exploited in Fig. 8. It shows the process of average energy consumption of each protocol per node during the entire simulation period. When it is compared with the throughput lines of the four protocols, it implicitly determines the number of collisions which occur in each protocol. DOTS mainly consume more energy than S-FAMA and DACAP because it delivers more frames than these two protocols. By inversely analyzing, throughput for CS-ALOHA is about 20% lower than that of DOTS. Hence, the energy consumption of CS-ALOHA is several times higher indicating that CS-ALOHA consumes significantly more energy due to collisions.

Guard time: If it is too long, packet collisions will rarely happen but have lesser chances of exploit temporal/spatial reuse. The upcoming Fig. 9, illustrate the throughput performance based on different guard time intervals ranging from 1-8 m sec. All intervals show positive correlation with offered load. It shows that the guard time interval of 2 m sec shows the best throughput performance. The guard time intervals of 1 and 8 m sec show slightly lower throughput performance due to collisions and lower utilization, respectively. Evaluating the performance of DOTS by varying the guard time intervals is important as the sensitivity of guard time with respect to the speed of nodes has been deeply analyzed. If the guard time is highly low, the chances of packet collisions will be gradually increases.

If it is too long, packet collisions will rarely happen but have lesser chances of exploiting temporal/spatial reuse. In Fig. 9, the throughput performance based on different guard time intervals ranging from 1-8 m sec has been clearly mentioned. All intervals show positive correlation with offered load. It also shows that the guard time interval of 2 m sec produces the best throughput performance. The guard time intervals of 1 and 8 m sec show the slightly lower throughput performance due to collisions and lower utilization, respectively.

Fairness: Due to the process of CS-ALOHA 's binary exponential bakeoff, it allows close sender-receiver pairs to potentially capture the channel, thereby strictly degrading the fairness but providing best throughput performance as indicated in Fig.10. This channel capture also directs to strict data collisions at other nodes which have not captured the channel, inducing poor energy utilization. Furthermore, Fig. 10 exemplifies that CS-ALOHA is subject to far greater amounts of instability and throughput variation as a result of this capture effect.

To overcome the above mentioned shortcomings, a new MAC protocol called DOTS has been introduced to alleviate limitations caused by the long propagation latency and the severely limited bandwidth of acoustic communications. DOTS can achieve better channel utilization by harnessing both temporal and spatial reuse. Henceforth the extensive simulation results have shown that, DOTS outperforms S-FAMA by 2 times and DACAP by 15% times in the line topology (exposed terminal) and S-FAMA by 2 times and DACAP by 70% in the star topology (higher node density and contention) and it also provides reliable throughput performance even with node mobility and preserves a high level of fairness for channel access.

CONCLUSION

The Delay aware Opportunistic Transmission Scheduling algorithm plays a vital role in determining the efficient channel utilization in the Under Water sensor networks. Since, its ability and inherent nature, fetches to the development for future work. First, DOTS can better harness spatial or temporal reuse during the delivery of out of order packets and also at the delivering period of sender side packets. Hence, this improved efficiency comes at the cost of degrading fairness. Second enhancement of DOTS is that it will consider the capture effect as in Interference Aware (IA) MAC where a receiver can correctly decode a packet even in the presence of other concurrent transmissions. Third development is that when a data frame is correctly received but the corresponding ACK gets lost due to loss channel or collision, Windowed ACK can help them by containing the number of spurious retransmissions and thus increases the throughput. Fourth thing is to investigate the impact of mobility and random topologies on the throughput and fairness. Finally, an effective plan has been designed to implement DOTS in a real world test bed for reexamining and verifying the simulation results.

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