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Enhanced Multichannel MAC Protocol Design for Underwater Sensor Networks

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Abstract— **A Wireless Sensor Network (WSN) consists of Sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. On comparing with radio transmissions the challenges in the designing of underwater sensor networks are battery power is limited, small bandwidth, sensors are more prone to failure due to corrosions, bit error rates are quite high, propagation delay, channel is severely impaired. In this situation collisions are likely to occur. These collision problems are handled effectively in single hop network and not in multihop network. In this paper we have reduced collision with a new protocol Enhanced multichannel MAC Protocol by including a concept called cyclic quorum systems. New features in this protocol are, the missing receiver problem which is often encountered in multichannel protocol is solved by using one modem, simultaneous channel negotiations on different channels can be completed by multiple sensor node pairs, data packets and control packets are not collided. Simulation results verify that our protocol can reduce collision probability significantly which enhances the network performance in a multi-hop UWSN.**

Index Terms — ***Multichannel MAC protocols, quorum systems, underwater sensor networks (UWSNs)***

I. INTRODUCTION

Advances in wireless communication technologies have attracted a lot of research in sensor networks. Underwater sensor networks (UWSNs) enable a wide range of applications, including environment monitoring, under sea exploration, tactical surveillance, disaster warning, and assisted navigation. Radio waves propagate at long distances through conductive sea water only at extra low frequencies (30-300 Hz), which require large antenna and high transmission power. Optical waves do not suffer from such high attenuation but are affected by scattering. So acoustic waves are used as a medium of communication in under water sensor networks.

Different factors may affect the design process.

a. Bandwidth: The acoustic band under water is limited due to absorption; most acoustic systems operate below 30 kHz.

b. Propagation delay: The speed of RF is 3×10^{8} m/s while the acoustic signal propagation speed in an underwater acoustic channel is about 1.5×10^{3} m/s. The propagation delay in underwater is five orders of magnitude higher than in RF.

c. Shadow zones: It can be defined as the area with high bit error rates and temporary losses of connectivity due to the extreme characteristics of the underwater channel. Salinity, density and temperature variations of the water can influence acoustic communication, such as temporary losses of connectivity. Sound speed under water is given by empirical formula

$C = 1449.2 + 4.6T - 0.055T^{2} + 0.00029T^{3} + (1.34 - 0.01T)(S - 35) + 0.016Z$ where, C- speed of sound (m/s), T- temperature (deg C)
S-salinity (practical salinity units “psu” equivalent to parts per thousand), Z- depth (m)

d. Energy: Battery power is limited because underwater batteries are extremely difficult to recharge. Unlike terrestrial WSN, UWSN cannot use solar energy to regenerate the power of the batteries.

e. Failure: Underwater sensors are prone to failure because of fouling and corrosion.

f. Attenuation: attenuation is the reduction in amplitude and intensity of a signal. Attenuation at distance x is given as

$$A(x) = x^{k}\alpha^{x}$$

Where, k is spreading factor, a is frequency dependent term obtained as $\alpha=10^{(.\alpha(f))}$ where, $\alpha(f)$ is absorption coefficient given by Thorp’s expression. The formula illustrate attenuation is dependent on frequency as well as distance. It is very important in determining signal strength as a function of distance.

Collision is indeed a serious problem. Existing MAC protocols in UWSN such as ALOHA is a class of MAC protocols that do not try to prevent packet collision. If two systems transmit packets at the same time, a collision occurs. Slotted Aloha in underwater has no effect different from Aloha except the cases where the propagation delay is a multiple of the time slot interval. In other words, the distance between nodes, when divided by the sound speed, results in an integer of time slots. In Slotted FAMA, RTS is sent, CTS is received, then data is sent and ACK is received. It eliminates long control packets and saves energy. Tone-Lohi (T-Lohi) is a contention-based protocol where data reservation uses short wake-up tones but used only in single hop network and also has efficiency problem. In Multichannel MAC protocol multiple modems with different transmission rate and range is used which steps to collision.

The complications in these protocols are

- Collision that occurs on a network when something happens to the data sent from the physical network that prevents it from reaching the destination,
- Extensive power consumption when staying in standby mode, measuring power, transmitting and receiving data. .
- Missing receiver problem occurs when a sender fails to access its intended receiver because they do not reside on the same channel.
- Retransmission overhead is the ratio of unsuccessful data transmission to the number of total data transmission.

II. RELATED WORK

A. *Terrestrial Multichannel MAC Protocols*

Multichannel MAC protocols in terrestrial wireless networks can be classified into two categories: single rendezvous and multiple rendezvous. In the single-rendezvous class, RTS/CTS based multi-channel MAC protocols have been extensively researched for terrestrial radio networks. The communication link is divided into one control channel and multiple data channels and channel assignment is integrated into the RTS/CTS handshaking process on the control channel. For single-transceiver multi-channel long-delay underwater networks, however, these approaches are not efficient, because, except for the traditional multi-hop hidden terminal problem for the single channel network, they will suffer from two new hidden terminal problems that are inherent in the new underwater network scenario: multichannel and long-delay hidden terminal problems .In MACA-MCP ,RTS and CTS packets are much shorter than the transmission latencies and round-trip delays to minimize collision probability.

Multi-channel MAC protocols design uses channel hopping techniques to avoid the bottleneck of a single control channel. The quorum-based channel hopping (QCH) system based on *quorum systems*, for designing and analyzing channel hopping protocols for the purpose of control channel establishment and it uses intersection property. Two optimal QCH systems under the assumption of global clock synchronization: the first system is optimal in the sense that it minimizes the time-to-rendezvous between any two channel hopping sequences; the second system is optimal in the sense that it guarantees the even distribution of the rendezvous points in terms of both time and channel, thus solving the *rendezvous convergence* problem. An asynchronous QCH system does not require global clock synchronization. **In m**ultiple-rendezvous class, in order to wait for information from other nodes each node with fixed channel has one fixed interface. The other $k - 1$ transceivers are switchable interfaces. By tuning one of node A's switchable interfaces to node B's fixed channel data transmission from node A to node B is enabled. In PCAM three half-duplex transceivers are used by a single node. Two transceivers, the primary and the secondary transceivers, are used mainly for data transmission purposes. A third is used for transmitting and receiving broadcast messages.

B. *UWSN MAC Protocols*

Existing underwater MAC protocols can be classified as centralized and distributed. Time division multiple access (TDMA)-based scheme is used in Centralized MAC protocols where the distances of all its neighbors are found through sink node. By the sink node transmission sequence is scheduled and the super frame finds all nodes.

In distributed MAC protocols, the single-hop protocol such as T-Lohi contend to send a short tone to reserve the channel in the reservation period. In slotted ALOHA, time is divided into slots of the same size. Packets can be sent only at the beginning of each slot. The collision probability is proportional to the packet transmission time and is minimized, at the expense of longer delay, when the size of a slot equals to the maximum propagation delay of the network. In FAMA, the lengths of request to send (RTS) and clear to send (CTS) packets should be greater than the maximum propagation delay to avoid packet collision. This produces severe power consumption burden in UWSN. To overcome this, slotted FAMA is adopted: Time is also divided into equal slots, and packets can be sent at the beginning of each slot. A slot is set to the duration of transmitting a data packet plus the maximum network propagation delay. In multihop environment, the RTS/CTS packets may collide with data packets. That is, two nodes that successfully exchange RTS and CTS packets are not guaranteed to have a collision-free data transfer. “Primary Channel Assignment based MAC” is based on the use of primary channel assignment, which is used by other nodes to find the corresponding node and eliminates the need for a separate dedicated control channel or time slot that is usually prone to saturation when the traffic increases. If a channel is dedicated for the control purposes, it results in severe performance degradation in the multi-channel environment and the failure of the protocol in taking advantage of the increasing number of channels. A multichannel protocol, multiple access collision avoidance with multiple channels and positioning information (MACA-MCP) where each node is equipped with multiple acoustic modems which has different transmission ranges and data rates. The channels in this work refer to different capability modems. A modem is utilized if the recipient is within its ideal range. For each channel, the MAC mechanism is RTS/CTS/DATA/ACK handshaking along with carrier sensing. MACA-MCP is different from other multichannel MAC protocols in that a modem does not have the option to select different channels. It does not aim to solve the collision problem. Moreover, in a UWSN with a lot of nodes, using multiple modems is not cost-effective.

III. COLLISION ANALYSIS

The Effect Of Collision Probability Depends On Throughput: Derived as the average probability of successfully transmitting one data packet p_s. Then, the average throughput η can be presented as

$$\eta = nl_d p_s$$

Energy Consumption*:* For a single data packet to be successfully transmitted, averagely speaking, $\frac{1}{p_s}$ times of data transmissions are needed, if every data transmission is independent. One or more control packets are needed for channel negotiation. The average number of transmissions for control packets used for each successful transmission of a data packet as α. Then the average (total) energy consumption per data packet can be written as $\epsilon = \frac{1}{p_s}\epsilon_d + \alpha\epsilon_c$.

Packet Delivery Ratio: The packet arriving process for a node is an independent identical Poisson process with parameter λ. Consider a network with *n* nodes. The total traffic in the network can be viewed as a Poisson process with parameter $n\lambda$. If a control packet is transmitted at time t_c in order for this control packet to be received correctly there should be no other control packets in the network during $(t_c - T_c)$, where T_c is the duration of one control packet.. Now we can have

$$P(A) = e^{-2n\lambda T_c}$$

For a data packet, even if its corresponding control packet has been successfully received, collisions can still happen. If another sender selects the same data channel within a very short time, the data packets will still get overlapped in the time domain and a collision occurs. Given a data packet, we use *x* to denote the number of other data packets which overlap with this data packet in the time domain .Then we have

$$P(x = k) = \frac{1}{k!}(2n\lambda(T_d - T_c))^k e^{-2n\lambda(T_d - T_c)}$$

IV. PROPOSED MAC

The proposed MM-MAC deals missing receiver problem and obtain Channel Allocation through the concept of cyclic quorum systems.

A. *Quorum Concept*

Quorum systems have been widely used for mutual exclusion in distributed system and for MAC protocol design in wireless networks. A quorum system can be defined as follows.

Definition1. Given a finite universal set *U* = {0…..n-1} *of n* elements, a quorum system *S* under *U* is a collection of non-empty subsets of *U*, which satisfies the intersection property:

$$p \cap q \neq \emptyset, \forall p, q \in s$$

Each $p \in s$ (which is a subset of *U)* is called a quorum.

Definition2. A set $D = \{a_1, a_2 \ldots. a_k\}$ is called a relaxed cyclic (*n, k*) difference set for every $d \not\equiv 0 (mod\ n)$ there exists at least one ordered pair (a_i, a_j), where $a_i, a_j \epsilon D$ *D*, such that $a_i - a_j = d$ (mod *n*). Here, Z*n* denotes the set of nonnegative integers less than n.

*Definition.3.*A group of sets $B_i = \{a_1 + i, a_2 + i \ldots a_k + i\} mod\ n \in \{0,1 \ldots. n-1\}$ is a cyclic quorum system if and only if *D*=$\{a_1, a_2 \ldots. a_k\}$is a relaxed cyclic *(n, k)*- difference set.

*Definition 4.*Let quorum systems *S*= $\{q_0, q_1 \ldots q_{k-1}\}$ be given over a universal set U. Then *W*∈ $[0,1]^k$is a strategy for *S* if it is a probability distribution over the quorums$q_j \in S$, *i. e*$\sum_{j=0}^{k-1} w_j = 1$.

*Definition 5.*Let a Strategy *W* be given for a quorum system *S*= $\{q_0, q_1 \ldots q_{k-1}\}$over a *universal set U.* For an element *i*∈ *U*.for an element $i \in U$ the load induced by *W* on it is

$$I_w(i) = \sum_{q_j \in S; i \in q_j} w_j$$

The load induced by a strategy *W* on a quorum system *S* is

$$L_w(S) = \max_{i \in v} I_w(i)$$

The system load on a quorum system *S* is

L(S) =$\min_w\{L_w(S)\}$where the minimum is taken as the system load over all strategies *W*.

Intersection property and rotation closure property can also be verified using cyclic quorum.

B. MM-MAC Protocol

The MM-MAC protocol aims to use a single modem to emulate multiple-transceiver multiple-rendezvous solutions. The assumptions that we made in the paper are listed as follows.

a. Totally, *m* equal-bandwidth channels are available.

b. Each node is equipped with one half-duplex modem which is able to switch to any channel dynamically.

c. Nodes are time synchronized. In MU-Sync, both large and time-varying propagation delays are considered.

d. Each node knows the identifications (IDs) of its one-hop neighbors. This information can be collected during the network initialization phase.

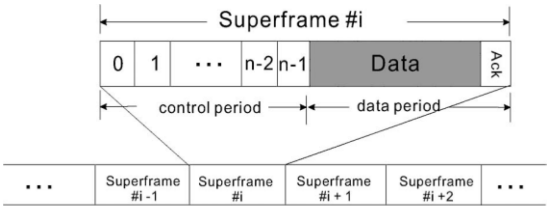

Fig 1. MM-MAC frame Structure

To enable a communication, a transmission pair must switch to the same channel at the same time. That is, the most important job is the joint allocation of channel and time for all the nodes in the network. In MM-MAC, we divide time into a series of super frames. Each super frame is further divided into control and data periods, as shown in Fig1. The control period consists of n slots, numbered from 0 to $n - 1$. The value of n is decided by the integer set from which each slot in the control period contains two mini slots. Control packets can be sent at the beginning of each mini slot.. A Data period follows control period which is dedicated to data transmission. To increase network utilization, the length of a data period is long enough to transmit several packets. At the end of each data period, there is a mini slot reserved for transmitting an ACK packet. To handle changes of physical property which affect acoustic transmission that leads to delay, guard time can be included in the super frame length setting. This provides the correctness of MM-MAC at the expense of a little efficiency reduction.

For each control period, control slots are partitioned into *default slots* and *switching slots.* At default slots, a node stays on its *default channel*, waiting for transmission requests. At switching slots, a node may switch to its intended receiver's default channel to initiate a transmission. Each node selects its default channel from its node ID. To solve the missing receiver problem, besides node ID, we use a cyclic quorum G_i under **Zn** along with the sequence number of the current super frame to identify a node's default slots.

Default slots and *switching slot* are partitioned from control slot in control period. At default slots, a node stays on its *default channel*, waiting for transmission requests. At switching slots, to initiate a transmission, a node may switch to its intended receiver's default channel. From the node ID each node selects its default channel. To solve the missing receiver problem, besides node ID, we use a cyclic quorum D_i under Z_n along with the sequence number of the current super frame to identify a node's default slots. Specifically, a node i 's default channel (denoted as DC_i) and default slots at the current super frame (denoted as DS_i) are chosen as follows:

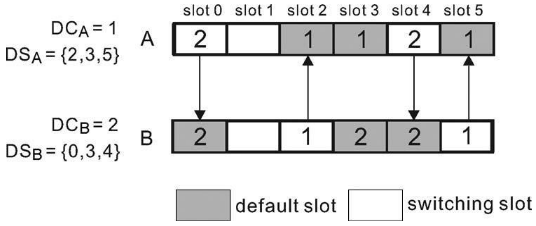

Fig 2. Example of MM-MAC channel and slot allocation.

$DC_i = node\_ID_i \pmod{m}$
$DS_i = Gj, j = (node\_ID_i + SF\_ID) \pmod{n}$ where $node\_ID_i$ is the ID of node i and SF_ID is the sequence number of the current superframe. We include the sequence number of the current superframe in the default slot selection for the sake of fairness: Each node will eventually adopt all different quorums with equal probability. The proposed channel and time slot allocation achieves multiple rendezvous in that multiple transmission pairs can concurrently complete handshaking at any control slot. It should be noted that two nodes selecting the same cyclic quorum have no overlapping of default and switching slots. Thus, they may never meet each other if their default channels are different. To solve this problem, one of the nodes, for example, the one with smaller ID can temporarily change some of its default slots to switching slots. This method is simple but the missing receiver problem may bother, although the probability is low. It can also be solved by asking a common neighbor node that has a different cyclic quorum to relay their traffic, if we handle this problem in the network layer. In such a case, route discovery between the common node and the two nodes must be applied. This method involves cross-layer operation.

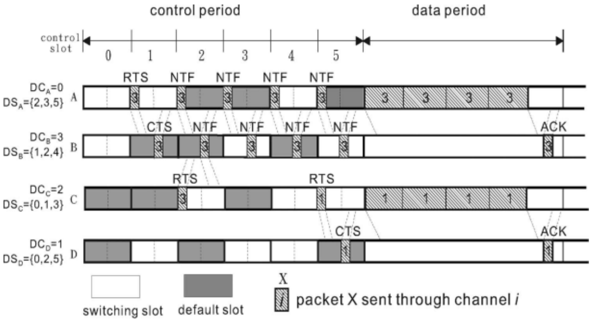

Fig 3.MM-MAC data transmission

Nodes running MM-MAC allocate a separate buffer for each of their neighbors to keep packets pending for them. Each node also maintains a free channel list to keep track of available channels. In the control period, each node checks its buffers, and the node with the most pending packets will be selected as its destination. To initiate this transmission, RTS and CTS packets are exchanged at an overlapping slot. Nodes that overhear an RTS or a CTS packet will update their free channel list. After a successful RTS/CTS negotiation, a notification packet (NTF) will be sent by both sender and receiver at each of the remaining control mini slots to declare that the channel has been reserved. Receiving this NTF, other nodes will modify their own free channel lists and will not try to access the channel. Note that free channel list modification may enable a node to reselect its destination. If neither CTS nor NTF is correctly received, a sender will resend the RTS until the retry limit is reached. Fig. 3 is an example of MM-MAC operation with four channels (numbered from 0 to 3) and six-slot control period. Assume that the sequence number of the current superframe is four and we choose the difference set {0, 1, 3} under **Z6** as Go. Four nodes A, B, C, and D, with IDs 4, 3, 2, and 1, respectively, form's a linear topology (from left to right).It is a multi-hop environment in that nodes can only communicate with their adjacent nodes. Suppose that nodes A and C have pending packets for node B while node A succeeds to exchange RTS and CTS packets with B at slot 1. For the ensuing mini slots, both A and B will broadcast NTF packets. Node C, trying to contact with B at slot 2 using channel 3, realizes that channel 3 has been reserved when an NTF instead of a CTS is received. Thus, node C changes its destination to the one that has the second most pending packets, node D in this example, and accomplishes handshaking at slot 5. At data period, both senders A and C send four data packets to their recipients B and D, respectively.

The effectiveness of the control slot allocation of MM-MAC relies on the overlapping of the sender's switching slots and the receiver's default slots. The intersection property of the cyclic quorum system is not enough since it only guarantees the overlapping of default slots. To justify the correctness of the channel/time allocation mechanism of MM-MAC, the following theorem is needed.

Theorem: Given a cyclic quorum system Q={$G_0, \dots..G_{n-1}$} under Z_n, for I, j=0,…n-1, then $G_i \cap G_j = 0$ if and only if $G_i = G_j$.

Proof: In the forward direction, we prove it by contraposition. If $G_i = G_j$, $G_i \cap G_j$=0. . This proves the forward direction. In the backward direction, we also prove it by contraposition. If $G_i \cap G_j$=0, $G_i = G_j$.This proves the backward direction.

Theorem verifies the feasibility of MM-MAC. It is guaranteed that a sender's switching slots and its receiver's default slots intersect. The missing receiver problem is solved accordingly. A node's default channel and default slots are derived from its ID. If a node i wants to join the MM-MAC operation, node i has to collect the IDs of its neighbor nodes and vice versa. To collect neighbor nodes' IDs, node i can monitor all available channels one by one for x superframes, where x is a system parameter. Any packet received by node i contains its neighbor's ID. To enable a new node announcing its existence, a possible way for MM-MAC is to arrange a broadcast super-frame periodically. A node may also fail due to hardware breakdown or running out of battery. A node removes a neighbor i from its neighbor list if retry limit is reached and no response is received from i.

Several other beneficial features can be found in the control slot allocation mechanism of MM-MAC. First, given that the node IDs are randomly distributed, the default channels for all the nodes in the network can also be evenly distributed among all available channels. This means that the traffic load can be evenly shared by all available channels. Second, the scattered overlapping of default and switching slots for different pairs helps to reduce packet collisions. Third, by separating control and data periods, data packets will not collide with control packets. To reduce energy consumption, sensor nodes usually work in a low duty cycle manner. To adapt to this condition, a superframe in MM-MAC can be applied during an active period. That is, a sleep period can be placed between two adjacent superframes. This also enables a node to adjust the duty cycle based on its traffic load. For example, sensor nodes near the sink usually have heavier traffic loads and should have higher duty cycles. There exist solutions that enable nodes with different traffic loads to have different duty cycles. Determining active periods by applying these mechanisms, nodes running MM-MAC are expected to operate in a more efficient manner. In a dense network with a fixed number of available channels, we could use a quorum system with relatively larger size to reduce collision probability. However, this produces a longer control period which implies increased control overhead. To compensate for the enlarged control overhead, a feasible way is to extend the data period. In fact, the performance of MM-MAC largely depends on the ratio of control period to data period. We will analyze this issue in the next section.

V. ANALYSIS OF MM-MAC

In this section, we investigate the impact of the sizes of control and data periods. The MM-MAC is compared with slotted ALOHA to verify its effectiveness. The terms used in our analysis are defined as follows.

1) T_d: The duration to transmit a data packet.
2) T_c: The duration to transmit a control packet.
3) T_{pd}: Maximum propagation delay.
4) N_c: The number of slots in a control period.
5) $N_{d:}$The maximum number of data packets can be sent in a data period.
6) CU_{sa}: The utilization for slotted ALOHA in a collision-free network. It is defined as the amount of data delivered in four slots. That is, $CU_{sa} = T_d / (4(T_d + T_{pd}))$.
7) CU_{mmm} : The utilization for MM-MAC in a collision-free network. It is defined as the amount of data delivered in a superframe and is given by CU_{mmm} =

$$(N_dT_d)\ /\ ((2N_c + 1)(T_c + T_p) + N_dT_d + T_{pd})5$$

More data packets should be sent in a data period for MM-MAC to achieve better performance. Longer data period is required to achieve the same throughput as control period enlarges,. This implies that our MM-MAC is suitable for a heavy-loaded network where multiple data packets can be sent in each data period. In addition to the aforementioned analyzed symmetric workload where N_d data packets are sent in each data period, we also consider the asymmetric workload where the number of transmitted data packets is varied for different data periods. We found that the performance of MM-MAC actually depends on the average number of transmitted data packets in a data period. If the number of data packets to be sent for each data period is uniformly distributed between 1 and N_d, the performance is the same as that of a symmetric workload with (l + N_d)/2 packets sent for each data period. The relationship between the sizes of control and data periods can be calculated.

VI. PERFORMANCE EVALUATION

We have developed a simulator using C++ to evaluate the performance of MM-MAC. We choose slotted ALOHA because it works in a single hop environment and performs better than Tone Lohi and it motivates our work. We implemented the revised "slotted ALOHA" where packets can be sent only at the beginning of a slot. For MM-MAC, a cyclic quorum system under Ze is implemented. A control slot is 2 s long. A data period is 8 s long, including the duration to transmit an ACK packet. This means that a maximum of four data packets can be sent in a superframe. Totally, three channels can be used in MM-MAC.

There are two models in our simulation: multiple sinks and single sink. In the multiple-sink model, nodes choose their destinations randomly from their one-hop neighbors. In the single-sink model, all the nodes have the same ultimate destination—the sink node located at the center of the network. In this model, the sink node is assumed to be equipped with multiple modems, each of which works on a different channel.

A. *Multiple-Sink Model*

As offered traffic load increases, the performance of MM-MAC increases proportionally before the network is saturated while the performance of slotted ALOHA reach a limit at much lighter traffic load. MM-MAC has higher throughput than slotted ALOHA since multiple transceivers/channels have been utilized. There are two reasons that explain why slotted ALOHA produces more collisions than MM-MAC. First, a sender running slotted ALOHA can send its intended receiver at any time slots. This means that, in any time slot, all the neighbors of a receiver may be the contending sender. For a receiver in MM-MAC, only a part of its neighbors have an overlapping of their switching slots to the receiver's default slot. Second, in slotted ALOHA, both control and data packets can be sent at any slot which means that every slot is collision vulnerable. These results verify that our MM-MAC reduces collisions effectively while slotted ALOHA do not. The retransmission overhead, which is defined as the ratio of the number of unsuccessful data transmissions to the number of total data transmissions. The slotted ALOHA produce a lot of retransmissions due to frequent packet collisions. The retransmission overhead of slotted ALOHA is over 84 %, respectively. For MM-MAC, the retransmission overhead is almost zero because of the separation of control and data transmissions. This separation eliminates the possibility of data packets being collided by control packets. The signaling mechanism, through exchanging RTS, CTS, and NTF packets, also helps keep the retransmission overhead low. Retransmission also produces energy wastage. To successfully transmit a data packet, the throughput for slotted ALOHA is at least seven times more than that of multi-channel protocol. MM-MAC reduces collision probability at the expense of a dedicated control period for transmission negotiation.

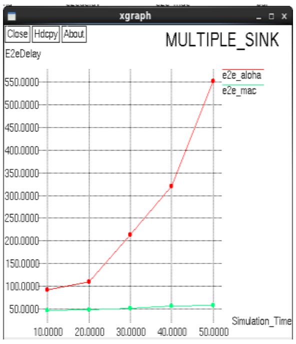

Fig.4. Average latency for multi sink

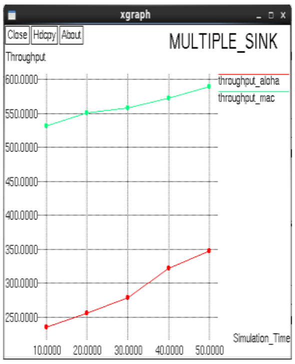

Fig 5.Average throughput for Multiple Sink

B. *Single-Sink Model*

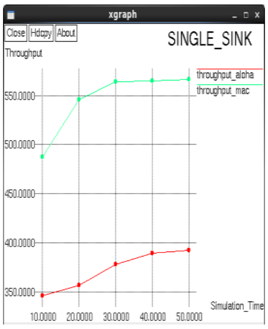

Fig6.Aeverage throughput for Single Sink

However, as packet arrival rate enlarges, the reduced collisions compensate for the control overhead and enable MM-MAC to achieve the shortest end-to-end delays. when the packet arrival rate is more than 0.05 packet/s, the achieved throughput is about four times higher than that of slotted ALOHA..At a packet arrival rate of 0.1 packet/s, the throughput of MM-MAC is 6.4 times higher than that of slotted ALOHA. Slotted ALOHA waste a lot of resource on retransmission while MM-MAC use the network capacity efficiently. The result of power

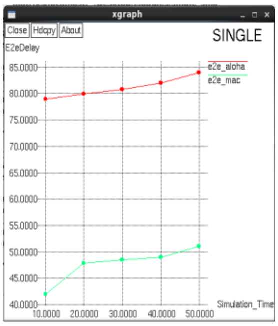

Fig7.Average latency for Single Sink

consumption per successful data packet is found. In the single-sink model, packets may travel several hops to reach the sink, and thus, the penalty of retransmission enlarges. Also, as packet arrival rate increases, the contention at the sink is severer and produces more power consumption. At light loads (packet arrival rate < 0.02), the penalty of using dedicated control periods in MM-MAC is the increased end-to-end delay. Again, the benefit of reduced collisions emerges as traffic load gets heavier

VII. CONCLUSION

We proposed an efficient multichannel MAC protocol for UWSNs in this paper. The proposed MM-MAC is a multiple-rendezvous protocol; only one modem is required for each node. Utilizing cyclic quorum systems, the missing receiver problem is solved and so nodes running in MM-MAC are guaranteed to meet their intended receivers. The multiple-rendezvous feature speeds up the channel negotiation and alleviates the contention problem. The separation of control and data transmissions also helps reduce the collision probability of data packets. Simulation results verified that MM-MAC has better performance in that it achieves higher throughput and keeps the retransmission overhead low. We believe that the proposed scheme is a promising multichannel MAC protocol for UWSNs since it achieves a great improvement over existing MAC protocols such as slotted ALOHA.

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