# Upgrading Design and Simulation Research of MACA Based on the Underwater Acoustic Networks

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***Abstract*—Combining with the characteristics of Underwater Acoustic (UWA) channel, this paper puts forward an improved MACA protocol. Based on the Multiple Access with Collision Avoidance (MACA) used for wireless communication networks, we review MACA with some related literatures at first and then analyze and improve the performances of MACA respectively from three aspects including presenting an effective strategy to solve the problem of collisions among control packets, reasonably making use of the retransmission times and making a simple modification to the state transition rules of MACA. Finally, under the circumstance of the underwater acoustic environment and by use of the simulation tool—OPNET, we separately simulate our proposed MACA and the original MACA introduced or modified in the former research. The simulation results show that compared to the original MACA, our proposed MACA could not only steadily maintains the performance in throughput but also dramatically reduces the packet loss rate. Moreover, our improved MACA distinctly decreases the average end-to-end time delay of data packets as well as remarkably lowers the average energy consumption for transmitting data packets. Therefore, it provides certain reference values for the design of the MAC protocol for Underwater Acoustic Networks (UAN).**

***Keywords-Underwater Acoustic Networks; MACA; OPNET; performance; MAC protocol***

## I. INTRODUCTION

In recent years, along with the accelerated pace of the ocean development, the need for such applications as Underwater Acoustic Sensor Networks (UASN), underwater surveillance system and underwater acoustic early warning networks in our society is becoming more and more urgent. As a result, Underwater Acoustic Communications (UAC) technology has become the worldwide studying hotspot. The research on the Underwater Acoustic Networks (UAN) is of great practical significance. At present, the study of UAN focuses on the network topology structure, routing protocol and MAC protocol.

As opposed to the terrestrial wireless communications which use the radio wave, UAC shows some unique characteristics such as the long time delay and high bit error rate (BER). Because of this, the traditional Media Access Control (MAC) protocol which is designed for Wireless Sensor Networks (WSN) cannot be directly applied to UAN. So it brings new challenges and difficulties to the design of the MAC protocol for UAN. Due to the existing of long propagation time delay, communication nodes could not determine the state in which other nodes stay in, and thus cause uncertainties of the judgment of the state transition conditions. Besides, with the high BER in the Underwater Acoustic (UWA) channel, more exigent request is made to the successful rate when nodes communicate once with each other. Hence, for the purpose of further improving the performance of MAC protocol for UAN, this paper lays emphasis on the study of Multiple Access with Collision Avoidance (MACA) which is more commonly used in WSN. Based on MACA and combining the characteristics of UWA channel, firstly, we analyze and point out the drawbacks of the original MACA which is discussed in some related references. Next we propose the method for the improved design of MACA and then establish the modified MACA which is better applied to UAN. Finally, with the help of the communication network simulation tool—OPNET, we carry on the simulation experiment on the improved MACA and eventually reach the conclusion of this paper.

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## II. ORIGINAL MACA AND EXISTING ISSUES

### *A. Original MACA Overview*

The MACA protocol was first introduced by Phil Karn and its purpose was for relieving such problems as "hidden terminal" and "exposed terminal" residing in Carrier Sense Multiple Access (CSMA). Paper [1] points out the basic thought of MACA. So as to obtain the right use of the channel, MACA adopts the interactive mechanism of Request-To-Send/Clear-To-Send (RTS/CTS) handshake control signal.

### *B. Existing Issues*

Based on the analysis of [1, 2, 3, 4], some important issues are still existing in the former study as follows:

*1) The first weak point:* The purpose of MACA is to solve the problems of "hidden terminal" and "exposed terminal". When MACA adopts the RTS-CTS handshake, the problem appears as that collisions may also occur among control packets like RTS or CTS. However, there is no solution as to the problem with regard to the related literatures.

*2) The second weak point:* When two nodes want to communicates with each other, they should first set up a successful RTS-CTS handshake. As to the BEB algorithm, the node retransmits RTS and doubles the backoff counter after every collision while it reduces the backoff to the minimum backoff counter after every successful RTS-CTS exchange. So the node that successfully receives the CTS packet after sending the RTS, has a minimal backoff time and then increases the probability of its next accessing to the channel. However, it shows that BEB algorithm is favorable to the nodes that establish the successful RTS-CTS handshake. Therefore, BEB algorithm brings about such problems as the phenomenon of "starvation" or "unfairness"[5, 6]. Besides, if the number of the RTS retransmission times is not took into consideration, with the disadvantages of BEB discussed above, the nodes would consume much more energy for endlessly retransmitting RTS and also increase the average end-to-end time delay after unsuccessfully receiving the expected CTS packet.

*3) The third weak point:* Consider the scenario of single hop underwater networks we study, according to the previous study, when the destination nodes staying in WFDATA state overhears any xCTS (The CTS is intended for other nodes), it shall transit to QUIET state for a silent duration. But this may make the destination node could not accept the expected data packet prior to other nodes. Consequently, it increases the packet loss rate as well as the average end-to-end time delay.

In view of the issues above, this paper improves MACA mainly from several aspects as section III presents and discusses.

## III. PROPOSED MACA

### A. Improvement Strategies

In order to enhance the performance of MACA, we propose the following three strategies to modify MACA.

*1) The first strategy:* Considering the situation when two or more source nodes have data packets to send at the same time, these nodes shall first send the RTS packet to their destination nodes for floor acquisition. It is then that will make the occurrence of the collision among the RTS packets. Thus we provide a good idea and method to avoid the RTS collisions. When these nodes have data packets to send simultaneously, we can greatly decrease the chance of RTS collisions by making the nodes send RTS in accordance with certain time intervals. And in the simulation it is realized by setting the timer to the multiples of $\tau_{\max} + T_{RTS}$, where $\tau_{\max}$ is the maximum propagation delay and $T_{RTS}$ is the transmission delay of RTS. As can be see clearly in Fig. 1, when node A and B have data packets to send simultaneously, we design the protocol by making node A and B separately select a random different starting time to send RTS. In this scenario, node A randomly chooses "2" as its starting time of sending the RTS packet while node B chooses "3" at random as its starting time of sending RTS. The time interval of sending RTS between node A and node B is $\tau_{\max} + T_{RTS}$. Although every node defers the transmission time of RTS, the chance of RTS collisions is able to be diminished significantly and the number of the RTS retransmission times is also reduced. Thus through this method, performances of MACA as packet loss rate can be improved to some extent. In addition, as the retransmission times of RTS decreases, the protocol could then save some energy which may be consumed for resending RTS in the original MACA without the strategy that avoids collisions among RTS packets. Therefore the performance of energy consumption can be improved in the meantime.

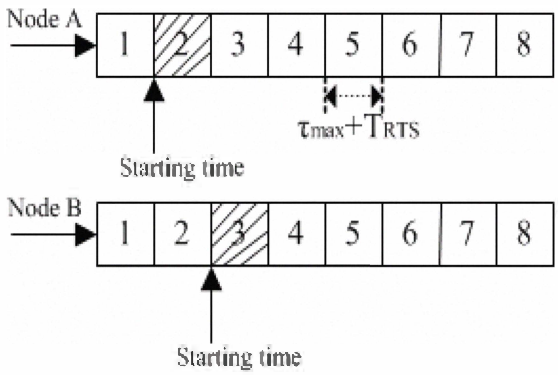


Figure 1. The circumstance under which node A and node B want to send data packets simultaneously

*2) The second strategy:* Our second strategy is designed to ensure the fair access between nodes and then further improve performances of MACA. As the second weak point presented before, this paper makes use of the competition failing times of communication nodes in the network. When a source node transmits an RTS, it transits to the WFCTS state for returning the expected CTS packet, and sets the timer to $2\tau_{\max} + T_{RTS} + T_{CTS}$, where $T_{CTS}$ is the transmission delay of CTS. On the one hand, when the timer expired, the source node increases the retransmission times and resends the RTS packet. Meanwhile it doubles the backoff counter according to the BEB algorithm. If the retransmission times exceeds the preset threshold, we consider sending RTS unsuccessful and then the source node should transit to the IDLE state. On the other hand, when the source node receives CTS which the destination node responds, it recovers the minimum backoff counter and starts to send the data packet. Accordingly, through this strategy that reasonably control the RTS retransmission times by presetting a threshold, we can relieve the problems caused by the BEB algorithm and then reduce the energy for retransmitting RTS and also the time delay.

*3) The third strategy:* The last strategy is that we simply change the state transition rules of MACA in the situation of the single hop underwater networks referring to the modification of the state transition mechanism for the multi-hop networks as [4] shows. When a destination node accepts the RTS, it sends the CTS to the source node, and changes its state to the WFDATA state for awaiting the expected data packet and simultaneously sets the timer to $2\tau_{\max} + T_{CTS} + T_{DATA}$, where $T_{DATA}$ is the duration of the data packet. During the waiting period, if the destination node overhears xCTS, it should remain in the WFDATA state rather than enters to the QUIET-CTS state and continue waiting for the expected data packet. As can be seen in Fig. 2, the source node A transmits RTS to the destination node B. After receiving the RTS node B responds CTS to node A and transits to the WFDATA state. Later node D corresponds with node C. When Node C accepts the RTS sended by node D, it transmits CTS to node D. On the other hand, node B could also overhear the xCTS (The CTS is transmitted to node D by node C). Moreover, it is the same to node C that it could overhear the xCTS (The CTS is transmitted to node A by node B). If we were to follow strictly with the state transition rules shown in the former study, node B (or node C) should enter to the QUIET-CTS state upon overhearing xCTS. Hence both the node B and node C waste a good chance of successfully receiving the anticipate data packet since a successful RTS-CTS handshake has been already established. Therefore, when we propose such an improvement to the state transition as the strategy discussed here, the data packet received successfully of nodes can be increased and then the network throughput can be ensured. Furthermore, compared to the situation in which the node transits to the QUIET-CTS state when overhearing xCTS, this strategy can also shorten the average end-to-end time delay of the data packet.

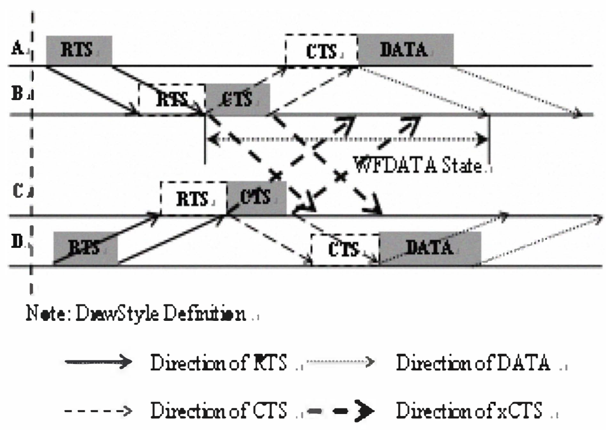


Figure 2. Node B (C) keeps WFDATA state when overhearing xCTS (The CTS is transmitted to node D (A) by node C (B))

## B. State Definition

Based on the strategies above, we specifically design our proposed MACA with six independent states which are described in detail as follows:

IDLE: A node stays in the state when it has no data packets to send or receive.

CONTEND: The state of competition among nodes in the given network. A node enters this state when it has data packets to send in the IDLE state.

WFCTS: The state of waiting for the expected CTS packet. A node transits to this state when it transmits RTS in the CONTEND state.

WFDATA: The state of waiting for the expected data packet. A node transits to this state when it transmits CTS in the IDLE state or CONTEND state.

QUIET-RTS: The state of keeping a silent duration equal to $\tau_{\max} + T_{CTS}$ to which the timer is set. A node enters this state when it overhears xRTS (The RTS is intended for another node) in any state except the WFCTS state and WFDATA state.

QUIET-CTS: The state of keeping a silent duration equal to $\tau_{\max} + T_{DATA}$ to which the timer is set. A node transits to this state when it overhears xCTS in any state except the WFDATA state.

# IV. Simulations And Results

## A. Simulation Scenario

In the simulation experiment, we choose OPNET as our network simulation tool. The network model we set is a distributed single hop network topology with a range of 1km×1km. There are 8 nodes randomly distributed in the network and any two nodes could directly communicate with each other. The maximum distance between nodes in the network is 0.884 km. As the acoustic propagation speed is 1.5 km/s, obviously, the maximum propagation delay of the control or data packet is equivalent to about 0.6 s. Meanwhile in the node model, we make the generation of the source data packets follows the Poisson distribution. The size of RTS, CTS, data packet and the data transmission rate in the simulation are separately assumed to be 20 bits, 20 bits, 1024 bits and 1000 bps. Therefore the transmission delay of the RTS, CTS and data packet can be calculated to be 0.02 s, 0.02 s and 1.024 s.

## B. Simulation Results

Through the simulation four aspects of performances as throughput, packet loss rate, average time delay and energy consumption are finally obtained. After then we compare the performances against the original MACA in the former study, especially the MACA in [1, 2, 3]. For contrast and analysis, as is shown in the simulation results (Fig. 3, Fig. 4, Fig. 5, Fig. 6), we separately define the MACA presented in [1, 2] and [3] as Org-MACA (Original MACA) and LPD-MACA (MACA in the large propagation delay situation). Also we name our recommended MACA the AUAC-MACA (Advanced MACA for underwater acoustic communication).

Besides in the simulation curves, the abscissa is the channel traffic that means the amount of the data packet information to send per unit time (unit: bits/s) while the ordinate is our interesting performance.

Firstly, we study the performance of throughput with the changing traffic, where the throughput is the successful receiving amount of the data packet information per unit time (unit: bits/s). We can see from Fig. 3 that when the traffic is small, with the traffic increasing, the amount of the data packets sent in the network increases as well as the number of successfully receiving data packets of nodes. So the throughput of all of the three MACA protocols increases. But when the traffic is heavy, on the one hand, as the traffic increases constantly, collisions become more and more intensely. Thus it decreases the number of successfully receiving the data packets. As to Org-MACA, the throughput increases first and then decreases; on the other hand, owing to the modification to the state transition of LPD-MACA and AUAC-MACA, the collision probability is reduced. Even though the amount of the successful receiving the data packets diminishes, the extent of diminution is much less than Org-MACA. Thereby, the throughput of LPD-MACA and AUAC-MACA increases with the traffic increment. Besides, although the throughput of LPD-MACA is slightly superior to that of AUAC-MACA in the condition of low traffic, the performance gap in throughput between AUAC-MACA and LPD-MACA is getting smaller and smaller with the growth of the traffic in the event of a high traffic.

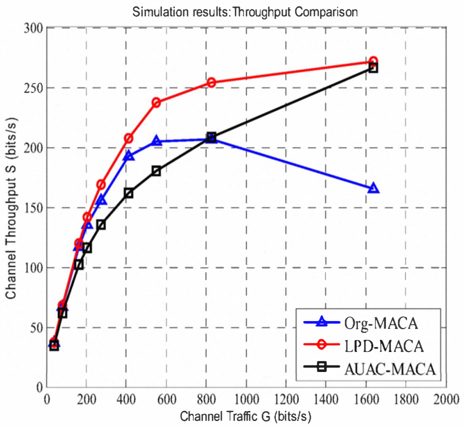


Figure 3. The change curve of throughput with the changing traffic

Secondly, we evaluate the performance of the packet loss rate which refers to the ratio of the number of the lost data packets to that of the sended data packets. As can be seen in Fig. 4, as the traffic grows, collisions among the control packets become violent, diminishing the number of the data packets which are successfully received. Consequently, the packet loss rate of three types of MACA presented and discussed above keeps growing. However, it is important to note that due to the improvement strategies, as to our proposed MACA, the extent of collisions relieves and the amount of the successfully receiving data packets is relatively much more than Org-MACA or LPD-MACA. Thus, the number of the lost data packets is reduced and this is why Fig. 4 shows that AUAC-MACA can be capable of achieving a preferable performance in packet loss rate with the traffic growth especially in the situation of high traffic.

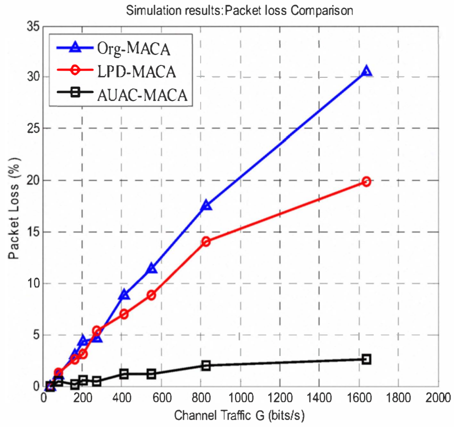


Figure 4. The change curve of the packet loss rate with the changing traffic

Next, we observe the performance of the average end-to-end time delay which means the time delay when a node per successfully receives a data packet (unit: s/packets). As Fig. 5 illustrates, we can know that the average end-to-end time delay of Org-MACA, LPD-MACA and AUAC-MACA all increases in the wake of the rapid growth of traffic. It is because that when the traffic is low, there are more and more sending data packets in the network as traffic grows, and thus the amount of the receiving data packets is gradually increased. Eventually the average time delay increases as well. Furthermore, when the traffic is large and as it increases persistently, collisions among the data packets are so intense that lead to the retransmission of the control packet. As a result, the average time delay is also increased. But obviously, the time delay of AUAC-MACA at the same traffic, as opposed to Org-MACA or LPD-MACA, is lower for the reason that the modification strategies in AUAC-MACA play an important part.

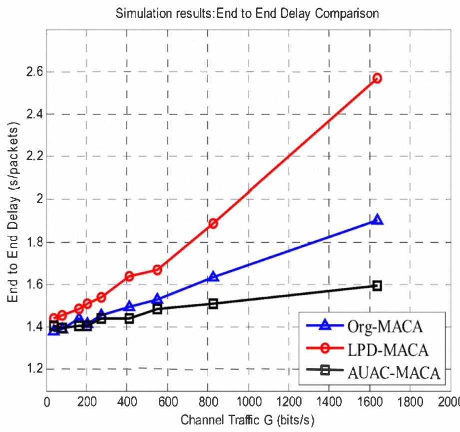


Figure 5. The change curve of the average end-to-end time delay with the changing traffic

Finally, the last performance we are interested in is the average energy consumption which refers to the consumed energy for per successfully sending and receiving a data packet (unit: J/packets). Fig. 6 indicates that similar to the performance of time delay, with the traffic constantly growing, the energy consumed as to the three different MACA protocols is increased for transmitting the control packet and data packet when traffic is small while it is augmented for the transmission of the control packet, data packet and also an extra retransmission of the control packet under the circumstance of high traffic. However, as the improved strategies in AUAC-MACA work effectively, the probability of collisions and retransmission times is greatly reduced as the traffic grows. Thereby, our proposed AUAC-MACA could then save so much more energy that it gets a better performance of energy consumption than that of Org-MACA or LPD-MACA as Fig. 6 clearly shows.

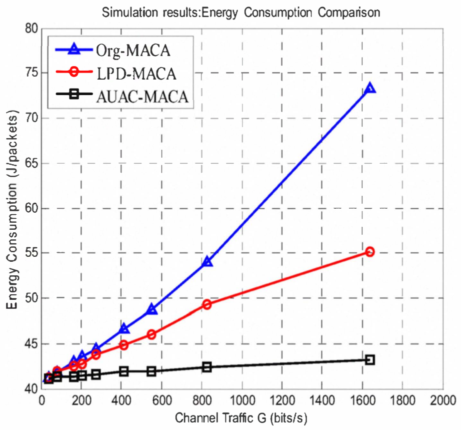


Figure 6. The change curve of the average energy consumption with the changing traffic

## V. Conclusion

Combining with characteristics of Underwater Acoustic (UWA) channel, this paper focuses on the upgrading design and the study of MACA on the basis of the previous research work and then puts forward the improved MACA—AUAC-MACA which is preferably applied to the Underwater Acoustic Networks (UAN). The simulation results suggest that compared to the original MACA mentioned in some papers, although the performance in throughput of AUAC-MACA is slightly inferior to LPD-MACA when the traffic is relatively low, the performance gap in throughput is narrowed gradually between AUAC-MACA and LPD-MACA with the increase of the traffic. Besides, when the traffic increases to a certain extent, the performance of the throughput of AUAC-MACA is nearly the same as the throughput of LPD-MACA. Moreover, when compared to Org-MACA or LPD-MACA, AUAC-MACA can obtain excellent performances in the packet loss rate, average end-to-end time delay and energy consumption such as the great reduction of packet loss rate, obvious diminution of average time delay and dramatic decrease of the energy consumed for per sending and receiving a data packet. Thus, our proposed AUAC-MACA has great significance in ensuring the communication reliability of the underwater acoustic communications system, prolonging the survival cycle of UAN, expanding the applications of UAN and so on. Therefore, it is a desirable and suitable substitute for UAN and also it provides great reference values for the design of the MAC protocol for UAN.

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