Acta Technica 62 (2017), No. 6B, 421–432

MAC protocol based on centralized time division multiple access in medium and small local area networks

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Abstract. The wireless network communication on land is achieved by wireless channel. The wireless communication has little propagation delay and relatively higher bandwidth. However, the underwater network adopts underwater acoustic channel, which makes MAC protocol design meet many challenges due to its low bandwidth and high propagation delay. When the wireless network is used under water, MACA protocol is changed to mitigate hidden terminal problem, improve channel utilization and make the whole communication network has higher throughput rate. The following aspects are changed: 1. When the node simultaneously communicates with several neighbor nodes, it shall comply with priority principle; 2. HRN algorithm is adopted in data transmission; 3. The channel switch adopts half-contention algorithm when the channels are divided into control channel and data channel. The simulation result shows the improved protocol has better performance than MACA protocol.

Key words. Acoustic sensor network, Multichannel, HRN algorithm, Priority mechanism, MACA protocol, Half-contention.

1. Introduction

With the development of network communication technology, the wireless communication technology is widely used. As an important part of wireless communication technology, the wireless sensor network (WSN) is also widely used [1, 2]. Most of earth surface is covered by sea water and the ocean has rich resources to be developed and explored by human beings. However, the exploration to marine environment cannot be executed only by human beings. Moreover, the environmental problems have become increasingly serious in recent years. The marine environment problems become increasingly important in environmental problems.

At this time, the acoustic sensor network appears. However, the wireless communication under water and on land has great differences. Therefore, there are

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many aspects requiring paying much more attention for the design of underwater communication MAC protocol. Firstly, the communication environment is different. The land communication adopts wireless channel. As the electromagnetic wave propagation speed is relatively faster in air, the land has little obstacles and has predictability; the propagation delay is relatively smaller. However, the low bandwidth and higher propagation delay of underwater acoustic channel will affect communication performance. Moreover, the underwater environment factors, such as water temperature, water velocity and fish shoal etc., have impacts on data transmission. Thus the network throughput capacity, error rate and propagation delay are also influenced, which makes the MAC protocol design meet great challenges [3–5].

This paper mainly researches MACA protocol based on wireless sensor network, firstly introduces existing typical MAC protocols, such as ALOHA protocol, CSMA protocol, MACA protocol, and then analyzes and compares with these MAC protocols. To make the WSN-based MAC protocols better apply in acoustic network, this paper changes the following aspects for MACA in accordance with the characteristics of acoustic channel-low bandwidth and high propagation delay: 1. The node can simultaneously communicate with several neighbor nodes and the priority principle shall be adopted when conflicts occur in control packet; 2. Highest Response-ratio Next (HRN) algorithm is adopted in data transmission; 3. The channel switch adopts half-contention algorithm when the channels are divided into control channel and data channel. The simulation result shows the improved MACA protocol PE-MACA (performance-efficient MACA) has better performance.

2. Correlation analysis

The media access control (MAC) protocol design is one of the key technologies of wireless acoustic sensor network. MAC protocol design will have direct impacts on network throughput rate, successful data transmission rate and end-to-end delay etc. The selection of a suitable MAC protocol will have great impacts on system efficiency, especially the acoustic channel with low bandwidth and higher delay [6, 7]. In this part, we introduce several MAC protocols, such as ALOHA protocol, CSMA protocol, MACA protocol and MACAW protocol improved based on MACA. The PE-MACA protocol is also improved based on MACA protocol.

ALOHA protocol is the earliest random access MAC protocol, which adopts DATA-ACK mechanism. As shown in Fig. 1, in ALOHA protocol, when the sensor node has data to be transmitted, the data transmission will be directly conducted and no channel monitoring is required. When the node requires data transmission, if other nodes are transmitting data, the channel contention may occur at this time, thus the impacts and conflicts will appear and then the channel utilization and system throughput rate will be influenced. Therefore, the system throughput rate is not very high [8–10].

CSMA protocol can effectively mitigate the conflicts. As shown in Fig. 2, DATA-ACK mechanism is still used but the carrier sense should be conducted for channel before data transmission. If the channel free signal is monitored, the data transmission can be conducted. If the data transmission is conducted in channel through

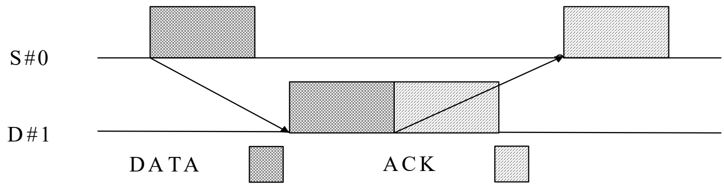

Fig. 1. ALOHA protocol transmission mechanism

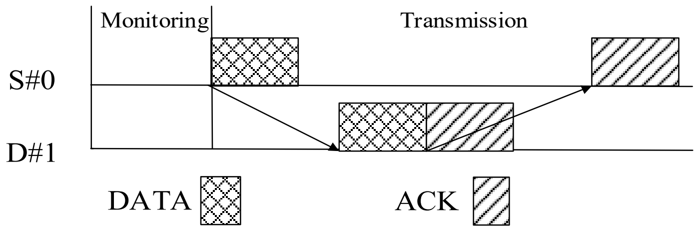

Fig. 2. CSMA protocol transmission mechanism

monitoring, then it is advisable to wait for a time to avoid data conflicts. CSMA can mitigate the conflicts to some extent. However, the hidden terminal and exposed terminal problems exist in CSMA, which greatly decreases the successful data transmission rate and throughput rate [11–13].

MACA protocol is proposed to resolve above problems. As shown in Fig. 3, MACA protocol adopts RTS-CTS-DATA mechanism. MACA protocol resolves conflict problems through handshaking mechanism. Such protocol also resolves hidden terminal and exposed terminal problems to some extent. However, but handshaking will spend some time, namely, increasing network delay. But the heavy network load will have positive impacts on retransmission times [14].

MACAW (MACA-Wireless) protocol has improved MACA protocol. As shown in Fig. 4, MACAW protocol increases ACK response mechanism on original MACA protocol, namely, RTS-CTS-DATA-ACK is adopted to avoid conflicts. When the data is successfully received by the receiver, an ACK will be sent to the receiver to confirm that the data is successfully received. The increased ACK acknowledgement frames can increase the throughput rate of the whole communication networks under relatively higher error rate of channel communication. But the network delay is also increased at the same time [15].

3. PE-MACA protocol

3.1. Protocol mechanism

As shown in Fig. 5, PE-MAMA mainly changes the following aspects to MACA protocol: 1. The node can simultaneously communicate with several neighbor nodes and the priority principle shall be adopted when conflicts occur in control packet; 2. HRN algorithm is adopted in data transmission; 3. The channel switch adopts

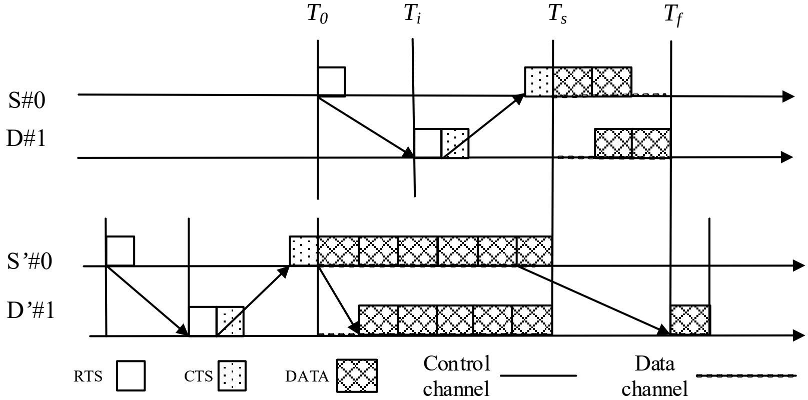

Fig. 3. MACA Protocol Transmission Mechanism

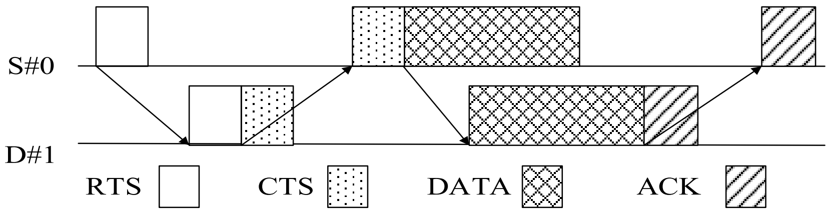

Fig. 4. MACAW protocol transmission mechanism

half-contention algorithm when the channels are divided into control channel and data channel.

PE-MACA protocol still adopts RTS-CTS-DATA handshaking mechanism. Assuming that the time of the whole system is synchronous, each node has its priority. To improve channel utilization rate and system throughput rate, we still adopt multichannel mechanism [16-18].

Firstly, the source node broadcasts RTS packet through control channel. RTS includes destination node ID, number of data packets received by destination node, timestamp and priority list of all requests. The destination node will record the time after receiving RTS packet broadcast by source node, calculate propagation delay based on timestamp in RTS packet and arrival time of RTS and send CTS response packet to source node through control channel. If RTS simultaneously arrives at receiving nodes, the conflicts may occur at this time if CTS packet is sent at this time [19]. Therefore, PE-MACA protocol decides which node should firstly send CTS response packet in accordance with priority principle. According to the request priority, the node with higher priority should firstly send CTS response packet. If the node priority is same, the priority should be determined based on HRN algorithm. The greater the R value is, the higher the priority is. Such priority can successfully avoid conflicts.

The control channel is switched to data channel after the source node receives CTS packet of the farthest destination node. In addition, the DATA transmission is conducted based on HRN algorithm. The control channel is occupied before channel switch while data channel can be used to data transmission between other nodes. The data channel is occupied after channel switch while control channel is released and can be used to RTS/CTS control packet transmission between other nodes. After DATA transmission, the data channel is released and can be used to DATA transmission between other nodes.

However, the switched channel may be occupied in channel switch. For example, when transmission is switched from control channel to data channel and the data channel is conducting DATA transmission between other nodes, the channel contention may occur at this time. For such circumstance, PE-MACA protocol adopts priority+FCFS half-contention algorithm. The channel can be occupied for transmission with higher priority. When the priority is same, the channel cannot be occupied and transmission should be made in accordance with FCFS principle.

The DATA transmission should be conducted after channel switch. But the same source nodes may have multiple groups of DATA to be transmitted. PE-MACA protocol selects DATA packet based on HRN algorithm. The data with greater R value should be firstly transmitted.

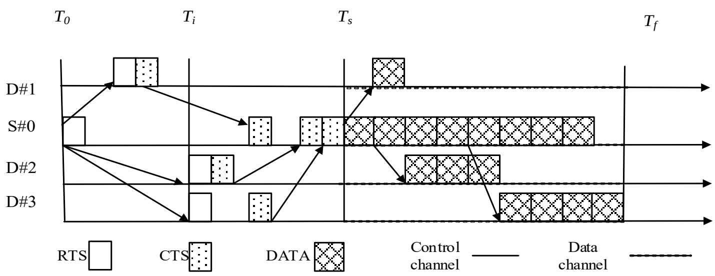

Fig. 5. PE-MACA protocol mechanism

3.2. Time calculation

$D_{\max}$ is the maximum propagation delay, i.e. time consumed when RTS control packet is transmitted from source node to the furthest destination node.

$$D_{\max} = \underset{i=1}{\overset{n}{MAX}}\{T_i - T_0\}\,. \tag{1}$$

Where, T_i is time when RTS packet arrives at destination node D#i; T_0 is timestamp, i.e. time when source node transmits RTS packet; n is number of destination node. T_s is time when the last CTS control packet arrives at source node S#0 and the time when source node starts to transmit DATA and channel switching time, then

$$T_s = \frac{L_{CTS}}{V_{Ctl}} * (N_C - 1) + D_{\max} + T_i + L_{RTS} + L_{CTS}\,. \tag{2}$$

Where, T_i is time when RTS packet arrives at destination node; L_{RTS} is length of RTS control packet; L_{CTS} is length of CTS control packet; V_{Ctl} is bandwidth of control channel; N_C is number of destination node of CTS packet with possible conflict at source node; $D_{\max}$ is the maximum propagation delay. T_f is the time when all DATA is transmitted and the time when source node releases data channel, then

$$T_f = L_{Data} * \sum_{i=1}^{n} N_i + D_{\max} + T_s\,. \tag{3}$$

Where, T_s is time when source node starts to transmit DATA; L_{Data} is length of DATA packet; N_i is number of data packet transmitted to destination node i; $D_{\max}$ is the maximum propagation delay.

3.3. Instance analysis

As shown in Fig.5, destination node D#2 and destination node D#3 receive RTS control packet transmitted by source node S#0 simultaneously, and then if destination node D#2 and destination node D#3 transmit CTS response packet promptly, then conflict will appear when CTS response packet arrives at source node S#0. To avoid unnecessary conflict, priority algorithm is adopted in PE-MACA, which makes destination node D#2 and destination node D#3 transmit CTS response packet at different time. If priority of destination node D#2 and destination node D#3 is different in priority list, then the node with relatively high priority transmits CTS control packet firstly. Priority of destination node D#2 and destination node D#3 is the same here, so R value of node shall be calculated through HRN algorithm, and the node with greater R value has higher priority, transmitting CTS packet firstly. In Fig.5, R value of D#2 is relatively great, so D#2 shall transmit firstly. Computational formula of R value is as shown in (4).

$$R = 1 + \frac{T_{wait}}{T_{delay}}\,. \tag{4}$$

Where, T_{wait} is CTS transmission waiting time; T_{delay} is transmission delay between nodes. In HRN method, the longer the waiting time is, the higher the priority will be, and infinite wait will not be applicable, which improves throughput capacity of the entire system.

After source node receives CTS packet transmitted by the furthest destination node D#3 at T_s, control channel shall be switched to data channel according to half-contention algorithm of priority +FCFS. As shown in Fig.6, when S#0 requests for DATA transmission, S'#0 is transmitting DATA, occupying data channel, but priority of S#0 is greater than that of S'#0, so S#0 can race to occupy the channel.

After channel is switched, DATA can be transmitted then. If source node S#0 has many groups of DATA to be transmitted, PE-MACA protocol can transmit DATA selectively according to HRN algorithm. The one with higher response ratio R shall transmit firstly and computational formula of response ratio is as shown in (4).

$$R = 1 + \frac{T_{wait}}{T_{data}}\,. \tag{5}$$

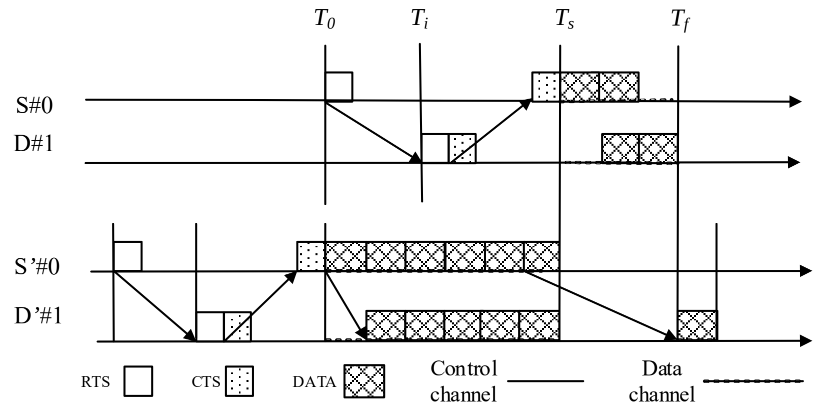

Fig. 6. PE-MACA protocol mechanism

Where, T_{wait} is DATA transmission waiting time; T_{data} is time required for DATA transmission. HRN method is beneficial to data with relatively short length, and the longer the waiting time is, the higher the priority will be, and infinite wait will not be applicable to relatively long data, which improves throughput capacity of the entire system.

As shown in Fig.6, after all DATA transmission of source node S#0 is finished at T_f, data channel will be released automatically. If other node with relatively high priority that needs to transmit DATA does not exist, then S'#0 node continues to transmit DATA.

4. Simulation result and analysis

To analyze performance of PE-MACA protocol, simulation of ALOHA, CSMA, MACA and PE-MACA is performed. These protocols are compared and analyzed in three aspects, i.e. throughput rate, successful data transmission rate and delay. Simulation results of protocols are as shown in Fig.7, Fig.8 and Fig.9.

4.1. Throughput rate

Fig.7 compares throughput rate of each protocol, and seen from Fig.7, PE-MACA protocol has the highest throughput rate and relatively high and steady throughput rate can be kept under high load. When load is comparatively small, throughput rate of each protocol increases with increase of load because of comparatively small conflict. When load is smaller than 0.05, throughput rate of ALOHA protocol is higher than that of CSMA protocol. When load increases continuously, throughput rate of AHOHA protocol will decrease gradually because of existence of hidden terminal problem. When load is comparatively great, throughput rate of CSMA protocol is better than that of ALOHA because of existence of carrier sense mechanism. Although conflict of real-time protocol MACA can be avoided, its channel

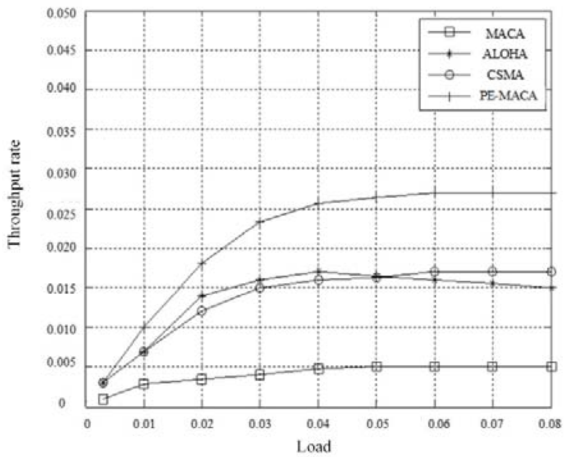

Fig. 7. Throughput rate of different protocols

utilization is not high, and with increase of relative propagation delay, performance of throughput rate will be low.

4.2. Successful transmission rate

In Fig.8, PE-MACA is compared with ALOHA and CSMA having relatively high throughput rate. With increase of load, successful data transmission rate of ALOHA, CSMA and PE-MACA protocols decreases continuously. When load increases to 0.04, successful data transmission rate of CSMA and ALOHA protocols decreases while that of PE-MACA protocol is kept steady gradually. Successful data transmission rate of ALOHA protocol and CSMA protocol is low because handshaking mechanism is not used. Before data transmission of CSMA protocol, carrier sense is performed, so successful data transmission rate is comparatively high. Conflict avoidance mechanism, such as handshaking mechanism, priority and HRN etc., is used in PE-MACA protocol to avoid conflict, and therefore packet conflict of PE-MACA protocol is lowered, which makes packet loss in data transmission process less. In a word, PE-MACA protocol has relatively high successful data transmission rate.

4.3. Delay

In Fig.9, delay of PE-MACA and ALOHA protocols is compared with that of MACA protocol. When load is lower than 0.06, delay of PE-MACA protocol is greater than that of MACA and ALOHA protocols obviously. When load is greater than 0.075, delay of MACA protocol and HP-ALOHA protocol increases rapidly, but delay of PE-MACA is superior to that of MACA obviously. When carrier sense mechanism and handshaking mechanism are not used in ALOHA protocol, the delay will be the smallest, but its throughput rate and successful data rate are not good.

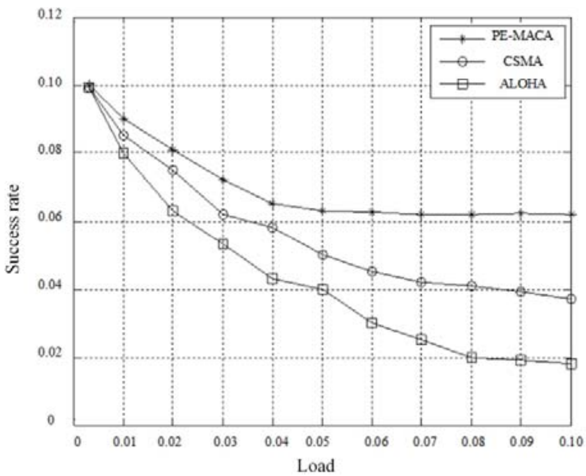

Fig. 8. Successful data transmission rate of different protocols

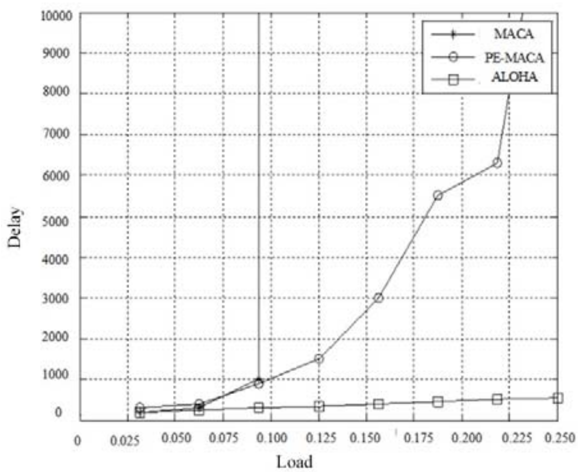

Fig. 9. Data transmission delay of different protocols

In a word, delay of PE-MACA protocol is comparatively small.

4.4. Overall performance analysis

Seen from above simulation results, in terms of throughput rate, PE-MACA protocol has the highest throughput rate and steady throughput rate can still be kept under high load. In terms of successful data transmission rate, PE-MACA is compared with ALOHA and CSMA having relatively high throughput rate. Conflict avoidance mechanism, such as handshaking mechanism, priority and HRN etc., is used in PE-MACA protocol to avoid conflict, and therefore its successful data transmission rate is the highest, i.e. less packet loss. In terms of delay, although carrier sense mechanism and handshaking mechanism are not used in ALOHA protocol with the smallest delay, its throughput rate and successful data rate are not good. Under high load, delay of PE-MACA protocol is smaller than that of MACA protocol. Through above analysis, PE-MACA protocol is a kind of performance-efficient MACA protocol.

5. Conclusion

Three-way handshaking mechanism is still used in PE-MACA protocol proposed in this paper. Node can be communicated with several neighbour nodes simultaneously. In RTS/CTS transmission, conflict can be avoided effectively according to priority principle to improve successful data transmission rate. HRN method is used in data transmission, which is beneficial to data with relatively short length, and the longer the waiting time is, the higher the priority will be, and infinite wait will not be applicable to relatively long data, which improves throughput capacity of the entire system. Half-contention algorithm is used in channel switch, which improves channel utilization greatly. In addition, delay of PE-MACA protocol is comparatively small, and PE-MACA protocol is a kind of performance-efficient MACA protocol.

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Received May 7, 2017