Adaptive Block ACK for Large Delay of Space-Terrestrial Integrated Network

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Abstract. Aiming at the large delay characteristics of space-terrestrial integrated network, an efficient MAC protocol based on TDMA adaptive block ACK is proposed in this paper. Among them, the adaptive block ACK can effectively reduce the delay of the space-terrestrial integrated network by reducing the probability of retransmitting, at the same time, it can reduce the overhead of the MAC layer and help to achieve high throughput of the Space-Terrestrial integrated network. The simulation results with different access strategies show that the proposed efficient MAC access protocol has great advantages over the traditional ACK and block ACK access methods in system delay and network throughput, and has certain guiding significance for Space-Terrestrial integrated network.

Keywords: Space-Terrestrial integrated network · Adaptive · Block ACK · MAC protocol

1 Introduction

With the rapid development of rocket launching technology, satellite platform technology and payload technology, satellite-centric or integrated satellite space-terrestrial network [1] has attracted worldwide attention. Satellite constellations based on space-based information sharing can provide a variety of services covering the world. For example, the Space-Terrestrial integrated network can not only provide network access services for ground base stations in remote areas, but also provide low-latency and high-reliability satellite network connection services for customers such as automobiles, airplanes, maritime transport, and land transportation in remote areas. In addition, it can meet the needs of Regional Disasters and temporary communications, and achieve real-time seamless access, monitoring, transmission and sharing of the status information of the Internet of Things worldwide [7]. Moreover, the space-terrestrial integrated satellite network can also meet the network requirements of scientific investigation, exploration and other activities in extreme and harsh environments.

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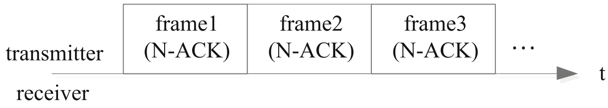

Fig. 1. N-ACK mechanism.

Terminals of space-terrestrial integrated network are widely distributed in the areas of sky, land, sea and so on. For GEO satellites in geosynchronous orbit, the one-way propagation delay between satellites and ground is more than 100 ms. Even LEO satellites in low orbit have several milliseconds of total propagation delay. Compared with the ground communication network, the inherent long propagation delay is a huge technical problem faced by satellite network [2]. Nowadays, the technology of ground network access [3–5] cannot solve the problem of large delay of space-terrestrial integrated network transmission. Therefore, the integration of space and earth network should adopt a new and efficient MAC access strategy.

In order to avoid the long delay caused by retransmit, improving the efficiency of random access channel is a key issue in the MAC strategy of space-terrestrial integrated network. An adaptive block ACK MAC access protocol based on TDMA is presented in this paper. It is proposed to overcome the problem of retransmit caused by inherent propagation delay of satellite communication by considering the use of adaptive block ACK, so as to solve the problem of large link delay in the space-terrestrial integrated network access.

2 Existing ACK Strategy

In terrestrial wireless communication systems, confirmation and retransmit mechanisms are commonly used to improve the reliability of the system, which is implemented through the MAC layer. There are three ACK mechanisms in the ground network. They are N-ACK mechanism, I-ACK mechanism and B-ACK mechanism respectively.

N-ACK means that the sender does not need to confirm that the receiver has received the data, but directly transmits the data. As shown in Fig. 1, this method has low latency and ensures high throughput, which is suitable for good communication link quality. It is often used in streaming media, etc. of course, because broadcast and multicast data cannot be confirmed, only N-ACK mechanism can be adopted.

I-ACK means that each received frame needs to immediately send a response frame (ACK frame) to the sender. The sender will continue to send the next frame only after receiving the correct response frame sent by the receiver. Otherwise, the previous frame will be retransmitted, as shown in Fig. 2. I-ACK mechanism can ensure the correctness of data service reception, but its delay is large and throughput is low. It is suitable for high reliability services.

The operation of B-ACK was introduced in IEEE 802.11e, which was further enhanced in IEEE 802.11n and applied with frame aggregation mechanism [6]. It

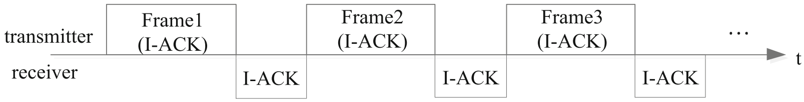

Fig. 2. I-ACK mechanism.

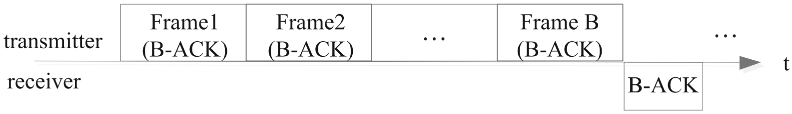

Fig. 3. B-ACK mechanism.

is a mechanism between N-ACK and I-ACK. This mechanism allows the sender to receive a confirmation frame to get which frames are received correctly and which frames need to be retransmitted after sending a certain frame. The specific process is as follows: the sending device first sends a B-ACK request frame, and if the receiving device can support the B-ACK mechanism, it will indicate the maximum frame size and the maximum number of frames that its cache can receive in the response frame. The first frame in this sequence needs to refer to the ACK domain as B-ACK, and the last frame needs to assign the ACK domain to the B-ACK request. In this way, when the receiving device receives the last frame, it will send a B-ACK frame, indicating which frames were received correctly and which ones were not received correctly. According to the instructions of B-ACK frame, the sender retransmits the frame that the receiver has not received correctly. As shown in Fig. 3, block validation mechanism improves reliability while maintaining high throughput.

3 Proposed Adaptive B-ACK Strategy

Because of the long distance and long propagation delay of satellite-earth link in Space-Terrestrial integrated satellite access network, B-ACK is considered to reduce the system delay. Considering the large link delay of Space-Terrestrial integrated network, the free space propagation is large, which leads to the high bit error rate of the system, i.e. "link unreliable problem", which may cause ACK loss, as shown in Fig. 4, so a large number of frames will be retransmitted. Because of the large propagation delay, the retransmit will further increase the system delay. Therefore, the current B-ACK cannot be directly applied to Space-Terrestrial integrated space-based access network system.

In order to reduce end-to-end delay, an adaptive B-ACK low-delay MAC access method based on TDMA is proposed in this paper. When the terrestrial integration network terminal (STA) needs to access the satellite (AP) uplink, the sender STA adaptively adjusts the length of Data B in the next block according to the received B-ACK. The steps of the adaptive B-ACK algorithm proposed in this paper are as follows:

1. Initialization: B-ACK, the number of data in the block B = 1, that is, each packet sent by STA, AP replies to an ACK.
2. During the time-out retransmit, STA receives the ACK that the data is sent successfully t times in succession, and the number of data in the block doubles, that is, B = 2B. In STA, there is one packet failure in successive t times, it means that the Block data is considered to fail. At this time, the number of Data in the Block is halved, that is, B = B/2.
3. When the channel state is poor, the minimum of B is Bmin, which keeps one ACK per Bmin packet; when the channel state is good, the maximum of B is Bmax, which keeps one ACK per Bmax packet.
4. STA needs to retransmit the wrong packet when it does not receive the ACK or the wrong ACK during the timeout of the retransmit.

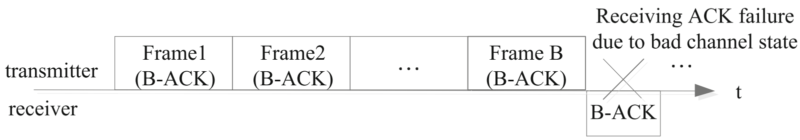

Fig. 4. Receiving ACK failure due to bad channel state.

The MAC access mode based on adaptive B-ACK strategy can overcome the loss of ACK caused by channel state difference, effectively reduce the probability of data frame retransmit, and thus improve the delay performance of data packet transmission. For each B packet, only one ACK is replied. This adaptive B-ACK strategy can also reduce the overhead of the MAC layer and help to achieve high throughput of the Space-Terrestrial integrated network. In order to achieve simplicity, TDMA access mode is adopted. For each slot, the data of different access nodes may be transmitted. The function of uplink low-latency multiple access is implemented simply and efficiently. It is very suitable for the application scenario of long time delay in Space-Terrestrial integrated network.

4 Simulation and Performance Analysis

4.1 Space-Terrestrial Integration Access Network Simulation Scenario

Space-based access network [6] refers to the terminal equipment of ships, vehicles, people, aircraft and UAV waiting for access to space-based satellite network in the sea, land, air and space domains. Unlike the ground network, the node-to-satellite transmission in the space-based access network is greater, and the delay from each node to the satellite is diversity. End-to-end two-way communication can be achieved through satellite access network for terminal nodes in space-terrestrial integrated network. This kind of service is widely used in various application scenarios and is the most important typical service type. As shown in Fig. 5.

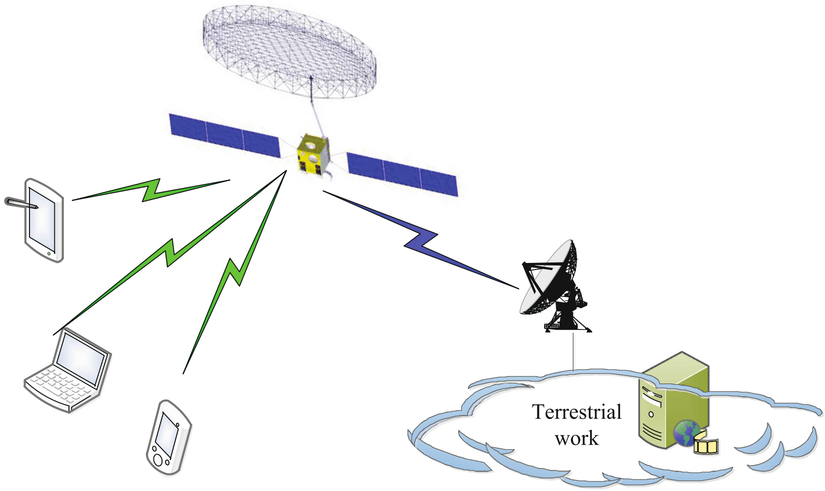

Fig. 5. Sketch of satellite access service.

The link characteristic of satellite access network is that the propagation time is prolonged and the delay deviation between the access nodes is large. Because of the large space span of satellite network, the link length between satellite and ground is much longer than the link length of ground network, which will bring significant propagation delay. And for different user terminals, due to the wide types of terminals, including land, sea, air and sky users, the transmission delay deviation from terminal to access node satellite will be very large.

The mobile access service of satellite communication means that the terminal nodes can directly communicate with the satellite through the satellite communication device under any state, including the mobile state and the stationary state, and realize the two-way communication service through the satellite communication system. In order to meet the access requirements in the mobile state, mobile communication satellites are usually used to provide services for mobile access services. Using satellite systems to provide mobile access services to end users, a scenario where there is no terrestrial network coverage, such as in areas such as countryside, desert islands, deserts, oceans, adjacent spaces, etc. and the civil servants have certain service target users; the other scenario is to support the high-speed mobile state of the end users, such as high-speed targets in subsonic or supersonic motion states, which are mainly targeted at military applications in the current state.

Assuming that the algorithm runs on the TDMA protocol and does not consider the synchronization problem, the algorithm only schedules the adaptive B-ACK strategy when the space-terrestrial integration network terminal STA needs to access the satellite AP uplink. The related parameters of the Space-Terrestrial integrated network are set as shown in Table 1.

Table 1. Simulation parameters of adaptive B-ACK MAC protocol

Items	Design requirement
Satellite altitude	1200 km
Data propagation time	4 ms
Overtime retransmit timing	10 ms
Service rate	500–5000 Packets/s
Packet size	100 Bytes
Dynamic adjustment threshold	3

In the simulation, the channel environment is directly simulated by the success rate of the packet (success rate refers to a single packet, not the whole block packet). The change of the success rate of the packet is used to simulate the change of the channel environment. The success rate varies from 10% to 100% with time, once per second. When the end of time is 0, that is, 0.0–1.0, the success rate is 100%; when the end of time is 1, that is, 1.0–2.0, the success rate is 90%; when the end of time is 2, that is, 2.0–3.0, the success rate is 80%, and so on.

4.2 Simulation Results and Analysis

The adaptive B-ACK algorithm proposed in this paper is used to simulate the throughput and average delay of data packets, and compared with the traditional I-ACK and B-ACK.

In this paper, Block ACK simulates three situations:

The first is I-ACK mode. Send a Data back to an ACK. ($B = 1$)

The second is B-ACK mode. Send multiple data back to an ACK. ($B > 1$)

The third is adaptive B-ACK. That is to say, according to the current transmission status, adjust the number of Data in the Block. (B Dynamic Adjustment)

The adaptive B-ACK dynamic adjustment method is as follows:

If Block data succeeds three times, the number of Data in Block doubles (B doubles). If Block data fails three times in a row, the number of Data in Block will be halved (B halved). In the simulation configuration, it is considered that there is a packet failure in Block data block, that is, Block data failure. The minimum and maximum of B is 1 and 128 individually.

(1) System throughput [8]

The purpose of MAC protocol is to maximize throughput under the condition of minimal access delay. Throughput is the transmission rate per unit time. It is defined as follows: assuming that the frame length is fixed L bits and the number of frames successfully transmitted within a unit time (s) is n, the throughput is nL (b/s). If the transmission rate of the channel is $R(b/s)$, then the normalized throughput $S = nL/R$. Define the transmission time of each frame on the channel as $T = L/R$, then S can be expressed as nT.

Throughput results are divided into two types: data volume per unit time (MB/s), data packet number per unit time (Packets/s). The simulation results are shown in Figs. 6 and 7 respectively.

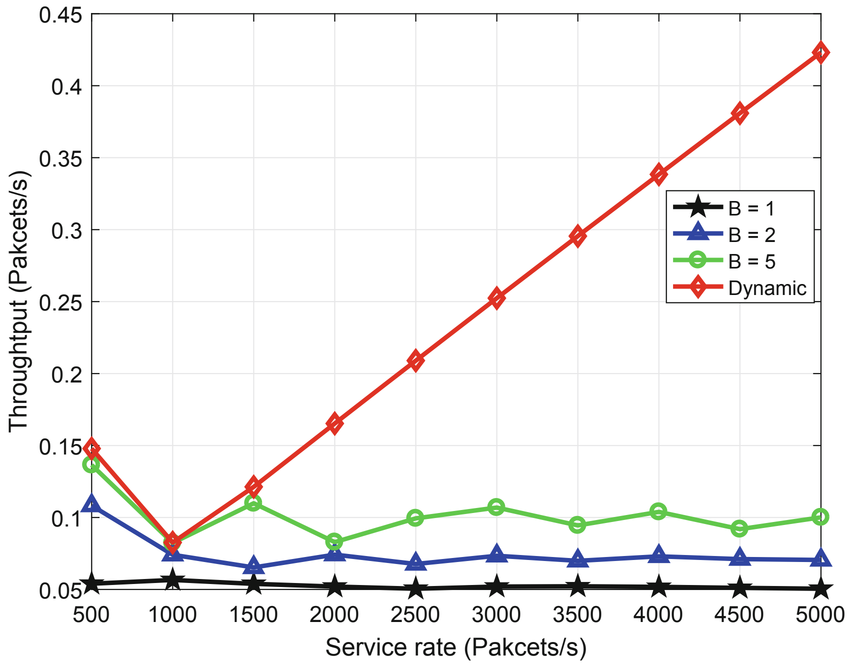

Fig. 6. Average throughput 1 for different ACK

From the above results, the two are basically the same, but the units of statistics are different, according to the size of the data packet, the two can be converted to each other. The average throughput of adaptive B-ACK is the highest, the average throughput of I-ACK mode is the worst, and the performance of B-ACK mode is in the middle. The performance of N = 5 is better than that of N = 2. At the service rate of the simulation configuration, the adaptive B-ACK mode has not reached the saturation state, and other modes have reached the saturation state.

The throughput decreases at 1000 Packets/s: it is related to the channel change of simulation configuration. At 500, the simulation time is 2.69802 s, and 500 packets can be sent successfully. At this time, the success rate of a single packet is 90%–70%, which is acceptable; at 1000, the simulation time is

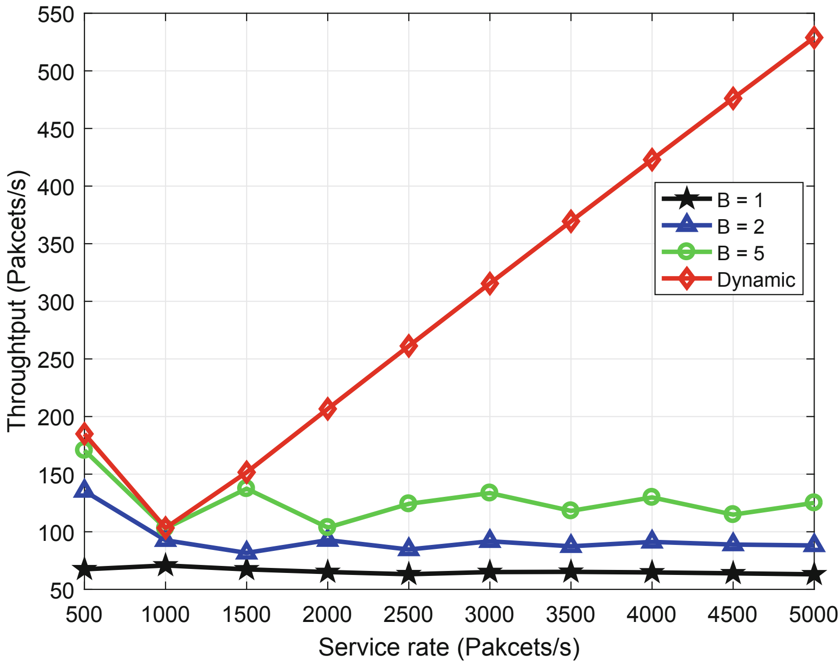

Fig. 7. Average throughput 2 for different ACK

9.14704 s, and the transmission efficiency of the last 500 packets is very low when the success rate is low, so when the backlog reaches 10 s and the success rate is 100%. Only in this way can a large number of data packets be successfully sent out.

(2) Average delay of packet [8] Delay is defined as: data packets are generated from the source, buffered by the MAC layer, processed by transmitters and receivers, and propagation delay. Because the propagation delay of Space-Terrestrial integrated network is much longer than other delays, other delays are ignored in the algorithm, which can be recorded as:

$$T_{delay} = 2T_{transmission} \tag{1}$$

Then the average delay of data packet is defined as the ratio of the total delay value of the successfully received data packet to the total number of data packets. The formula is as follows:

$$T_{average-delay} = \sum_{i=1}^{n} T^{i}_{delay}/n \tag{2}$$

The average delay from packet generation to successful reception simulated in this paper is shown in Fig. 8.

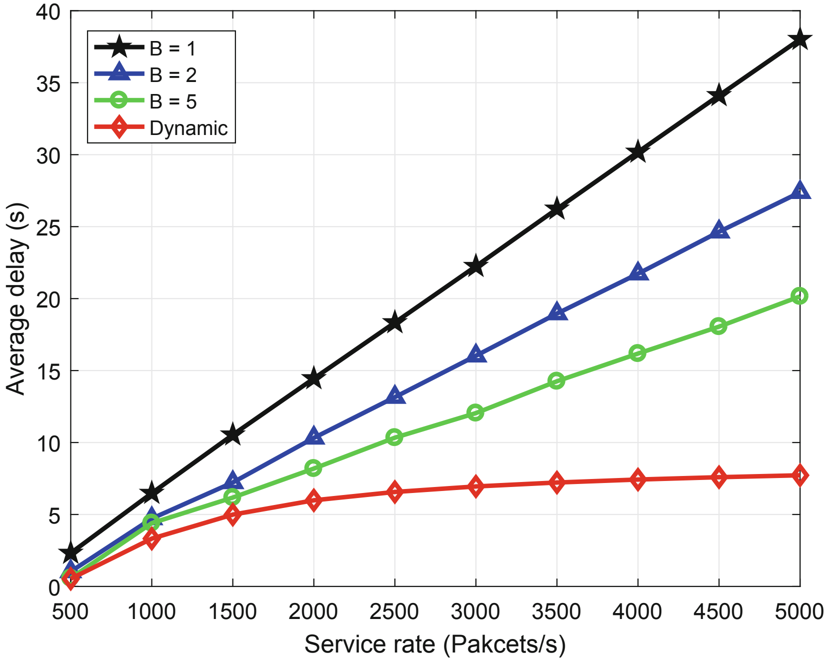

Fig. 8. Average delay of packet

In terms of time delay, the adaptive Block ACK mode has the smallest time delay, the I-ACK mode has the largest time delay, and the fixed B-ACK mode has the middle time delay. The time delay in the case of B = 5 is smaller than that in the case of B = 2. Generally speaking, the results of average delay and average throughput show that the adaptive Block ACK mode has the best performance.

5 Conclusion

In order to achieve low delay transmission in Space-Terrestrial integrated network, an adaptive B-ACK MAC protocol is proposed based on TDMA. The adaptive B-ACK not only improves the transmission delay, but also reduces the overhead of MAC layer, which is helpful to achieve high throughput of space network. The simulation results of adaptive B-ACK access strategies with different channel characteristics show that this MAC mode has great advantages in network system delay and throughput compared with the access mode without adaptive reservation B-ACK, which has certain guiding significance for the integration of heaven and earth.

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References

1. Yao, H., Wang, L., Wang, X., Lu, Z., Liu, Y.: The space-terrestrial integrated network: an overview. IEEE Commun. Mag. **56**(9), 178–185 (2018)
2. Zhang, X., Zhu, L., Li, T., Xia, Y., Zhuang, W.: Multiple-user transmission in space information networks: architecture and key techniques. IEEE Wirel. Commun. **26**(2), 17–23 (2019)
3. Kim, Y., Kim, G., Lim, H.: Cloud-based Wi-Fi network using immediate ACK in uplink data transmissions. IEEE Access **6**, 37045–37054 (2018)
4. Aijaz, A., Kulkarni, P.: Simultaneous transmit and receive operation in next generation IEEE 802.11 WLANs: a MAC protocol design approach. IEEE Wirel. Commun. **24**(6), 128–135 (2017)
5. Jang, H., Kim, E., Lee, J., Lim, J.: Location-based TDMA MAC for reliable aeronautical communications. IEEE Trans. Aerosp. Electron. Syst. **48**(2), 1848–1854 (2012)
6. Karmakar, R., Chattopadhyay, S., Chakraborty, S.: Impact of high throughput enhancements on IEEE 802.11n/ac PHY/MAC transport and application protocols-a survey. IEEE Commun. Surv. Tutor. **19**(4), 2050–2091 (2017)
7. Chien, W., Lai, C., Hossain, M.S., Muhammad, G.: Heterogeneous space and terrestrial integrated networks for IoT: architecture and challenges. IEEE Network **33**(1), 15–21 (2019)
8. Li, P., Fang, Y., Li, J., Huang, X.: Smooth trade-offs between throughput and delay in mobile ad hoc networks. IEEE Trans. Mob. Comput. **11**(3), 427–438 (2012)