Low Latency MCS Design for LEO Satellite Communication Based on 5G

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***Abstract*—With the development of mobile communication, satellite communication technology has met new opportunities. In the future, the joint development of satellite and 5th Generation (5G) is the general trend. However, the characteristics of the low earth orbit (LEO) satellite and the different transmission environment will bring huge challenges to the current 5G technical standards. In this paper, we first carry out link budget for LEO satellite under Non-Terrestrial Network (NTN) channel. Then, we design a 21 level Modulation and Coding Scheme (MCS) combined of modulation mode of Digital Video Broadcasting (DVB) and the encoding mode of 5G. Inspired by the analysis of retransmission times and initial block error rate (BLER), we simulate signal noise ratio (SNR) thresholds under different target BLER and obtain a MCS table with target BLER of 10%, 1% and 0.1%. Subsequently, the retransmission times and throughput of the MCS table are simulated. Simulation results show that the designed MCS tables have better reliability and lower feedback delay, which improves throughput for LEO communication system.**

***Index Terms*—satellite communication, 5G, MCS, feedback delay, throughout**

I. Introduction

Adaptive Modulation and Coding (AMC) is one of the typical link adaptive technologies [1]. In 1968, J. F. Hayes proposed the adaptive transmission technology [2]. It is proved that the system throughput can be effectively improved by appropriately changing the modulation and coding scheme in time-varying fading channels and Nakagami multipath fading channel [3] [4]. The specific method of AMC is to design or adopt Modulation and Coding Schemes (MCS), and dynamically select MCS level which is most suitable for channel transmission according to the real-time channel parameters fed back by the receiver. Therefore, the design of MCS plays an important role in the accuracy and performance of AMC. For the consideration of different goals, the current design of MCS is mainly based on the target BER/BLER criterion and the maximum throughput criterion [5]. These researches have laid a foundation for the application of AMC technology.

With the continuous development of communication technology, AMC technologies are widely applied in wireless communication systems. In Long Term Evolution (LTE) and LTE-Advanced system, AMC technologies are used to match channel characteristics and maximize effective communication rate [6]. Due to the good performance of AMC in bandwidth utilization and throughput performance, 5G communication also uses AMC to match transmission parameters with changing wireless channels [7] [8]. AMC has the advantages of strong anti-multipath fading ability and high spectrum efficiency, but it is sensitive to measurement error and measurement delay. Therefore, the technology and performance of the combination of AMC and Hybrid Automatic Repeat reQuest (HARQ) have attracted great attention. Studies have shown that the performance of the AMC-HARQ system is better than the pure AMC system or the HARQ system with a fixed MCS [9]. The research and application of these technologies greatly improve the efficiency and reliability of the wireless communication system.

The integration of 5th Generation (5G) mobile communication and LEO satellite communication system can form a global communication network with seamless coverage and handover [10]. In the vision of 3GPP, the integration of ground 5G and satellite communication system will have a beneficial impact on 5G service coverage, reliability, user bandwidth, system capacity and many other aspects [11]. In order to make full use of spectrum resources, AMC technology has become a research hotspot of satellite communication system because of its intelligent and dynamic characteristics [12]. In [13], the MCS scheme composed of Turbo code and different modulation modes is used to solve the problem of nonlinear characteristics of satellite channel. Reference [14] studies MCS combining LDPC code with different modulation technologies, which can save the overhead of satellite power and improve throughput at a given code rate. However, these MCS schemes do not consider the long feedback delay between the satellite and the ground user.

In this paper, we design MCS for LEO satellite communication system based on 5G to reduce the retransmission latency. We first analyze the link budget of LEO satellites to calculate the SNR range. Then, by considering different modulation, code rate and SNR range of satellite beam, a 21 level MCS based on 5G standard is designed. Aiming at the problem of feedback delay of LEO satellites, we use a lower target BLER to reduce the number of retransmissions and decrease the communication latency. Finally, simulation results show that the designed high reliability MCS table reduces the transmission feedback delay and improves the throughput.

II. System Model

The LEO satellite channel model is similar to the ground channel model, the signal propagation will also experience

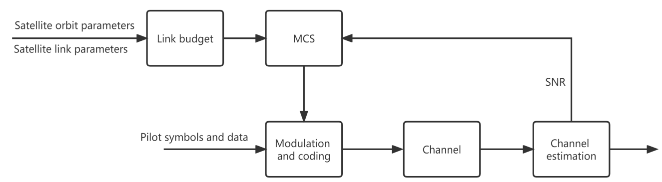

Fig. 1. LEO satellite modulation coding scheme.

large-scale fading and small-scale fading. However, the large-scale fading of LEO satellites includes atmospheric attenuation, ionospheric and tropospheric scintillation. The multipath delay and Doppler frequency offset in small-scale fading are also different from the ground. The channel model used in this system is a NTN channel model based on TR38.811 [15].

After obtaining LEO satellite parameters and orbital altitude, the satellite communication system selects the modulation and coding mode according to the scheme in Fig. 1. Firstly, the SNR variation range of the satellite transit in the target scenario is obtained through the LEO satellite link budget. Then the MCS is designed based on this SNR variation range. LEO satellite system selects appropriate modulation and coding mode to transmitted pilot signal in MCS module according to SNR value obtained from link budget. At the same time, the receiver uses the transmitted pilot signal to perform channel estimation, and dynamically switches the modulation and coding mode according to the equivalent SNR in the satellite beam. The threshold switching of MCS uses the SNR obtained by channel estimation, which has higher throughput than ACK/NACK algorithm. The threshold selection algorithm based on SNR divides the variation range of SNR into M intervals, and adopts the optimal modulation and coding method for each interval. M intervals correspond to $M+1$ switching threshold SNR $\gamma_1, \gamma_2, \ldots, \gamma_{M+1}$. When SNR is in the interval $[\gamma_n, \gamma_{n+1})$, $1 \leq n \leq M$, communication system choose MCS_n. Compared with the fixed modulation and coding scheme, the dynamic selection of modulation and coding modes according to the actual channel state can increase the throughput of LEO satellite communication.

III. Modulation Order and Code Rate in MCS Design

A. Link budget

Before MCS table design, it is necessary to analyze the communication link through link budget. In the link budget process, the total path loss of LEO satellites is defined as:

$$PL = PL_{fs} + PL_{atm} + PL_{\sigma} + PL_{sl} + PL_{ad}, \quad (1)$$

where PL_{fs} is the free space path loss; PL_{atm} represents the atmospheric path loss caused by gas and rain attenuation, which can be calculated according to ITU-R P676; PL_{ad} refers to additional loss; PL_{σ} is shadow loss; PL_{sl} is the flicker loss, its value can be calculated by the program described in ITU-R P.618 [16].

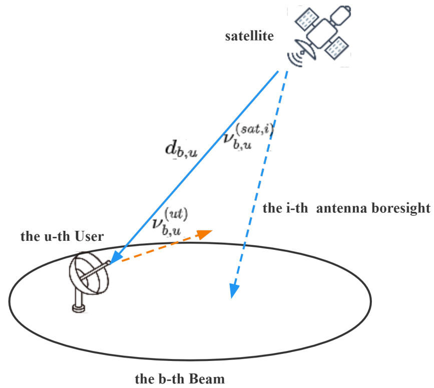

Fig. 2. LEO satellite downlink budget.

Fig. 2 shows the downlink budget of LEO satellite. In Fig.2, $d_{b,u}$ is the tilt range of the u-th user of the b-th beam; $\nu_{b,u}^{(sat,i)}$ represents the included angle between the i-th antenna boresight and the u-th user of the b-th beam; $\nu_{b,u}^{(ut)}$ is the included angle between the antenna pointing of the u-th user of the b-th beam and the satellite. Then, we can calculate the SNR value of the satellite beam coverage interval as:

$$C_{b,u} = EIRP_{b,u}\left(\upsilon_{b,u}^{(sat,i)}\right) + G_r^{(ut)}\left(\upsilon_{b,u}^{(ut)}\right) - PL_{b,u}, \quad (2)$$

where $G_r^{(ut)}\left(\upsilon_{b,u}^{(ut)}\right)$ is the receiving gain between the UE antenna pointing and the satellite direction; $PL_{b,u}$ is the path loss of the u-th user in the b-th beam. $EIRP_{b,u}\left(\upsilon_{b,u}^{(sat,i)}\right)$ is the Equivalent Isotropically Radiated Power of the u-th user in the b-th beam, and the transmitted EIRP can be calculated by the following formula:

$$EIRP_{b,u}\left(\upsilon_{b,u}^{(sat,i)}\right) = EIRP_{\max} + 10\log_{10}\Omega\left(\upsilon_{b,u}^{(sat,i)}\right), \quad (3)$$

where $EIRP_{\max} = \delta_{EIRP} + 10\log_{10}\left(\frac{B}{r}\right)$ is the maximum EIRP, δ_{EIRP} is the density of EIRP, B is total bandwidth, r is bandwidth classification factor. Therefore, the SNR required by the link budget, can be obtained by subtracting the noise power N of the receiver from (2):

$$\mathrm{SNR}[dB] = C_{b,u} - N. \quad (4)$$

B. MCS design criteria

After SNR range within LEO satellite beam coverage is obtained through link budget, we need to determine the modulation type, code rate and SNR interval Δsnr of MCS curves through simulation. There are M combinations in total, and we take the combination of the lowest code rate and the lowest order modulation as the first curve (MCS_1). The specific design criteria are presented in Algorithm 1.

At present, most LEO satellite communication adopts he second-generation satellite broadcasting standard (DVB-S2) and its extension (DVB-S2X) standard. DVB-S2/S2X adopts Quad-Phase Shift Keying (QPSK), 8 Phase Shift Keying

Algorithm 1: MCS design criteria

```
set n = 1;
if n < M and MCS_n is within SNR range then
    if Only one curve within Δsnr to the right of MCS_n then
        Take this curve as MCS_{n+1};
    else if Multiple curves within Δsnr to the right of MCS_n then
        Take the curve with high spectral efficiency as MCS_{n+1};
    else if No curves within Δsnr to the right of MCS_n then
        Select the nearest curve and adjust its bit rate until the distance between the curve and MCS_n is Δsnr ;
        Take this curve as MCS_{n+1};
    end
    n = n + 1
else
    output MCS table;
end
```

TABLE I
COMBINATIONS OF MODULATION MODE AND CODE RATE FOR DIFFERENT MCS LEVELS.

MCS level	Modulation mode	Code rate
1	QPSK	0.2500
2	QPSK	0.3296
3	QPSK	0.3994
4	QPSK	0.5000
5	QPSK	0.5996
6	QPSK	0.6694
7	QPSK	0.7500
8	QPSK	0.8198
9	8PSK	0.5999
10	8PSK	0.6696
11	8PSK	0.7500
12	16APSK	0.6697
13	16APSK	0.7500
14	16APSK	0.7998
15	16APSK	0.8499
16	16APSK	0.8899
17	32APSK	0.7500
18	32APSK	0.8000
19	32APSK	0.8299
20	32APSK	0.8699
21	32APSK	0.8850

(8PSK), 16 Amplitude Phase Shift Keying (16APSK) and 32 Amplitude Phase Shift Keying (32APSK). In our designed MCS, we also selected above modulation mode. On the other hand, same as 5G standard, we choose LDPC code as the channel coding scheme, and the code rate is selected from 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9.

In the SISO system, the signal passes through LDPC encoder, interleaver, scrambler and modulator at the sending end. After passing through the channel, the signal performs OFDM demodulation, descrambling, deinterleaving and decoding at the receiving end. Based on the MCS design criteria, we set the SNR range to -5dB$\sim$ 20dB, and set Δsnr to 0.7dB$\sim$ 1.1dB refer to 5G MCS curve interval. 21 MCS level are obtained by continuously adjusting the modulation mode and LDPC code rate, as shown in Table I. MCS with higher level has higher modulation mode and LDPC code rate. Compared with 32 MCS levels in 5G standard,, the MCS designed in this section has fewer levels of MCS.

IV. SNR threshold design for feedback delay reduction

A. Feedback delay reduction analysis

In this section, we firstly analyze the block error rate (BLER) and throughput of the LEO communication system based on 5G under different retransmission times. In the 5G communication system, retransmission is used for incorrect transmission to ensure the reliability of transmission. Each retransmission can be regarded as an independent event. Define the BLER in the first retransmission as $bler$, the remaining $BLER_r$ after the r-th retransmission is:

$$BLER_r = bler^r. \tag{5}$$

Assuming that the BLER of the first transmission is 10%, then the BLER of the second retransmission is 10%*10%=1%, and the BLER of the third retransmission is 0.1%.

Next we calculate the throughput of the system.Throughput is defined as the number of information bits transmitted per unit time. The throughput ζ without retransmission is:

$$\zeta = \frac{(1 - BLER) \times TB\,\text{size}}{T}. \tag{6}$$

Suppose a total of L group are transmitted. When the HARQ scheme is adopted, after r_{max} transmissions, the number of received blocks is:

$$\text{Block}_r = L \times (1 - BLER) \times \sum_{n=1}^{r_{max}} BLER^{n-1}. \tag{7}$$

Transmission time for all group consumed is:

$$\text{Time } = r \times T. \tag{8}$$

After r_{max} transmission, the throughput of the system is:

$$\begin{aligned}\zeta' =& \frac{Block_r \times TB\text{size}}{\text{Time}} \\ =& \frac{L \times (1 - BLER) \times \sum_{n=1}^{r_{max}} BLER^{n-1} \times TBsize}{r_{\max} \times T}.\end{aligned} \tag{9}$$

From the equation (9), it can be seen that although retransmission can reduce the BLER, the throughput will decrease as the transmission time is enhanced due to the increase of r_{max}.

B. MCS for different target BLER

In order to verify the performance of MCS under different target BLER, SNR-BLER curve of MCS is needed to obtain the MCS table under different target BLER. we use Matlab to

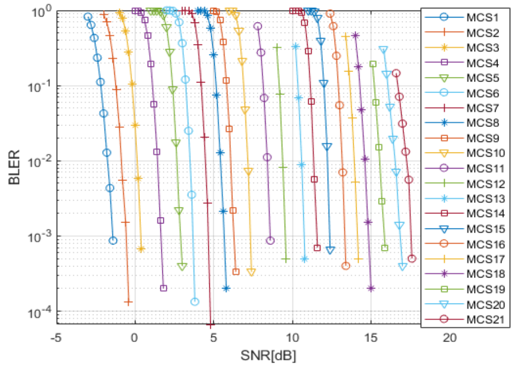

Fig. 3. BLER-SNR curve corresponding to MCS level.

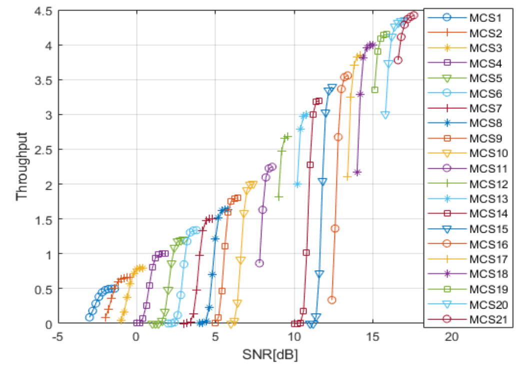

Fig. 4. Throughput curve corresponding to MCS level.

TABLE II
SISO SIMULATION PARAMETERS

Parameters	Value
Altitude of satellite orbit	1200m
Carrier frequency	20GHz
Subcarrier spacing	30KHz
Channel model	NTN-TDL-D
SNR range	-5:20
MCS	MCS1∼MCS21
Modulation schemes	QPSK 8PSK 16APSK 32APSK
Encode/Decode	LDPC/Min-Sum decoding

build the PDSCH link-level simulation platform that meets the 5G standard. The NTN-TDL-D channel of 3GPP standard is used in the simulation platform. Specific simulation parameters are shown in Table II.

Fig. 3 shows the SNR-BLER curve of 21 MCS in NTN-TDL-D channel. We can see that the BLER for the same SNR is higher with higher modulation order and higher code rate. This is because with the increase of modulation order and code rate, each modulation symbol contains more information bits, which puts forward higher requirements for channel quality. If the quality of the channel is good, high-level MCS can be used to obtain higher spectrum efficiency by using higher modulation (e.g. 16APSK, 32APSK) and higher code rate. Similarly, in the case of poor channel conditions, we can choose low-level MCS with low-order modulation schemes such as QPSK to combat transmission errors at the cost of lower spectral efficiency, which is more robust.

According to Fig. 3, the SNR threshold values under different target BLER can be obtained and decrease the feedback delay, we set a lower target BLER to increase the reliability of the first transmission. Therefore, we set the target BLER as 1% and 0.1%. We also set target BLER as 10%, i.e., the same as 5G standard, for comparison. By searching the SNR thresholds corresponding to 21 MCS levels when BLER achieves target value, three MCS switching thresholds with different transmission reliability can be obtained, as shown in Table III.

TABLE III
MCS SWITCHING THRESHOLD UNDER DIFFERENT TARGET BLER

MCS level	SNR@10%BLER	SNR@1%BLER	SNR@0.1%BLER
1	-2.2	-1.78	-1.4
2	-1.18	-0.88	-0.57
3	-0.2	0.17	0.39
4	1.12	1.42	1.61
5	2.39	2.61	2.84
6	3.22	3.48	3.7
7	4.21	4.42	4.66
8	5.18	5.40	5.64
9	5.8	6.08	6.26
10	6.86	7.18	7.38
11	8.17	8.40	8.6
12	9.18	9.40	9.52
13	10.21	10.60	10.76
14	11.18	11.37	11.58
15	12.00	12.17	12.4
16	12.9	13.18	13.34
17	13.64	13.95	14.16
18	14.32	14.6	14.84
19	15.2	15.52	15.89
20	16.1	16.48	16.82
21	16.5	17.22	17.54

V. Simulation Results

In this section, the performance of the proposed MCS tables is evaluated. The maximum number of HARQ retransmission is set to 4. The main performance indicators are HARQ retransmission times and throughput.

Fig. 4 shows the normalized throughput curve of 21 MCS in NTN-TDL-D channel. The normalized throughput ζ_n is defined as:

$$\zeta_n = \eta \times R \times (1 - BLER). \tag{10}$$

where η represents the modulation order and R is the coding rate. We can see that higher level MCS have higher throughput, and lower level MCS have lower throughput. Combined with Fig. 3 and Fig. 4, we find that with the increase of MCS level, BLER and throughput of satellite communication system are both increasing. It can be concluded that higher level MCS brings higher transmission efficiency, but reduces the reliability of satellite communication system.

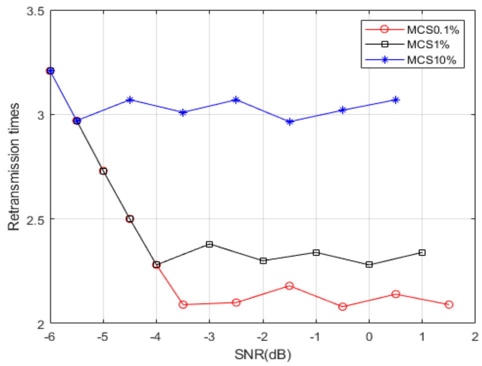

Fig. 5. Retransmission times comparison of three different MCS tables.

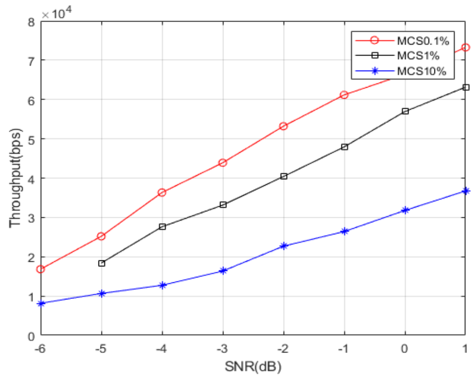

Fig. 6. Throughput comparison of three different MCS tables.

Fig. 5 and Fig. 6 show the average retransmission times and throughput for three MCS tables. we select MCS1∼MCS8 for adaptive modulation coding transmission. MCS0.1%, MCS1% and MCS10% are used for MCS table with target BLER of 0.1%, 1% and 10%, respectively. The overall transmission delay under adaptive transmission is the number of retransmissions multiplied by the single transmission delay of LEO satellite. As can be seen from Fig. 5, the transmission delay is smaller for the MCS table with lower target BLER. The retransmission times of curve MCS0.1% decreases by 30% and 23.3% compared with MCS10% and MCS1%. It can be seen from Fig. 6 that the throughput of LEO satellite communication increases with the improvement of channel quality when the system performs adaptive transmission. The MCS0.1% curve has the maximum throughput, which indicates that MCS with higher reliability can reduce the number of retransmissions and feedback delay of HARQ, which improves the throughput of LEO satellite communication.

VI. CONCLUSIONS

In this paper, we studied the low latency MCS of LEO satellite communication based on 5G. By combining the modulation mode of DVB and the encoding mode of 5G, we designed a 21 level MCS for 5G-based LEO communication. Then, we analyzed the relationship between the number of retransmissions and the initial BLER, and found that MCS with smaller initial BLER has lower feedback delay. Inspired by the analysis, we obtained the MCS table under different target BLER through simulation. Finally, we simulate the retransmission times and throughput of the proposed MCS tables. Simulation results show that the MCS tables with lower target BLER are effective in reducing the number of retransmissions and improving the throughput.

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