Research on Adaptive Transmission Protocol of TT&C of Launch Vehicle Based on TDRSS

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Abstract—The application of TDRSS in TT&C of launch vehicle can improve the coverage and transmission rate of TT&C link. But the transmission protocol based on fixed transmission rate can not ensure the stable TT&C link based on TDRSS. The adaptive transmission protocol proposed in this paper can adjust the transmission rate according to the real-time transmission status during the whole flight. According to the different types of rocket-borne subscriber terminals, the open loop adaptive transmission protocol and closed loop adaptive transmission protocol are designed, which can both keep the stable transmission and improve the transmission efficiency.

1. Introduction

With the development of the technology of launch vehicle, the demand for TT&C coverage rate and telemetry data amount increases greatly. The traditional segmented relay TT&C mode based on earth stations and measurement ships is not enough now. With the construction of Tracking and Data Relay Satellite System(TDRSS) constellation, the technology of TT&C of launch vehicle based on TDRSS is developing rapidly[1]. TT&C of DELTA Launch Vehicles, Atlas Launch Vehicles and Falcon Launch Vehicles are mainly supported by TDRSS[2]. TT&C of Long March series Launch Vehicles based on TianLian TDRS is also applied successfully in launching many times[3]. When the TT&C method of launch vehicle is changing from ground-based to TDRS-based technology, how to ensure the high reliability of TT&C link is becoming a new issue.

Compared with the TT&C link based on ground stations, the link based on TDRSS has the long transmission distance, long time delay and big loss of link[4]. And the high speed movement of launch vehicle brings big doppler frequency shift. During the whole flight of launch vehicle, in order to ensure precision tracking of TDRS to rocket-borne relay subscriber terminal, the terminal antenna needs to keep precision pointing to the antenna of TDRS, which can not be assured when the launch vehicle attitude varies greatly. The factors above will lead to large changes of transmission channels of TT&C link based on TDRSS and the SNR. As a result, the link interruption will occur if the fixed rate is used in TT&C based on TDRSS. Thus the high reliability can not be achieved. The technology of adaptive transmission has be applied widely in wireless communication, in which the adaptive rate transmission is used by changing the transmit power, signal coding method, signal modulation method and symbol transmission rate. It has been proved that the system transmission error rate is reduced by the adaptive rate transmission method[5]. And the high link service efficiency and high reliability are also achieved.

According to the TT&C demands of launch vehicles, an adaptive transmission protocol is designed in this paper, which can estimate the current channel transmission quality through estimation of SNR...
of received signal or the pointing angles of rocket-borne relay subscriber terminal. And the transmission rate can be adjusted according to the estimation result.

2. TT&C method of launch vehicle based on TDRSS

2.1. TT&C demands of launch vehicle using TDRSS

As a fundamental principle, the measurement and control system should try to cover the whole flight of launch vehicle\(^{[6]}\)[\(^{[7]}\)]. But as the new developed launch vehicle series are put into service, the measurement and control equipment of ground stations can not achieve the 100% coverage of the whole flight profile\(^{[8]}\). TDRS is located at geostationary orbit, which has the advantages of flexibility of TT&C supporting and high coverage\(^{[9]}\)[\(^{[10]}\)]. The demands of launch vehicle using TDRSS include:

1. Higher coverage rate

The new developed large launch vehicles such as Long March-5 has the demand of higher coverage rate because of longer flight time and distance than the other launch vehicle series\(^{[11]}\). The new developed small solid launch vehicle and middle liquid launch vehicle such as Long March-6 and Long March-11 has the demands of whole flight coverage, extensive coverage and rapid launching supporting ability because of the variety of launching directions\(^{[12]}\).

2. Higher transmission rate

The data of launch vehicle needs to be transmit includes tele-measurement data and real time image video information of launching. The real time image video information can show the flying status of launch vehicle directly, which can provide better visual effect and quick reaction support\(^{[13]}\). As a result, there are more optical real time image collecting equipment on the new developed launch vehicles, which leads to the increase of data amount needs to be transmit.

3. More reliable TT&C link

At the experiment stage, the new developed launch vehicle may have abnormal attitude during flight. When the attitude is abnormal, it is very important to perform safety telecommand in time and collect telemetry data as much as possible. So the reliable TT&C link is necessary to the emergency disposal caused by the variety of attitude and unstable transmission environment.

2.2. TT&C Scheme for Launch Vehicle based on TDRSS

2.2.1. System Composition

The TT&C Scheme for launch vehicle based on TDRSS is shown in Figure 1. The forward and backward link between the launch vehicle and the TDRS is established by configuring the relay subscriber terminal on the rocket. After launching, the rocket-borne relay subscriber terminal controls its antenna to point to the TDRS according to the real-time attitude position of the rocket platform, so as to keep the forward and backward link transmission normal.

According to the working frequency band of TDRS, the rocket-borne relay terminal can choose S-band terminal or Ka-band terminal, all of which adopt phased array antenna. S-band has narrow bandwidth and limited transmission rate, but the antenna beam width is large and easy to capture and track. Ka-band can support high-rate data transmission, but the antenna beam is narrow and difficult to capture and track. Reference \(^{[6]}\) and \(^{[10]}\) analyze and calculate the equipment composition and transmission link of S-band rocket-borne terminal, while reference \(^{[3]}\) puts forward the design scheme of Ka-band rocket-borne terminal.
2.2.2 TT&C process.

- Before the launch vehicle uses the relay satellite system, the launching control center confirms the work plan and sends the theoretical trajectory and takeoff time of the launch vehicle to the operation management center of TDRS.
- Before the forward/backward data transmission of the launch vehicle, the operation management center of TDRS controls the antenna of TDRS to capture and track the rocket-borne subscriber terminal at a predetermined position, and exchanges the working status information of launch vehicle and TDRS with the launching control center in real time.
- The backward telemetry data of the launch vehicle is sent to the relay satellite, which is then forwarded to the ground terminal station of TDRS, where the operations such as signal decoding and demodulation are completed, and then forwarded to the launching control center through the operation management center of TDRS.
- When necessary, the launching control center sends the forward safety control command to the operation management center of TDRS, which forwards it to the ground terminal station in real time, completes the operations of data encoding and modulation, sends it to TDRS and forwards it to launch vehicle via rocket-borne subscriber terminal.
- During the tracking process, the launching control center and the operation management center of TDRS exchange information such as the attitude and position of launch vehicle in real time. The operation management center of TDRS analyzes the tracking situation of TDRS to launch vehicle in real time according to the actual flight trajectory, and monitors the maintenance of the link between the launch vehicle and relay satellites and the working status of rocket-borne subscriber terminal according to the telemetry data of launch vehicle.
3. Design of Adaptive Data Transmission Protocol

At present, the transmission protocol based on fixed transmission rate is mainly used as the link protocol for TDRSS. In order to improve the reliability of TT&C channel based on TDRSS, this paper designs an adaptive transmission protocol. The basic idea is that, based on the channel status information feeding back by the receiver (or judging by the transmitter independently), the parameters of the transmitter are adaptively adjusted to match the channel, so as to improve the spectrum efficiency and transmission reliability. When the link is unstable, the links are interrupted under the fixed transmission rate protocol. If the adaptive transmission protocol is adopted, the transmission rate can be adjusted by lowering the gear to ensure the link is uninterrupted thus improve link reliability. Considering the asymmetry of the forward and reverse transmission rate of launch vehicles’ TT&C link and the channel exclusivity of TDRSS, the adaptive transmission protocol designed in this paper choose to change the data transmission rate through channel quality estimation, while the modulation and the coding mode are unchanged.

There are two application modes of rocket-borne relay subscriber terminal in TDRSS. One has only reverse telemetry data and the other has both the forward remote control and the reverse telemetry data. For the former, the data transmission rate is determined by the rocket-borne relay subscriber terminal independently. For the later, it is determined by the ground terminal station according to the link monitoring data and the data transmission rate is changed by the remote control command. The adaptive transmission protocols in open loop mode and close loop mode are designed respectively for the two application modes.

3.1. Link budget analysis

Phased-array antenna is generally arranged in reverse transmitter for the rocket-borne relay subscriber terminal, and its EIRP is closely related to the beam scanning Angle: the EIRP is the largest in the normal position, and decreases with the increase of the scanning Angle due to the expansion of the beam. Taking rocket-borne relay subscriber terminal of CZ-3A as an example, the EIRP test value and the scanning Angle are shown in Table 1. Compared with the normal position, the EIRP decreases to more than 7dB when the scanning Angle reaches ±60°.

| Scanning Angle | EIRP(dBW) |
|----------------|-----------|
| (α,β)=(0°,90°) | 33.844    |
| (α,β)=(30°,120°) | 32.025    |
| (α,β)=(60°,120°) | 28.319    |
| (α,β)=(60°,60°) | 26.124    |
| (α,β)=(30°,150°) | 28.839    |
| (α,β)=(60°,150°) | 26.901    |

When the EIRP of rocket-borne relay subscriber terminal is 26dBW, the transmission rate of the reverse link can be up to 1Mbps by link budget. And so on, the transmission rate of the reverse link can be up to 4Mbps when the EIRP can reach the maximum value. If the scanning angle of Phased-array antenna is always small, the EIRP of rocket-borne relay subscriber terminal would be much larger than the boundary condition, which means it can support much higher transmission rates. In reference [14], a simulation calculation is made for the typical trajectory of Long March launch vehicle. The simulation result shows that, in the whole flight, the azimuth angle changed by 25.91°and the phase angle changed by 48.74°, when the East Node TDRS satellite is used. The EIRP has fluctuated between 28dBW to 33dBW, with the highest transmission rate can reach 4Mbps.
3.2. Open loop adaptive transmission protocol

The adaptive transmission protocol in open-loop applies to scenarios where there is no forward link: the rocket-borne relay subscriber terminal interprets the scanning angle of phased-array antenna and EIRP independently, and adjusts the transmission rate automatically according to the real-time status and the pre-agreed policy, in order to maintain the efficient and stable transmission. Specific threshold can be set based on type of rocket-borne relay subscriber terminal and launch trajectory. As for the example in the above section, three transmission rates are set, which are 4Mbps, 2Mbps and 1Mbps, with 32dBW and 29dBW as the switching boundaries, the corresponding working Angle of phased-array antenna is shown in Table 2.

| Gear1 | Gear2 | Gear3 |
|-------|-------|-------|
| 4Mbps | 2Mbps | 1Mbps |
| 0°<α<30° | 90°<β<120° | 0°<α<30° |
| 120°<β<135° | 30°<α<45° | Others |
| 90°<β<120° |

EIRP >32dBW >29dBW >26dBW

3.3. Closed loop adaptive transmission protocol

The closed loop adaptive transmission protocol applies to scenarios where there is forward link. The ground terminal station judges the strength of the signal by the signal-to-noise ratio (Eb/N0) of the reverse signal and controls the transmission rate by sending the remote control command. Which means that if the received signal is strong, the transmission rate is increased to transmit more data, and when the received signal is weak, the transmission rate should be decreased and the content should be simplified in order to transmit only key parameters to save the resources.

When the reverse transmission rate needs to be changed, the rate information is contained in the forward remote control frame transmitted to rocket-borne relay subscriber terminal. The rocket-borne relay subscriber terminal set the transmission rate according to the received data. Taking rocket-borne relay subscriber terminal in this paper as an example, three rates are classified as 4Mbps, 2Mbps and 1Mbps, and the format of the remote control frame is laid out in the figure below.

Figure 2. Format of remote control frame for rate adjustment.

The rocket-borne relay subscriber terminal receives and resolves the remote control frame, and takes the data to adjust the transmission rate. The segment “XX” is used to set transmission rate, which is defined as follows, “00” indicates the reverse data transmission rate is 1Mbps, “01” indicates the data transmission rate is 2Mbps, “02” indicates the data transmission rate is 4Mbps.

In closed loop mode, a steady-state Eb/N0 value should be set, which is related to the demodulation threshold. If LDPC coding is adopted, the demodulation threshold is about 2.5dB, the lower limit of the reverse link Eb/N0 is about 5dB, therefore, the steady-state Eb/N0 value should be set as 8dB, so that there is some certain margin on the system that can ensure the normal operation of the reverse link. Based on this, the initial transmission rate corresponding to the steady-state Eb/N0 can be estimated. Take the rocket-borne relay subscriber terminal above as an example, the initial rate could
be 2Mbps. If the measured $Eb/N0$ is 3dB higher than the stable $Eb/N0$, the rate should be double. If the measured $EB/N0$ is 3dB lower than the stable $Eb/N0$, the rate should be lowered by half so as to guarantee the $Eb/N0$ of state ground terminal is within the stable $Eb/N0\pm3dB$. Closed loop adaptive transmission protocol is shown in Figure3.

4. Conclusion
The TT&C scheme of launch vehicle based on TDRSS is designed in this paper. Aiming at the TT&C transmission demands of launch vehicle and two kinds of rocked-borne relay subscriber terminal, the open loop adaptive transmission protocol and closed loop adaptive transmission protocol are designed. The adaptive transmission protocol can keep the stable transmission of TT&C link based on TDRSS by adjusting the link transmission rate according to the real-time transmission status. So the reliability of the TT&C method of launch vehicle based on TDRSS can be increased remarkably when the transmission environment has considerable variation during the whole flight.

References
[1] Baoguo L, Bin W. (2012) Application of TDRSS in Chinese Space TT&C. Journal of Spacecraft TT&C Technology, 6:1-5.
[2] Ted S, Donald W, Harry S. (2018) NASA Space Network Project Operations Management: Past, Present and Future for the Tracking and Data Relay Satellite Constellation. SpaceOps Conferences. Marseille. pp.1-12.
[3] Yang W, Changhui G, Jingang Z. (2020) Research on Key Technologies of High-speed TT&C based on TDRSS over Vehicle’s Whole Flight. Missiles and Space Vehicles, 5:112-116.
[4] Jiasheng W. (2011) Proposal for Developing China’s Data Relay Satellite system. Spacecraft Engineering, 20:1-8.
[5] Xiulan Y, Siyi W. (2019) Adaptive Information Transmission Scheme for LEO Satellite Based on Ka Band[J].Computer Science,46:72-79.
[6] Jing L, Yulong H. (2012) Space-Telemetry Technology of Launch Vehicle Using Relay Satellite. Computer Measurement & Control,10:2731-2734.
[7] Jinsong Z, Jing L, Xiangwu G. (2009) Telemetry Transmission Technology for Launch Vehicle Based on Relay Satellite System. Missiles and Space Vehicles,6:11-15.
[8] Changhui G,Ying Z, Yimin S. (2019) Link Visibility Analysis in Flight Telemetry Track and Command of Launch Vehicle. Missiles and Space Vehicles,4:124-126.
[9] Gang W, Li F, Weiping He. (2010) The Research on Tracking Control Technology of TDRS Applied to Space Launch. Manned Spaceflight,16:24-29.
[10] Wenping F, Jianxin L. (2017) Research on Space-based Telemetry Data Transmission Technology for Launch Vehicle. Radio Engineering, 8:36-39.
[11] Dong L, Pingqi L. (2021) General Scheme and Key Technology of Long March 5 Launch Vehicle. Journal of Deep Space Exploration, 4:1-9.
[12] Weidong Z, Dongbao W. (2016) New Generation Cryogenic Quick Launching Launch Vehicle and Development. Aerospace Shanghai, 33:1-7.
[13] Hongwei C, Fufeng X. (2019) Research on Differentiating Method of Flight Feature Event of Launch Vehicle Based on Real-time Image Processing,Computer Measurement&Control, 27:129-132,150.
[14] Jing L, Yuepeng S. (2012) Antenna Cover Performance Analysis for Space-based Launch Vehicle TT&C System. Journal of Telemetry,Tracking and Command, 5:51-55.