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Design of Medium and Long Distance Satellite Signal Transmission Scheme Based on Baseband Resource Pool

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Abstract: In order to solve the problems such as the delay and jitter in the transmission of medium and long distance satellite signals, as well as the transmission capacity, switching capacity, number of ports and optical crossover capability caused by multiple high rate channels, a signal transmission scheme based on baseband resource pool was proposed in this paper. Firstly, through OTN device, intelligent switching function is introduced to increase optical crossover capability to reduce the long distance transmission delay. On this basis, the baseband resource pool technology was used to construct large-scale optical cross network, and then realized the dynamic sharing and allocation of baseband processing resources. Experimental results show that the proposed scheme can provide deterministic low time delay, and the clock synchronization accuracy can reach less than 50PPB.

Keywords: Baseband resource pool technology, OTN equipment, Medium and long distance transmission, Satellite signal.

1. Introduction

The ground receiving station undertakes the tasks of land observation satellites and space science satellites, and also receives part of foreign land observation satellite data [1]. Abundant satellite resources have provided basic satellite observation data for various industries and made important contributions to national economic construction, social development and scientific research.

The existing satellite ground receiving processing stations are usually designed as independent stations, in which there is no equipment sharing between stations, and they are in a "chimney" structure. This architecture lacks a unified interface standard, and the receiving and processing performance of similar devices varies greatly, and the devices in a single station are tightly coupled, leading to the solidified performance of the ground station and poor scalability.

With the rapid development of satellite constellation and satellite Internet constellation, the number of satellites will increase dramatically [2]. By the end of 2020, China has released 53 plans to build commercial satellite constellations, with a total of 6,487 satellites. In the future, the construction of earth stations will be in the form of station groups to meet the requirements of simultaneous transit of multiple stars. However, if the independent "chimney" structure is still adopted, the receiving and processing needs of multi-star transit can only be met by increasing the number of ground stations, which will increase the equipment manufacturing cost and manual maintenance cost. Therefore, the ground station group [3] gradually adopts a new type of resource pool architecture design of ground station. With the above architecture, the feeders and back-end processing equipment of the ground station group can be deployed separately. In order to reduce electromagnetic interference, the feeders of ground stations are usually far away from populated and signal intensive areas. A back-end data processing device is usually deployed in a resource-rich central equipment room.

When the satellite data received by the ground receiving station is transmitted over a long distance, the use of optical fiber to realize signal transmission has become a research focus of scholars [4]. The existing transmission schemes usually use analog optical transmitter to modulate the analog signal into optical signal for transmission. After entering the machine room, the optical receiver is converted into electrical signal and output to switching and frequency conversion equipment. For example, Finisar has proposed 100G SR4 CFP modules that comply with various CFP standards to meet the requirements of data transmission at different rates and different link lengths. According to the development demand of high network speed, QSFP28 optical transceiver integrated module emerges at the historic moment, which has significant advantages in volume, port density and power consumption [5]. Meanwhile, in view of different transmission scenarios and transmission distances, QSFP28 optical transceiver module series mainly includes four types: 100G SR4, 100G PSM4, 100G LR4 and 100G CWDM4 [6]. Although the above scheme can solve the problem of signal attenuation in cable transmission and avoid inducting lightning into the central machine room, the optical terminal machine is usually priced in the channel unit, and the equipment cost is high.

The proposed digital optical transmission method breaks this deadlock, that is, down conversion and digital signal acquisition equipment are deployed in the antenna feed base to convert analog electrical signals into digital optical signals, which are transmitted through the digital optical transmission equipment for long-distance access to the central machine room. After that, the core optical switching equipment is used to complete the point-to-point exchange of digital optical signals to realize baseband resource pooling.

Although the above method can reduce the type and size of the receiving device and the introduction of signal noise, and improve the data quality and reliability, there are also problems in the application of digital optical transmission scheme. That is, after the digital ADC (analog-to-digital conversion circuit) is put on the front, the ADC is far away from the signal processing module (more than five kilometers), which will lead to a series of problems such as signal time delay and delay jitter, asynchronous sampling clock and signal processing clock, transmission capacity, exchange capacity, number of ports and optical crossover capacity brought by multiple high rate channels.

Therefore, this paper proposes a satellite signal transmission scheme based on baseband resource pool, which mainly uses baseband resource pool and OTN equipment to build large-scale optical crossover network, provide deterministic delay, reduce the delay of medium and long distance transmission, and greatly improve resource utilization and system flexibility.

2. System Model

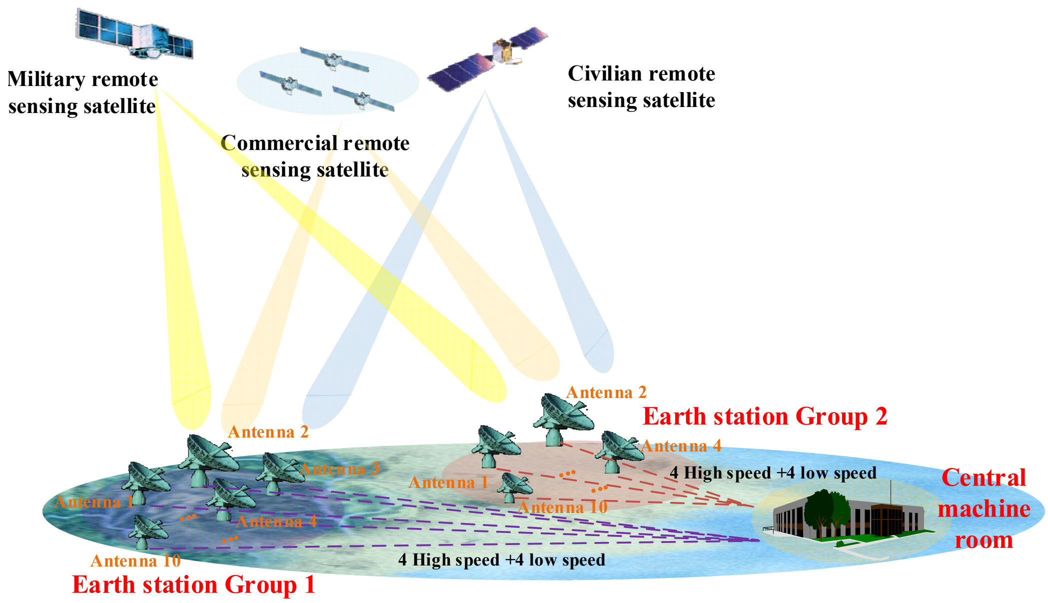

Figure 1. System model

Figure 1 described the system model of multi-source satellite signal transmission, which consists of military remote sensing satellite, civil remote sensing satellite, commercial remote sensing satellite, ground station group (including multiple sets of receiving antennas, multiple A/D converters, multiple OTN access equipment), central machine room (OTN core equipment and signal processing resource pool). The system transmission process is mainly divided into three stages. In the first stage, the antenna tracks and receives the satellite signal. After the downlink RF signal is amplified, exchanged and converted to output the 1.2GHz/70MHz IF signal, the high/low speed digital ADC in the signal acquisition equipment is used to complete the analog/digital conversion and other processing of the signal. In the second stage, the signal is output to the OTN (optical transmission network) access equipment through the optical module, and then 80 signals (10 sets of antennas, 8 channels each) transmit the digital optical signal back to the central machine room through the remote optical transmission channel, and then unified access to the OTN core equipment. The specific process of digital optical transmission is shown in Figure 2. In the third stage, the upper computer management software commands the OTN core device to complete the optical signal exchange output, signals are selected as required into the signal processing resource pool to realize the demodulation, decoding and other processing of 80 signals.

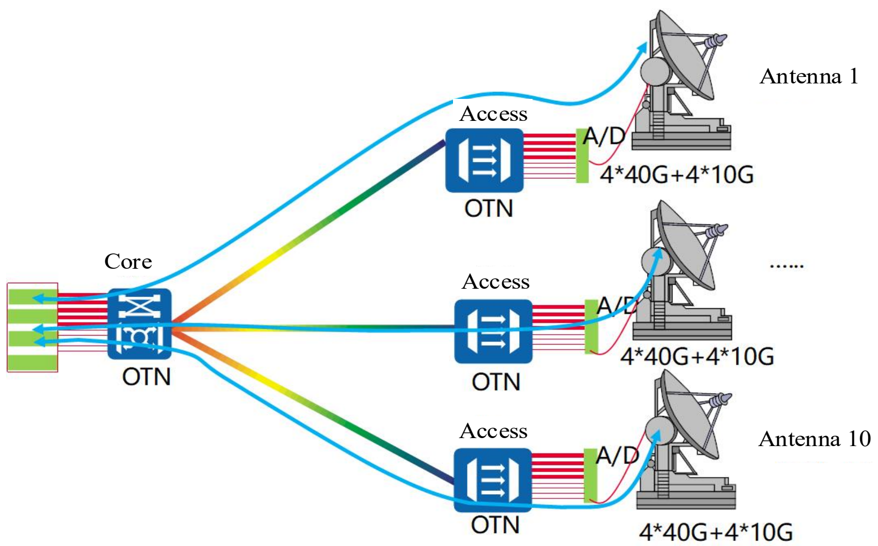

Figure 2. Schematic diagram of digital optical transmission

3. Remote Transmission Scheme Based on Baseband Resource Pool

The multi-set receiving system uses optical fiber to realize the transmission of medium and long distance signals, which will face the problems of high cost of optical terminal equipment, large number of switching equipment in the central machine room and difficulty in wiring. At the same time, multistage switching of signals with different frequencies will introduce more signal noise and reduce the signal-to-noise ratio of the system. To solve the above problems, this paper puts forward the scheme of down-conversion and digital signal acquisition equipment pre-positioning, that is, down-conversion and digital signal acquisition equipment are deployed in the antenna base to convert analog electrical signals into digital optical signals, and then complete long-distance transmission through digital optical transmission equipment. After access to the central machine room, The core optical switching equipment is used to complete the point-to-point exchange of digital optical signals and realize baseband resource pool.

3.1. Satellite signal reception

(1) Ka-band data transmission signal

The four-channel Ka data transmission signals are amplified by Ka-LNA, then converted to X band by Ka/X down-converter and entered into X band RF switching matrix. After conversion to 1.2GHz intermediate frequency through matrix, signals are entered into signal acquisition equipment to complete filtering, AGC control, high-speed sampling and digital quantization.

(2) X-band data transmission signal

The 2-channel X data transmission signals are amplified by X-LNA and directly enter the X-band RF switching matrix. After the matrix is output, they are converted to 1.2GHz IF by X/ 1.2ghz down-converter and enter the signal acquisition equipment to complete filtering, AGC control, high-speed sampling and digital quantization. Since Ka band and X band are used in time sharing, 8 input signals can be selected and output through 8×8 (X band) RF switching matrix, and 4 X/1.2GHz down converters and back-end transmission links are shared.

(3) X band telemetry signal

The 2-channel X telemetry signals are amplified by X-LNA and enter the X-band RF switching matrix. After conversion to 70MHz IF through the matrix, they enter the signal acquisition equipment to complete filtering, AGC control, medium-low speed sampling and digital quantization.

(4) S-band telemetry signal

The 2-channel S-telemetry signal is amplified by S-LNA and entered into the S-band RF switching matrix. After conversion to 70MHz IF through the matrix, the signal acquisition device is completed after filtering, AGC control, medium-low speed sampling and digital quantization.

3.2. Medium and long distance transmission

In this paper, down conversion and digital signal acquisition equipment are adopted to realize the satellite signal transmission in the long distance. At the same time, in order to effectively avoid the jitter caused by signal delay and delay after digital ADC prepositioning, the failure of synchronization between sampling clock and signal processing clock, and the problems of transmission capacity, switching capacity, number of ports and optical crossover capability caused by multiple high rate channels, the OTN access device and OTN core device are added in the antenna base and the central machine room respectively. And all have smart switching features. Therefore, the signal acquisition device converts analog electrical signals into digital optical signals and outputs them to the OTN access device. Then, 80 optical signals (10 x 4 40GE and 10 x 4 10GE) are transmitted to the central equipment room at a distance (more than 5 km) through optical fibers and connected to the OTN core devices in a unified manner. The use of OTN equipment can increase the transmission distance of satellite signals, where single-wave and single-fiber pipeline capacities will exceed 200G and 20T, respectively.

3.3. Data processing

After the satellite signal is connected to the OTN core device, the upper computer management software directs the OTN core device to complete the exchange and output of 80 optical signals through the encapsulation/mapping protocol, that is, 80 optical signals are received at the NE1 end of OTN to form 80 virtual optical signals, and then exchanged by the convergence/core layer. After the exchange, 80 channels of virtual optical signals are output through NE2 terminal of OTN. The switched optical signals are selected as required and then added to the signal processing resource pool. The signal processing resource pool consists of 10 VPX chassis with a total of 80 general signal processing modules. The boards and cards in 10 cases are the same and backup each other to satisfy the processing of 80 signals in the whole station.

As the basic unit of the feed baseband resource pool, each signal processing board can have the function of signal synthesis processing. Therefore, all 80 optical signals of the station can be switched to any signal processing board in the baseband pool for signal demodulation, decoding and other processing. At the same time, in order to improve the utilization rate of board resources, this paper adopts dynamic resource scheduling strategy, which is mainly divided into two modes:

When the signal processing is less than full load, idle board resources can be called for signal synthesis processing. If there are several idle boards, multiple boards can be integrated to complete the processing business together and efficiently utilize board resources.

When the existing processing boards are fully loaded, the baseband pool supports horizontal expansion of hardware resources, increasing the number of physical chassis and boards, and signal synthesis processing can be realized.

4. Application Embodiments

As shown in Figure 3, the application example of this paper is as follows: 10 sets of receiving antennas and channel devices are configured in the medium and long distance satellite data transmission system based on baseband resource pool. The frequency band for data reception is S/X/Ka band, and each set is the same configuration. Therefore, only one set of devices and data transmission process are shown in detail in the figure. And the LNA, down converter, switching matrix, data acquisition equipment and OTN access equipment involved are all deployed in the antenna center body and the base. Therefore, the application example is as follows:

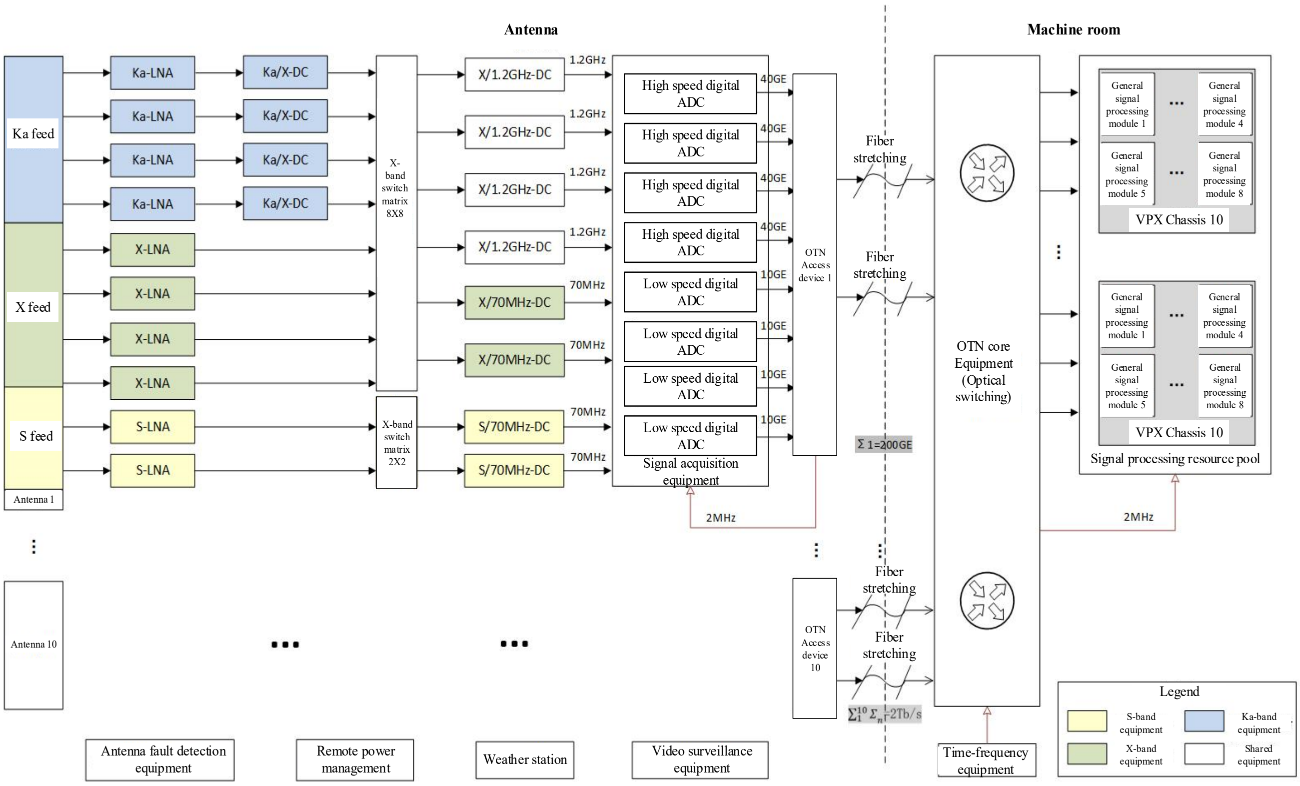

Figure 3. Working principle diagram

Step 1: After the antenna tracks and receives the satellite signal, it first amplifies the downlink radio signal in the corresponding frequency band LNA, as shown below:

(1) Four-channel Ka data transmission signals are amplified by Ka-LNA, then converted to X-band by Ka/X down-converter, and enter X-band RF switching matrix;

(2) Two X-data signals are amplified by X-LNA and directly enter the X-band RF switching matrix;

(3) The 2-channel X telemetry signals are amplified by X-LNA and enter the X-band RF switching matrix;

(4) The two-channel S telemetry signals are amplified by S-LNA and enter the S-band RF switching matrix.

Step 2: After switching, frequency conversion, output 1.2GHz/70MHz IF signal and then enter the signal acquisition device, including the following details:

(1) After the 4-channel Ka data transmission signal passes through the matrix, it is converted to 1.2GHz intermediate frequency and then enters the signal acquisition equipment;

(2) Two X data transmission signals are output from the matrix and converted to 1.2GHz if by X/1.2GHz down converter to enter the signal acquisition equipment;

(3) The 2-channel X telemetry signals enter the signal acquisition device through the matrix after conversion to 70MHz if frequency;

(4) The two-channel S telemetry signals enter the S-band RF switching matrix, and then convert to 70MHz IF frequency after passing through the matrix to enter the signal acquisition device.

Step 3: Use the high-speed/low-speed digital ADC in the signal acquisition equipment to complete the analog/digital conversion and other processing of the signal.

Step 4: Output the digital optical signals to the OTN access device through the optical module, and transmit the digital optical signals back to the central equipment room through four 40GE and four 10GE remote optical transmission channels. The details are as follows:

(1) After completing filtering, AGC control, high-speed sampling and digital quantization, four Ka band data transmission signals and two X band data transmission signals are output to the OTN access device through the 40GE optical module;

(2) After filtering, AGC control, medium-low speed sampling, and digital quantization, two channels of X-band telemetry signals and two channels of S-band telemetry signals are output to the OTN access device through the 10GE optical module.

In particular, after the digital ADC is prepositioned in the present invention, the distance between ADC and signal processing module is far, so the digital optical transmission scheme is adopted, and only one set of access terminal equipment and transmission cable can be used to realize the remote signal access to the central machine room, and it is convenient for the subsequent addition of mobile ground station access processing.

Step 5: After the digital optical signal is transmitted to the central equipment room, the OTN core devices are connected in a unified manner.

A total of 80 signals (8 signals per antenna, namely 4 40GE channels and 4 10GE channels) are transmitted back to the central equipment room and connected to the OTN core devices in a unified manner.

Step 6: The upper computer management software directs the OTN core device to complete the optical signal switching and output, and the signals enter the signal processing resource pool after being selected as required.

To process 80 channels of signals, the baseband processing subsystem is deployed in four cabinets. Cabinets 1, 2, and 3 are composed of three sets of 9U VPX chassis (including panel integrated machines) and one set of network switching devices. Cabinet 4 consists of a 9U VPX chassis (including a panel appliance), a network switching device, a time-frequency generation device, and a time-frequency distribution device.

The baseband resource pool consists of 80 signal processing modules in 10 chassis. The boards in each chassis are the same and backup each other. A baseband pool cabinet consists of multiple identical expandable cabinets, which can be expanded or reduced based on actual requirements.

Step 7:80 signals are demodulated and decoded in the signal processing resource pool.

The feed baseband resource pool based on 9U VPX chassis is the core part of this embodiment. It adopts dynamic resource scheduling policy to pool baseband devices and efficiently and flexibly provide feed link sending and receiving services to users.

The basic unit of baseband resource pool is signal processing board. The optical crossover network is used to realize point-to-point switching of feed-baseband input signals. All 80 signals of the station can be switched to any signal processing board in the baseband pool for signal processing. Since each board can have the function of signal synthesis and processing, the application of antenna array is considered in this paper, which is as follows:

(1) When the number of signals processed is less than 80, idle board resources can be invoked for signal synthesis and processing. In addition, if multiple boards are idle, multiple boards can be integrated to complete processing services together and efficiently utilize board resources.

(2) When the existing processing boards are fully loaded, the baseband pool supports horizontal expansion of hardware resources, increasing the number of physical chassis and boards, and signal synthesis processing can be realized.

5. Conclusion

In this paper, the medium and long distance transmission scheme of multi-source satellite signal is studied. In view of the long distance between digital ADC and signal processing module before and after transmission, OTN device is used to solve the problems of delay, delay jitter and clock synchronization, and baseband resource pool technology is adopted to improve the flexibility and convenience of the system.

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