Research of flexible terminal

Quan Wang¹, *, Xuqiong Chen¹, Qingbo Liu², Liting Wang², Yue Xiong², Li Yuan²

¹Satellite Telecommunication Department, Space Star Technology Co., Ltd, Beijing, China
²Satellite Telecommunication Department, Xi’an Aerors Data Technology Co., Ltd, Xi’an, China
*wangquan0007@126.com

ABSTRACT—In recent years, with the rapid development of high-low Earth Orbit Commercial Satellite Communication Technologies and products, and the increasing demand of aviation, navigation and space trunking communication, satellite Communication has entered the stage of satellite Internet development with hybrid application of GEO Satellite and NGSO Constellation. Based on the characteristics of GEO satellite and NGSO satellite, this paper studies the flexible terminal which can access the GEO and NGSO Constellation, designs and analyzes the key technologies such as low cost phased array antenna and flexible waveform, providing some insights and ideas around the development for the mixed application of the terminal in GEO and NGSO satellites.

1. INTRODUCTION
At present, GEO satellite is still the most mature and popular type of satellite communication, which is widely used in aviation, navigation and trunking communication. However, there are still some limitations in the application of GEO satellites. Firstly, GEO satellites cannot cover the polar regions, making it impossible for achieving seamless coverage of global communication. Secondly, GEO satellites has the characteristics of long propagation distance and high communication delay, therefore cannot meet the low latency requirements of IoT, 5G, etc.. The outstanding performance of the NGSO Constellation in the above aspects can effectively compensate for the problems of GEO Satellites: On the one hand, the NGSO Constellation can orbit around the earth to achieve no dead corner coverage for seamless global communication; on the other hand, thanks to the short transmission distance and low communication delay, the NGSO constellation can effectively meet the communication requirements of low-delay service. However, considering the number of satellites required in NGSO constellation, problems such as long construction cycle, complex networking, and high operation and maintenance cost need to be effectively solved. Both GEO satellite and NGSO constellation have complementary advantages for each other, and their fusion application will be the development trend for future satellite communication. Flexible terminals that can be connected to GEO and NGSO constellation are gradually entering the public view.
2. DEVELOPMENT STATUS AT HOME AND ABROAD

2.1 High-low orbit switching application of US Navy Terminal

According to C4ISRNET November 29, 2019, the U.S. Navy recently conducted field tests on a new type of antenna that can switch between low Earth Orbit and geostationary orbit, whose is perfect for small U.S. Navy ships, meeting the military's critical needs.

The new antenna, made by Intellian, is 1.5 meters long. The antenna enables the United States Navy to switch between the Telesat LEO and GEO satellites while maintaining a broadband connection. Demonstrations have been made to show how the antenna can be switched to the LEO satellite to maintain a persistent broadband connection when the GEO satellite is attacked or deactivated. "Field testing of the Telesat Ka-band satellite using INTELLIAN's 1.5 m KA convertible Very-small-aperture terminal confirms that the antenna is an important innovation in the next-generation space architecture for accessing to space-based satellites," concluded by Kurt Fiscko, technical director of PMW / A 170 at the executive office of the US command, control, communication, computer and intelligence (Poc4i). One of the key elements that the government is seeking for military purpose is how to achieve a more resilient and flexible space network. In this demonstration, Telesat and Intellian focuses on addressing one of the key issues around flexibility requirement, which is the ability to switch between GEO and LEO constellations.

2.2 SES and Thales demonstrate the GEO / MEO Satellite Airborne Terminal Service

In October 2019, SES and Thales successfully demonstrated FlytLIVE's airborne broadband service across the GEO / MEO satellites. A Gulfstream G-III aircraft fitted with Thinkcom KA2517 phased array antenna flew from Florida to the Atlantic coast of Nicaragua, passing through several GEO, MEO satellites and different beams of each satellite, and the FlytLIVE on-board service remained normal throughout the trip. This demonstration was the world's first on-board communication using MEO satellite. Seamless switching between MEO and GEO satellites was achieved. In-flight data download rate exceeded 265Mbps, 4K video online broadcast and other large bandwidth applications test was successfully completed[1].

2.3 Gilat performs GEO / LEO on-board Service Handover Verification

Gilat announced on February 18, 2020 that the first all-electric scanning antenna developed for aerospace had flown through the LEO Communication Constellation Satellite Network, instantaneous switching between the Telesat LEO Constellation Test satellite and the ANIK-F3GEO satellite was achieved. During the test, the aircraft continuously communicated with the GEO satellite, switched to the LEO satellite instantaneously after entering the LEO Satellite Coverage area, and then switched back to the GEO satellite from the LEO satellite[2].

"The multi-orbit switching capability of Gilat's all-electric scanning antenna allows airlines to choose their interconnection options without having to worry about it," said Michel Forest, director of the Telesat telecommunication constellation system engineering. "Airlines can now use off-the-shelf, high-performance Ka-band communications services (high-orbit satellites) to easily access LEO constellations without having to replace terminals when LEO constellations are ready.

With GEO, MEO and LEO multi-orbit satellite resources in the industry, the major manufacturers have always believed that multi-orbit satellite network has an unprecedented advantage for ship-borne and airborne broadband applications.

2.4 Hughes Develops Flexible Satellite Communication Terminal

Hughes announced that it has been awarded a $2.2 million contract funded by the U.S. Air Force Space and Missile System Center, according to Spacenewsfeed on September 16, 2019, to realize the prototype for flexible satellite communication products. The prototype will include Hughes'flexible Modem Interface FMI[3], which will enhance interoperability between military and commercial satellite communication networks to form a unified hybrid network architecture.
Under the contract, Hughes will demonstrate a solution that will allow satellite communication terminal to automate task planning through automated control while roaming between networks. In this way, when transmission is degraded or interrupted, the terminal can "self-heal", using a back-up network to stay connected, thus increasing resilience.

Hughes will use the company's AI based FMI and mission management system MMS prototype to implement intelligent roaming in a variety of satellite networks and services. The demonstration will also take advantage of Hughes' modem system, which enables drones, helicopters and other aircraft to transmit high-definition video and other intelligence, surveillance and reconnaissance ISR data in real time via satellites.

Vice President and general manager of defense and Intelligence Systems, said: "This contract represents another step forward in the department's efforts to achieve high flexibility and interoperability between communication networks."

The flexible terminal has already entered the substantial research stage worldwide, and some related test and verification work has already been carried out. The flexible terminal is still in the conceptual stage in China because the NGSO constellation is just starting, research needs to be actively carried out to cope with the future trend of multi-orbit fusion applications.

3. FLEXIBLE TERMINAL DESIGN
Flexible terminal can quickly roam between satellites and networks, can operate across multiple operator networks in multiple satellite orbits and support different waveforms.

3.1 System Architecture
The core of the flexible terminal architecture is the multi-waveform Modem System[4], which provides broadband satellite communication through a variety of communication waveforms, which includes proprietary vendor communication waveforms for HTS management services in high and low orbits, commercial standards such as DVB-S2x / RCS 2, and even military waveforms such as PTW, NCW, EBEM and CDL. Terminal Controller is a part of the multi-waveform Modem System, which provides terminal control and management function.

The actual implementation will depend on the terminal or Platform, for example:

1) hardware plug and play
Multi-modem and Terminal Controller is integrated together. The external port of the modem is used to connect to the terminal controller for control and management. The implementation of hardware plug and play does not need to change the existing modem, terminal controller perform local control and management through the Modem network management interface.

2) software defined Modem (SDM)
Deployment of a universal SDM platform capable of supporting multiple waveforms. The function modules of embedded terminal controller in SDM is illustrated in the figure listed below.

![Flexible Terminal Architecture](image)

Figure 1. flexible terminal architecture

The terminal controller is the "brain" that controls and manages the terminal operation. The main functions of the Terminal Controller include:

a) management of Modems
The Terminal Controller connects to the modem network management (NM) port via interface D to perform local network management function, including failure, configuration, billing, performance, and security (FCAPS). To support the network management interface, standard protocols such as simple network management protocol (SNMP) can be used. Modem management functions may also include dynamically loading waveforms or selecting the correct hardware configuration and triggering network initialization (network boot, network access, user login, and so on).

b) antenna control

The terminal controller is connected with the Antenna Control Unit (ACU) through interface E. This interface allows the terminal controller to direct the antenna to track a particular satellite and receive antenna status information. Open Antenna Modem interface protocol (OPENAMIP) can be used to support interface F.

c) autonomous decision-making

The choice of Modem, satellite or service is made according to the current state of Terminal and local environment interference, user network load, time, interference condition, etc.

3.2 key technologies design

In order to realize flexible terminal access to GEO Satellite and NGSO Constellation, the issues related with Terminal Antenna and waveform should be solved.

1) all-electric scanning phased array antenna

In order to cope with the frequent switching of terminal between multi-orbit satellites, an all-electric scanning phased array antenna is designed, with the advantages of no mechanical rotating parts, full electronic control of the beam, flat structure and very low profile, it can realize the instantaneous switch between GEO communication satellite and NGSO Communication Constellation.

All-electric scanning means that the antenna beam can be phased scanned in both Azimuth and elevation directions, a typical phased array antenna consists of an antenna array, T/R modules, a feed network, a wave control unit, a power supply, and structural elements including heat sinks, as shown in the following figure:

![Figure 2. traditional phased array framework](image)

The antenna array mainly includes antenna radiation unit, metal substrate, RF connector and so on. The T/R module consists of module structure cavity, PCB board or LTCC board, power amplifier, low noise amplifier, phase shifter, serial-to-parallel converter, filter, temperature compensation, RF connector, and low frequency connector, etc. For active phased array antenna, T/R module is the main part of the cost[5]. A feed network consists of a receiving and transmitting common feeder, a transmitting power distribution network, and a receiving synthesis network, usually in order to ensure the gain of the receiving branch and to saturate the final amplifier of the transmitting branch, it is necessary to add a driver-level low noise amplifier in the receiving branch and a driver-level power amplifier in the transmitting branch. The key components of the wave control system are FPGA and...
ARM, whose main function is to complete the transformation of geodetic coordinate system and phased array surface coordinate system, and calculate the instructions of the phase shifter in each T/R channel according to the pointing command sent by the terminal, and send down to every T/R module in parallel through SPI or TTL, thus changing the phase factor of antenna array, completing the beam scanning of active phased array antenna. The main function of the power supply is to convert the DC/AC voltage into the power value required by the active components.

Considering the high cost of phased array at present, this paper aims at low cost phased array design, which is mainly realized by tile layout and CMOS multifunctional chip.

a) Tile layout

The tile based circuit layout design can significantly reduce the number of printed circuit boards and connectors, and enable the adoption of a large scale PCB compression process and vertical interconnect technology, high density integration between antenna unit and RF channel PCB saves a lot of connectors, PCB and related installation components, and greatly reduces the cost[6].

The tile structure phased array antenna adopts the overall structure technology of stacked embedded system, generally adopts the three-layer structure, the top layer is the antenna-radio frequency part, the antenna element and the radio frequency T/R module chip are on the front and the bottom of the multi-layer PCB, respectively, the multi-layer PCB is designed with mixed-press design. The top and bottom layers are high-frequency soft substrates and the middle layers are hard media substrates. The middle layers are designed with Radio Frequency Power Division Network (1 to N Power Division Network), power supply network and control network, the heat loss of the active part of the phased array antenna is transferred out by the heat characteristic of the working medium and the network of micro-capillaries. The bottom layer includes wave control power supply board, up-conversion Channel Board, down-conversion Channel Board, realizing wave control solution, power supply distribution, and signal up-down conversion.

By drilling holes in the middle layer, the top layer and the bottom layer connect vertically through the perforated vertical plug to realize the transmission of radio frequency signal and the distribution of command and power. In addition to the three-layer structure, the antenna also includes the Radome, Fan frame and baseboard.

Figure 3. tile layout diagram

b) CMOS multifunctional chip

The way to further reduce the cost of phased array antenna is to design multi-function chip to reduce the number of chip and improve the multi-function and multi-channel integration of the chip. Its core idea is to integrate power amplifier, low noise amplifier, radio frequency switch, phase shifter and some digital control circuits in the chip, so as to reduce the number of chip, interconnection process and connection, CMOS technology is used to integrate multiple channels on a wafer-level chip, which improves the integration degree and comprehensive performance of T/R module, greatly reduce the cost of phased array antenna.

The general functional architecture of CMOS multifunctional chip is shown in the following figure.
Each chip contains several (four or eight) complete RF channels. Each channel contains basic unit circuits such as amplifiers, phase shifters, attenuators, etc., therefore has the high accuracy amplitude and phase control function. The digital control circuit and the power management circuit are integrated in the chip. The digital control circuit can communicate with the outside and control the amplitude and phase of each channel, the power management circuit provides a stable reference voltage and current to ensure the stable operation of each functional module. A temperature compensation circuit with gain is designed to realize the automatic temperature compensation function, the temperature data can be transmitted back through the SPI digital interface protocol. The transmitter chip also has the function of power self-test, which can send back power information through the SPI interface.

![CMOS transmitter block diagram (up) and CMOS receiver block diagram (down)](image)

2) waveform dynamic reconfigurable

In order to meet the requirements of flexible terminal access to any network, the terminal needs to run across multiple satellite orbits, run across multiple operator networks and support different waveforms.

The design adopts the waveform dynamic reconfigurable architecture, which is developed from the top to the bottom, and realizes the online dynamic reconfiguration of all communication waveforms of the terminal on the limited programmable logic resources by using time-division multiplexing technology. GEO satellite waveform, NGSO constellation waveform and 5G waveform are integrated into the waveform reconfigurable platform through the integrated RF transceiver system. The integrated RF transceiver system processes the waveform for differentially decoupling and distributes different waveforms to different analytical channels. The waveforms separated by the RF unit are connected to the communication middleware; Communication middlewares are the core portion of the waveform dynamic reconfiguration platform, which complete the information interaction between different waveform with the system bus by using together with the bus interface adapter, they can break the underlying communication protocol shielding mechanism of different waveform, realize the unbinding between the waveform protocol and the hardware platform, complete the deployment and transplantation of multi-waveform on the platform; At the same time, the control management system of the platform realizes real-time monitoring and scheduling management of the waveform dynamic reconfigurable platform, so as to ensure the orderly execution of the waveform reconfiguration queue and avoid the generation of competition and congestion.
Virtualization technology is adopted to virtualize the waveform processing function of the terminal, centralize all signal processing units into a unified virtual resource pool, so as to conduct centralized rapid processing of a large number of signals. Signals sent or received on each RF unit are completed in the virtual resource pool. Adopting SDN (Software Defined Network) technology can provide more flexible configuration of virtual network. The terminal waveform processing can be controlled centrally and waveform reconfiguration can be carried out independently through SDN.

In order to shorten the time of waveform dynamic reconfiguration, this design adopts the method of directly extracting waveform operation files from the local FLASH memory devices connected with programmable logic devices[7]. When the platform receives the waveform switching excitation, the waveform reconfiguration control system directly calls the corresponding waveform operation file in FLASH, loads it into the corresponding waveform reconfiguration area, and quickly performs the dynamic waveform reconfiguration. In order to further improve the efficiency of waveform reconfiguration, it is necessary to plan and deploy the FLASH sector in advance (sector capacity, waveform storage region, executable file size, etc.) so as to quickly and accurately extract the waveform running file.

4. CONCLUSION
The fusion application of GEO satellite and NGSO constellation is an important development direction of future satellite communication, an effective means to realize global broadband seamless communication, and also a necessary stage for the development of fusion application of space and earth. This paper analyzes the features of GEO satellite and NGSO satellite, studies flexible terminal that can...
be connected to GEO and NGSO constellation, designs and analyzes the key technologies such as low-cost phased array antenna and flexible waveform, provides ideas on research and development of flexible terminal for fusion application with GEO and NGSO satellites.

REFERENCE

[1] CHEN Zhuwen. SES and thales demonstrate airborne satellite communications dual-track seamless switching capability. https://new.qq.com/omn/20191024/20191024A0PTGK00.html

[2] Gilatwebsite news, February 18. http://www.gilat.com/pressreleases/gilats-fist-to-flight-esa-terminal-achieves-another-industry-first-with-in-flight-connectivity-over-ngso-well-positioning-gilat-to-win-the-vast-opportunities-in-the-esa-market/

[3] Daniel Zeleznikar, “Flexible Modem Interface(FMI) In Space-Extending Standardized Commercial Satellite Communications Services to Space Users”, 25th Ka and Broadband Communications Conference, 2019.9.

[4] “The Flexible Terminal Concept Enabling Resilient SATCOM”, white paper of Knight Sky, LLC, 2018.11.

[5] CHEN Yiqiao. Low-cost technology for phased array antennas. Information Engineering, issue 6, 2015.

[6] Corey. A survey of Russian low cost phased-array technology[J].IEEE Transactions on AP, pp.255 ~ 259, 1996.

[7] LU Xiaochao. Dynamic reconfiguration design of airborne waveform based on FPGA chip. Electrical communication engineering, issue 3, pp..301-305, 2019.

[8] SHEN Yongyan, MA Fang. Global satellite communications industry development frontier report(2019).China Institute of Communications. Sep-2019.

[9] MU Yubo, CHAI Yaolin, SONG Ping, BI Libo. SD-WAN industry development and key technology research. Information and communication technology and policy, issue 11, pp.73-78, 2019.

[10] CHEN Wei, HAN Xiaoong, NI lingfei. Discussion and practice on the key issues of NFV application in mobile core network. ZTE Communications, issue 3, pp.12-15, 2014.