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Analysis of the development status and future development trend of deep space network (DSN)

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Abstract. With the increase in the demand of space exploration in recent years and the increase in the amount of communication data between the earth and spacecrafts, the development of deep space communication is undoubtedly a great support for space exploration. Deep Space Network (DSN) is an important organization that helps people to get in touch with spacecrafts. This paper introduces the communication technology and achievements of the DSN and the problems that are still facing by it, and look forward to the future development trend of deep space communication and exploration technologies, so as to promote the development of Deep Space Network.

Keywords: DSN, deep space communication, antenna array, parabolic antenna.

1. Introduction

Since the successful launch of Sputnik I by the Soviet Union in the 1950s, human exploration of space has entered a new era. Hundreds of satellites were then launched into space, but problems followed. For example, the problems of how the damaged satellites are repaired, how to communicate effectively with satellites thousands of kilometers away from the earth and how to coordinate the operation between satellites, etc. As a result, terrestrial communications facilities play a vital role in addressing these issues. And National Aeronautics and Space Administration (NASA) established the Deep Space Network (DSN) in 1958 as part of the Jet Propulsion Laboratory (JPL) in order to support radio communications, interstellar missions and the use of radio astronomy to probe and observe the solar system and the universe [1]. It is the most sensitive and largest communication system on Earth for scientific research, and it also supports certain Earth orbital missions. This paper introduces the developing situation and achievements that were made by DSN, it also analyzes some of the challenges faced by DSN System and show my own expectation and advice on the further development in technology of this organization, so as to promote the development of Deep Space Network.

2. The current situation of DSN's development and achievements

2.1. Components

DSN currently consists of three deep space communication stations located near California, USA, Madrid, Spain, and Canberra, Australia. In the three stations, there are antenna groups for generating and receiving space signals. There are three 70m-diametre antenna and three 34m-diameter antenna

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locate in the three stations respectively: In the station of California, there is a 70m-diameter antenna “DSS-14”, 34m-diameter antennas “DSS-24”to“DSS-26”. In the station of Madrid, there is a 70m-diameter antenna “DSS-63”, 34m-diameter antennas “DSS-65” and “DSS-53” to “DSS-56”. In the station of Canberra, there is a 70m-diameter antenna “DSS-43”, 34m-diameter antennas “DSS-34” to “DSS-36” [2]. All of them are able to receive and and generate microwaves of X-band and S-band and only receive microwaves of L-band. They can support radio astronomical observations. Besides, there are a lot of antennas in smaller size like the 26m -diameter antenna and 12m-diameter antenna. Most of these antennas are constructed in arrays. The three stations are distributed 120 degrees in longitude apart from each other across the earth, so that there must be at least one spot could be used to do space detection and communicate with satellites at any moment of a day. In addition, these stations had made a planet-size signal receiver, which makes it easier to send information from satellites to the Earth, as antennas on satellites only need to send waves to the direction of earth instead of a particular receiver on the ground. Besides, at the aspect of space observation, there is time difference for pulses of waves from deep space to be received by receivers in the three stations as the distance of those waves traveled are different and interference occurs between different waves. As a result, the waves received are likely to be different both in intensity and phase. Therefore, valuable information about the universe like the chemical components of stars and climate change on planets can be easily calculated by analyzing those difference between waves.

2.2. Parabolic antenna

Most of the radio telescopes used by DSN adopted the design of parabolic antennas, as the satellites and objects in the universe are very far from Earth, so that their radio signals are transmitted to the ground in form of parallel waves. At the receiving side, a parabolic antenna will reflect these parallel waves to its signal receiver at its focus. Here is the principle:

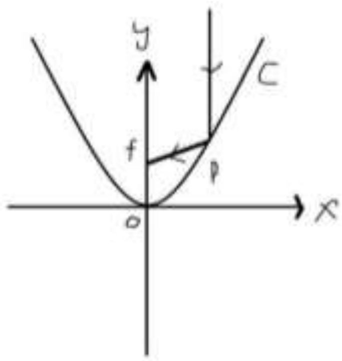

Figure 1. Parabolic antennas.

As it can be seen in Figure 1, the curve C satisfied the equation:$x^2=2py$. And its focus is f:(0,p). Incidence (I) moves along $x=a$, where a is a constant. And then be reflected by C at P. Therefore, $dy/dx=x/p$, and the tangent line of C at P is $y=ax/p-a^2/2p$ and the direction of the vector normal line at P is $n=(a/p,-1)$, so the vector of the I is $b=(0,1)$. Let the vector of reflection(R) be $c=(x,y)$, so, $\langle n,b\rangle=\langle n,c\rangle$ and $\cos\langle n,b\rangle=\cos\langle n,c\rangle$ and $y-xa/p=(x^2+y^2)^{0.5}$. So $c=(2ap, a^2-p^2)$, so the gradient of R is $(a^2-p^2)/2ap$, so R:$y=[(a^2-p^2)/2ap]x+p/2$. When $x=0$, $y=p/2$. So R pass through the focus.

Thereby, antenna can achieve the reception of space signals, and this can reduce the interference of noise which come from elsewhere since noises would not be reflected to the receiver. At the sending side, microwaves sent by these parabolic antennas would be transmitted to particular spots in the universe instead of separate in many directions, and this is likely to reduce the energy loss of signal transmission. If we send microwaves by using generators directly, wavefront would be transmitted like

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a sphere surface. According to E=I/r^2, the energy loss is proportional to the square of transmission distance.

2.3. Antenna arrays

"To get the same details of observations as advanced optical telescopes, you need a telescope of 100,000 meters in diameter. Obviously, you cannot build a 100,000 m telescope, but you can build a network of telescopes that can do the same thing by connecting them together", Said Simon Galington [3]. huge antenna tend to be massive, and costly to be maintained. For example, the 70m-diameter antenna DSS-14 in California is about 3.1 million kilograms [4]. Only the operation to replace the steel runner, walls and supporting grout, was predicted to cost about $1.25 million in 2010 [5]. Besides, in the antenna array, the unit antenna caliber is small and the manufacturing process is simple, while the sensitivity and resolution of the antenna array composed of multiple single antennas are significantly higher than the large caliber single antenna with the same price [6]. Antenna array helps generate stronger signal because when same wave pulses are sent in phase, there are likely to be constructive interference between waves which make wave more powerful and enable them move longer. And at the angle of receiving waves, antenna arrays means greater reception surface area, so that more signals can be received and coped with at same time which means DSN can communicate with farther satellites and more satellites at same time period. In a word, the function of an antenna array is a larger antenna. On the other hand, components in antenna arrays can be turned to many directions to send signals to different spacecrafts and receive waves from many spot of the universe at a moment when we communicate with satellites in short distance. And this also decreased the destructive interference between waves, which means the flexibility and working efficiency of antenna array is better than a large antenna.

2.4. Current achievements (some examples)

Since 1963, the DSN has been a mainstay in NASA's deep-space communications,and it took part in almost all the essential missions of NASA. For example, DSN served as a communications facility during the “Voyager 1” and “Voyager 2” missions, launched in 1977. Instead of using microwaves of s-band, x-band wave was used as the main role of downlink, which was also the first time that the DSN had used this band for the main downlink. besides, the improved antennas situated in the DSN stations also played an important role in this mission: The parabolic antenna can be adjusted to sub-millimeter level accuracy when “Voyager 2” flew across the Neptune, the diameter of the 64-meter parabolic antenna was expanded to 70 meters, using a double-line design scheme, which increased the effective design area of the antenna by more than 60% [7], then its signal receiving strength was improved by 1.4 db, therefore the x-band RF signal could be accurately used.On the other hand, the signal receiving strength of the 70m-diameter antenna could be increased by 0.8 db, by combining it with another 34m-diameter high efficiency (HEF) antenna array. Also, the strength could increased by 0.12 db while combining the 70m antenna with two HEF antennas with diameter of 34m. The Neptune intersection mission of “Voyager 2”, was also supported by an larger antenna group: the facilities of DSN in Canberra, together with the Parkes’ 64m-diameter radio telescope located in Canberra Australia, the combined signal strength is more than double of the that of 70m-diameter antenna, so that the two Voyager probe could get in touch with earth in such long distance. At the same time, other planetary probes launched by NASA, such as “Juno” and “New Horizons”, which were all served by DSN when they communicated with NASA. The DSN has also made great achievements in space observations. In the projects for planet defence, DSN has played an important role, as it now has observed thousands of near earth asteroids (NEA). Furthermore, antennas in the stations sent microwaves to NEA and located them by receiving signals back calculating the distance. In this approach, NASA was able to monitor those NEA with potential risk to imperil earth and take action to reduce loss in future NEA disasters.

3. The challenges faced by DSN

3.1. Exploit microwaves of higher frequency

Nowadays, more and more spacecrafts are sent to the trails in the universe and this has lead to an increasing quantity of data transformation per unit of time and the space for microwaves between S-band to Ka-band is becoming more and more crowded. As a result, the DSN need to complicate the communication system using the waves in the frequency of Ka-band, as "The Ka-band bandwidth is four times that of the x-band, while the actual allocated spectrum bandwidth is 10 times that of the x-band, and its data reception rate can reach hundreds of megabits per second" [8], and expand the available frequency range as soon as possible. After the lunar mission in the 1960s and in 1970s, quantity of data transmitted between earth and space had increased dramatically. As a result, NASA started to send signals in X-band in late 1970s to solve this problem. In the future, the total data amount is likely to see a jump in 2030s as NASA wants to send human to Mars. And NASA need to move the communication frequency to a higher level. And DSN will deploy a Time-frequency system with long-term (1000-1000 s) stability of 10-16ss and short-term (1-100s) stability of 10-14s/s [9].

3.2. Laser communication

Laser communication is a brand new technology,and it planed to be used in scale in the industry of deep space communication in the future, as it has a lot of advantages. Firstly, laser light has greater bandwidth, which means more information can be carried. Secondly, laser's directive property is better than that of microwave. As a result, large and heavy parabolic antenna will no longer be used. Instead, only small and light generators and receivers are needed for transformation. Thirdly, the cost of laser communication would be much lower than using microwaves because the accuracy of laser pulses minimizes the energy loss on its route to receiver, which is beneficial for long distance communication. In 1992, JPL conducted the first deep-space optical communication experiment, "Galileo Optical Experiment" (GOPEX), which was on the "Galileo" flying to Jupiter Advancing [10]. And this autumn, NASA's Laser Communications Relay Demonstration (LCRD) will launch and showcase laser communications – a revolutionary way of communicating data from space to the ground [11]. There will be two optical stations. And in the future, DSN will also construct laser communication facilities in its stations. And those massive antennas are likely to be replaced. After all, it is too costly to maintain the daily routine of those microwave antennas.

4. Conclusion

In a final analysis, increase in quantity of data and increasing demand communication efficiency is not only the largest challenge that DSN faces today, but also the major trend in the future. As a result, this situation might be improved by magnifying the scale of DSN and this can be achieved if DSN can build more stations or even expand the stations out of Earth. And now NASA is planning to send human to Mars in 2030s. And this shows the trend that mankind tend to extend our footprint apart from earth. As a result, it is possible for The DSN to construct their astronomical observation and communication sites on Mars, Venus, Mercury, and even on the moons of other planets in outer solar system such as Jupiter and Saturn. At that time, human's abilities for deep space communication and observation are likely to be further enhanced, and the distance that we can communicate with satellites will also increase dramatically which will enable us to detect farther stars and planets using probes instead of analysis a great deal of vague pictures taken by telescopes on the ground. Whereas, construction of new stations is really costly, and maintaining the operation of those new stations is also costly. If we want to set our stations on other planets like Mars, the first problem is the high cost of delivery of people,material and equipments to the places in the solar system where we want to build the stations. And it is not affordable for any organization currently. So this is an unachievable plan in short-term for NASA. But in the long-term, the total productivity of human are enhanced. We would have spare money to set and maintain an emerged super-large global space administration in the following centuries, which is powerful enough

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economically to support the expand of deep space network. And this may be witnessed by following generations in the future.

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