Anti-jamming Technology in Small Satellite Communication

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Abstract. Small satellite communication has an increasingly important position among the wireless communications due to the advantages of low cost and high technology. However, in view of the case that its relay station stays outside the earth, its uplink may face interference from malicious signal frequently. Here this paper classified enumerates existing interferences, and proposes channel signals as main interference by comparison. Based on a basic digital communication process, then this paper discusses the possible anti-jamming techniques that commonly be realized at all stages in diverse processes, and comes to the conclusion that regarding the spread spectrum technology and antenna anti-jamming technology as fundamental direction of future development. This work provides possible thought for the design of new small satellite communication system with the coexistence of multi-technologies. This basic popular science can be consulted for people interested in small satellite communication.

1. Introduction
Classical mechanics and other modern physics provided academic support for the embryonic form of cross-continental long distance communication. In 1945, AC Clarke purposed an ideal that put the relay station outside the earth, which eventually led to the birth of worldwide satellite communications technology [1]. People immediately foresaw the coming of satellite era in synchronous orbit. Through the adjustment of orbit height and frequency band, the new communication based on on-board relay station could give global radio coverage [2]. In 1954, American designed the first passive satellites. Regarding the moon as natural satellite, United States Navy (USN) sent telegrams successfully. However, due to the relative change of the position between earth and moon, it is not reliable to continually use moon as relay station [3]. As a result, the opposing superpowers started to design artificial satellite. In 1957, the former Soviet Union launched the first active satellite named Sputnik I [4]. During 60s to 80s, synchronous satellites such as Early bird and INTELSAT brought a wider range of coverage area and further distance of communication [4]. Thus the study of satellites is gradually going from military to civilian. To the 21st century, mobile communication system application to low orbit widened the civil market with valuable frequency band and business. The development of satellite communication is less than a hundred years, in which the anti-jamming technique plays an important role [5].

At present, satellites have a variety of different functions. They can be classified according to the frequency band as well as the use. As the classification of the height of orbit, the satellite can be divided into Geosynchronous Earth Orbit (GEO), Medium Earth Orbit (MEO) and Low earth orbit (LEO)[2]. Among them, the coverage of satellite located in medium and low orbit are not as wide as high orbit’s. So, it is necessary to connect multiple satellites with entire constellation to achieve the
complete coverage of time and space domain around the whole world [3]. However, at that time, the cost of a large satellite that was heavier than one ton, which was at least 100 million dollars each. This could be typically evidenced by famous Alphasat from Inmarsat, 350 million dollars per satellite. Therefore, considering the cost of manufacturing and launch, small satellites defined by less quality than 900KG draw the attention of scientist [4]. Iridium system is the first introduction of mobile communication system composed by 66 small satellites [4]. The entire cost of this system only needs more than one billion dollars. The cost of some small constellations is almost as same as single satellite synchronization. This has a great attraction for medium-sized enterprise and Institute lacking of research funds. As a result, the development of small satellite systems has gradually become the mainstream.

Prior to the application of satellite broadband to personal communication, the early small satellites were limited to the background of the era [3]. Military use resulted in the importance of anti-jamming capability of satellites. This has become an important evaluation standard for communication system in addition to cost savings, simplified construction and shortened transmission time [4]. Both the countermeasure of tactical interference and the confidentiality of communication signals are important propositions at that time. The small satellite communication didn’t come across the globalization for civil use until 21st century. At that time, Anti-jamming technique in small satellite communication was still the focus of this area. The focus could be divided into electromagnetic interference, natural interference and a variety of other factors [5].

Thereby this paper is going to discuss anti-jamming technique in small satellite communication. The first part will introduce some possible interference in small satellite communication. The second part gives detailed study and analysis of diverse anti-jamming. And the last part proposes suitable anti-jamming program in different process of small satellite communication.

2. Possible interference

Even if the relay station from small satellite communication is located outside the earth, it is still influenced by interference from external factors, which is a force majeure. Thus the research on anti-jamming technology has been an important subject of small satellite communication.

Depending on the sources, the possible interference in the communication process could be classified in two parts. The first is natural interference from environment and physical phenomenon. The second is man-made interference from faulty operations and electronic equipment [6]. Both of these are likely to cause typical electromagnetic interference. They will make significant varying degrees of impact on the uplink and downlink signals [7].

2.1 Natural interference

The natural interference could be mainly regarded as harsh climate and special astronomical phenomena, causing passive effect on the radio waves in the space. Some natural phenomena, including rainstorm, blizzard and thunder, will cause physical damage to the ground base station. The climatic noise is the main reason for the impact of satellite communication. This can be typically evidenced in rain attenuation, an energetic attenuation of the radio signal caused by rainfall. That means the radio waves will be absorbed and scattered by dense water molecules when through the atmosphere. At the same time, the ground receiving system will be affected by rain noise [8]. Above the band commonly used in satellite communications, the Ku-band is believed to be most seriously affected due to the similar size of wavelength compared with raindrops [8]. Another instance is sun outage. When time passes the spring equinox or the autumnal equinox, the orbital positions of the earth, satellite and sun overlap into a straight line. The downlink signal from ground station will become practically unusable resulting from severe noise created by solar radiation [9]. Thus sun outage interference cannot be overcome with current technical means; there won’t be more detailed analysis.
2.2 Man-made interference

Man-made interference in satellite communication mainly refers to mistaken spatial layout and channel allocation. In view of the fact that there is totally hundreds of in-orbit satellites, plus disused space garbage (satellite debris), indubitably the outer space will be more crowded in the future. Particularly, satellites sharing geosynchronous orbits will be subject to severe adjacent satellite interference [7]. Thus small satellites are mainly located in the low orbit with unified connection controlled by the same link. The influence for small satellite communication is not as serious as synchronous satellite’s. What should be in consideration is adjacent channel interference, which is caused by partial overlap of the different carrier frequencies [7]. At present, the small satellite system based on mobile business has been popular in most parts of the world. In view of the number of users has far exceeded expectations, the impact of adjacent channel interference is worthy of attentions.

2.3 Electromagnetic interference

Electromagnetic interference is the focus of small satellite anti-jamming technology to overcome. The transponder of small satellite is different from synchronous satellites’ Synchronous satellites use geosynchronous. In order to allocate frequency resources reasonably, the data is almost transparent. The downstream receiver thus can be easily disturbed by illegal signals [6]. Although small satellite communication is not bothered by this issue, other factors like ground microwave, radar, radio and others are still possible to damage terrestrial base stations during the process of long distance communication. It is essential to prepare for possible malicious attacks from third parties. Both active interference from the jammer that spontaneously generates electromagnetic energy, and passive interference through the reflector to weaken the effective radio waves, is the range that needs to be considered.

Directly against these possible interferences, the next section will introduce and illustrate some potential solutions in detail, with the analysis of specific anti-jamming method.

3. Small satellite communication system

Similar to synchronous satellite system, small satellite systems are always divided in two parts, the ground station and the on-board system.

Assume a digital satellite communication system as an example.

When a baseband signal is transmitted by the source, it will experience the source coding, the channel coding stage, and modulation respectively. Then the modulation signal will be sent to satellites by antenna using upstream channel. This weak signal is received by the satellite communication antenna. After that, it comes to the amplification, frequency conversion and power amplification in the communication transponder. Finally the amplified on-board radio wave will be sent to the ground station by the satellite communication antenna. This will achieve long distance communication between two ground stations or multiple ground stations.

Meanwhile, satellite communications have the most complex wireless channels as well as the complexity of their relay stations located outside the stars. As a result there may be more threats, and the various processes of entire communication systems have their own anti-jamming means correspondingly.

The first that needs to consider is the natural phenomenon of interference. However, rain attenuation, sun outage and other natural interference cannot be resolved by recent existing techniques. What the ground station could do is just making forecasts for advancing notice as well as timely repairing faulty equipment to reduce losses.

The second problem is the power limitation of satellite communications. Although cannot equal synchronous satellites, low-orbit system still need a large amount of power to launch its satellites to the corresponding orbital height. Furthermore, the on-orbit satellites can only rely on limited means to survive such as solar energy, while the application of multiple access technology generated intermodulation interference. Under comprehensive consideration the utilization of frequency band is not high in satellite communication, which means it can be easily interfered by other carrier signals.
The third is the interference from the illegal signals from the third party, which is also the main problem among satellite system. In general, the interference to be considered is mainly noise and false signals. This paper thus makes a decision about interference that may exist in the ground station and on-board environment respectively.

4. Anti-jamming in entire process

One of the focuses of the development of modern satellite communications is to study the noise in the wireless communication process to improve the effectiveness and reliability of transmission.

4.1 Modulation techniques

In the channel coding stage before modulation, such as Pulse Code Modulation (PCM), it is possible to increase the interference tolerance by changing the encoding method, or add extra partial code in the information code group according to certain rules. So that it can check and correct potential error according to the corresponding rule of verifier [7]. To more detail, the cost of satellite communication is enormous, which is also one-side communication. This system is mainly suitable for Forward Error Correction (FEC), which belongs to the application without the requirement of receiver to reverse the request to retransmit the data. That means the transmitting station will send the data attached by a certain redundant error correction code sent together, which based on the receiver to inspect its error [7].

4.2 Wave filtering

It needs higher cost and technical requirements to interfere with the downlink signals transmitted by satellites. So the active interference, using illegal Radio-frequency (RF) signals to attack the uplink signal transmitted by ground station, is the main method [6]. It thus becomes the focus of anti-jamming technology. To deal with signals that may partially or completely coincide with the modulation signal, which will causes serious confusion, filtering will be the most effective method.

In modulation process, this paper lifts an uplink working on the Ku-band as an example. Its frequency band is about 12 to 18GHz. By comparison the modulation wave occupies the narrow bandwidth relatively. And for the possible narrowband interference, the encoded discrete signal is Fourier transformed to eliminate the small frequency point of the interference in the frequency domain model. Then relevant procedure reduces the attenuation of the modulated signal and returns it to the time domain [5]. Furthermore, in the more complex model there is also the broadband interference at same time. In this situation, the combination of frequency domain and space-time filtering is more suitable [5].

4.3 Spread spectrum technique

The third step is to use the spread spectrum technique (SS) to further process the modulation signal before the ground station transmitter transmits the modulation signal. In this way, the system could occupy much more bandwidth than the bandwidth of the modulation signal. And the receiver uses corresponding spreading code to recover the data. The first method is direct sequence spread spectrum (DS) [7]. The transmitter sends extended series of spectrum, so that the unit band power becomes smaller, which means the signal power spectral density becomes low. Then the entire communication can be hided in the background of channel noise and thermal noise. So that the signal will be submerged in the noise, and be hard to be found by third parties. At the receiving end, the same spreading code sequence is used for dispreading. And the existing noises also dispread in this process as well as widened, and then through an intermediate-frequency filter. Thus its interference power will be greatly reduced. The second method is Frequency-Hopping Spread Spectrum (FHSS) [7]. The transmitter uses a certain code sequence to select the Multi-Frequency Shift Keying (MFSK), and constantly change the transmission frequency in a wide range. The number of these random frequencies can reach to thousands or even million. Real modulation signal is therefore difficult to be
The signal is intercepted by a third party which aims to use the illegal signal with corresponding frequency for interference.

4.4 Smart antenna technology
The fourth step, through the antenna to send uplink signals. This process also has abundant anti-jamming technology. One typical method is the adaptive antenna technology [7]. The antenna automatically control and optimize the array. When the system is subject to interference, the nulling of antenna pattern automatically point to the direction of the interference source, achieving interference suppression. Another method is Multi-Beam Antenna (MBA), which generally has 19 emission source beams [7]. This system can detect the location of the interference source according to the sensor. Then it controls the relative amplitude and phase of each beam through network beams forming. As a result, the gain of the antenna in the direction of interference vanishes.

4.5 On-board anti-jamming technology
The fifth step, the signal reaches the satellite. Transparent transponder is one of the most vulnerable satellite communication system links. Because of data transparency, it is easily interfered by third parties. This process corresponds to a variety of on-board anti-jamming technology, for which the development is relatively slow. Using the satellite switching (SS) as an example, which also called the exchange of multi-beam satellites. Firstly, the system uses time division multiplexing (TDM) before the circuit exchange [10]. Taking advantages of time interval of sampling pulse makes it possible to transmit multiple baseband modulation signals in the single channel. This process will also use a large number of invalid bands from direct sequence. Another method is Code Division Multiple Access (CDMA) [10]. That is using the orthogonal address code to send the modulation signal to achieve the beam forming. Then, disspread and spread the user unit on the satellite to achieve connectivity between different channels through exchanging. As a result, the efficiency and convenience of the entire satellite communication system will be greatly improved. At the same time, this MBA is more controllable in the face of interference, for example, giving up the interference beam to reduce the overall system loss.

4.6 Others
In the sixth step, the relay station transmits the downlink signal to the ground receiving station. This process mainly uses the C-band. The frequency band is about 4 to 8GHz, lower than Ku-band. The on-board modulation mainly faces broadband interference. Compared to narrowband, space-time filtering is more appropriate [6].

The seventh step, the signal will be disposed under dispersing, demodulation and decoding to obtain the corresponding original signal. This process is mainly based on the feedback and destination of many anti-jamming technologies from previous process. At the same time, the ground station to accept the signal usually works on the S-band. It should pay attention to the ground microwave interference and radar interference [11]. They may cause the increase of Bit Error Rate (BER) for useful signals. Receiver can adjust the elevation of receiving antenna though measuring the interference signal to reduce the bit error rate, or directly using electromagnetic shielding means [11].

The above is based on a specific satellite communication digital transmission process, from which this paper enumerates the anti-jamming technologies in various stages that can be used.

5. Conclusion
The previous parts of the classification introduce the development of small satellites, the possible interference in the communication process, and the specific analysis of the existing major anti-jamming technology in a complete communication process.

Satellite communication is one of the most important means of wireless communication. Based on the idea of controlling cost and optimal performance, the construction of constellation made by multi-beam satellites is undoubtedly the main direction of satellite development.
Among them, the noise treatment, while increasing the signal-to-noise ratio (SNR) to approach the Shannon limit at the same time, is the common research theme of all communication methods. Therefore, anti-jamming technology will continue to be a long-term mission of small satellite communications in the future.

For most of the wireless communications, including satellite communications, spread spectrum technology and antenna anti-jamming technology are the main anti-jamming means. It is because the user base of satellite communication is larger. Spread spectrum, which has no connection with the location of interference, has more advantages than others. Although satellite communication witnesses later development of on-board anti-jamming technology, the achievement of the functions of the ground station on the star as well as the multi-user signal exchange have greatly improved the communicating efficiency and fault tolerance rate.

In addition, in the future, it is appropriate to focus on the coexistence of a variety of anti-jamming technologies of communication system, requiring the ability of on-board signal processing technology, smart antenna technology, spread spectrum technology, optimizing the modulation, to ensure that the interference for different types can be disposed by corresponding confrontation technologies to resist and control.

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