# Research on Intelligent Transmission of Space-Based Information

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**Abstract.** Cognitive radio and artificial intelligence are hot research topics in the field of communication. This article discusses how to efficiently and reliably transmit space-based information from satellites to the ground. Related theories of cognitive radio and artificial intelligence are used to study the intelligent transmission of space-based information. This article also proposes ideas and strategies to improve the transmission efficiency and reliability of the satellite-earth data link. Several key issues including spectrum sensing and cognition, waveform reconstruction, the design of the intelligent decision engine, the massive data processing, spaceborne reconfigurable transmission platform, and signaling parameters synchronization were analyzed. The research results can provide help for real-time and reliable transmission of space-based information in the future.

**Keywords:** Space-based information · Cognitive radio · Intelligent data transmission · Communication system

## 1 Introduction

In this paper, the space-based information mainly refers to the data captured by satellite platforms (mainly by various sensors on the satellite). These kinds of information are mainly from the ground or the air targets, and stored in various forms (voice, text, image, etc.) for transmission to users. With the rapid development of space technologies [1], there are more and more satellites in the outer space, including the meteorological satellite, the remote sensing satellite, the imaging satellite, the communication satellite, the navigating satellite, etc. Furthermore, the future development of space-based information sensors will be accelerated in terms of resolution, transmission rate, and on-board processing capacity. As a result, the amount of the space-based data will increase exponentially. A large amount of space-based data needs to be transmitted from satellites to the ground, which brings high requirements for the capacity of the satellite-ground data transmission link.

The increase demand of the data transmission capacity will take up more frequency resources, but the frequency resources allocated by the ITU's Radio rules frequency division table are very limited. On the one hand, scheduled frequency resources limit the improvement of the satellite-ground data transmission capacity; on the other hand, the


Q. Wu et al. (Eds.): WiSATS 2020, LNICST 358, pp. 297–307, 2021.
https://doi.org/10.1007/978-3-030-69072-4_25

increasing number of satellites on orbit may also cause frequency interference to neighbor receivers. In such a complex electromagnetic environment, the wireless communication equipment is vulnerable to interference, including not only the natural interference and the man-made interference of docking receiver caused by overlapping frequency bands of nearby satellites, but also the malicious interference that may come from a hostile attacker. Therefore, the contradiction between the data-throughput demand of the space-based information and the transmission reliability of the satellite-ground data link becomes more and more serious. How to effectively avoid the interference spectrum, improve the reliability of the satellite-ground data link, and maximize the use of the limited and valuable frequency resources in a space-based system, need to be solved urgently.

According to the development of related techniques, there are three aspects deserves attention. First, in recent years, satellite communication technology has developed rapidly towards a direction of high throughput and high reliability. Through reuse of higher frequency band and multi-beam techniques, high-throughput communication satellites can make full use of frequency resources and significantly increase communication capacity [2]. Second, the software-defined satellite becomes a new developing trend. Through software-defined radio, software-defined payloads, software-defined data processing computers, software-defined networks and other means, different function modules of a satellite can be realized based on software. Then, a new satellite system with an open architecture is formed, which has re-definable function, reconfigurable software and reconfigurable hardware. Third, intelligent spectrum radio technology continues attracting attentions of the research field [3, 4]. In the literature, Haykin [5] defined the future intelligent radio as brain-empowered wireless communication. Then, related scholars carried out a lot of research, mainly focusing on understanding and prediction of the spectrum environment based on deep learning methods, intelligent decision-making of communication parameters based on spectrum situation, and dynamic spectrum access based on the deep reinforcement learning method (DRL) [6–8].

Based on deeply analyzing the aforementioned three aspects of related new technical trends, this paper studies an intelligent transmission strategy of space-based information. We propose a new idea to improve the efficiency and reliability of data transmission by combining the transmission subsystems of various types of satellites (e.g. the remote sensing satellite, the imaging satellite, the communication satellite, etc.) to form an integrated intelligent transmission system. In the rest of this paper, Sect. 2 analyzes the intelligent transmission strategy of space-based information. Section 3 discusses several critical issues for the design of an intelligent data transmission system. Conclusions are presented in Sect. 4.

## 2 Intelligent Transmission Strategy of Space-Based Information

Before we introduce the intelligent transmission strategy, we first review some basic methods to improve the capacity of the satellite-ground data link: 1) Expand the carrier frequency band. Raising the frequency band of the carrier can increase the transmission bandwidth, which is an effective way to improve the downlink data rate. For example, the available bandwidth of Ka band almost reaches 3GHz, and it has a great advantage over the lower X band. 2) Improve the communication waveform. Adopting higher-order modulation and demodulation types, more efficient coding and decoding schemes, is another effective way to improve the data rate between the satellite and the ground. Using high-order modulation (such as 8PSK, 16QAM) can achieve higher data rate in the same bandwidth. In addition, the variable code modulation schemes can also be used to improve the data link. 3) Increase the visibility time between the satellite and the ground. The data transmission time between the satellite and the ground can be prolonged by increasing the visibility time, which may indirectly improve the data transmission ability. On the one hand, this method can be realized by reasonably arranging the positions of the ground receiving stations in a larger area. On the other hand, the relay satellite can be used as a bridge between the satellite and ground receiving station.

The above basic methods have certain value for improving the transmission capacity of the satellite-ground data link. Each method has its own characteristics, but there are still some problems more or less. Raising the frequency band to the Ka band has the disadvantages of large transmission loss, easy to be affected by rain and snow, narrow beam width, and high requirements for acquisition and tracking of the ground equipments. Receiving high-order modulation signal requires higher signal-to-noise ratio and amplitude-frequency performance of the data link. Also, the structure of the receiving equipment may be more complex. If dealing with a static or slowly changing electromagnetic spectrum environment, these basic methods may work. Whereas, with the scarcity of frequency resources and increasing complexity of electromagnetic environment, only using fixed transmission modes is difficult to dynamically adjust with the changing environment. Their abilities to improve the transmission capacity of the satellite-ground data link are very limited. To solve this problem, a new transmission strategy is introduced as follows.

So far, the transmission subsystems of various types of space-based information systems are basically designed independently, and their transmission frequency bands are also divided in advance. Each system uses individual frequency band. In order to improve the overall transmission efficiency and reliability of the space-based information system, we could consider an overall design in such a way that the data transmission platform of each information system is designed in an unified scheme and the transmission frequency bands are planned as a whole to form a new integrated and intelligent transmission network to transmit the space-based information.

In order to achieve this goal, we need to design a data transmission system whose satellite-ground link has the ability of environmental perception and analysis, so that the data link has the ability of dynamic reconfiguration. In this manner, the onboard load is required to adjust the link transmission scheme corresponding to the interference environment. Cognitive radio techniques, which have the cognitive and reconstructive ability, can be employed. If the key techniques of the cognitive radio are introduced into the data transmission scheme, the system may have the ability of environmental perception, intelligent decision-making and link reconstruction, which will probably bring great benefits to the improvement of the satellite-ground data transmission ability in complex electromagnetic environment.

Cognitive radio was first proposed by Dr. Joseph Mitola in 1999 [4]. It is considered as a kind of radio that dynamically changes its parameters based on interactions with the external environment. Software radio is an ideal platform to realize it. Cognitive radio is an intelligent wireless communication system, which can use artificial intelligence techniques to learn from the radio environment. By changing the transmitting frequency, modulation and coding mode, transmission power and other working parameters, it can adapt to the change of wireless signal statistics, achieve highly reliable communication at any time and any place, and effectively use the spectrum resources [5, 9, 10].

Combining the cognitive radio with the space-based data transmission, and using theories and methods of artificial intelligence, the data transmission system will have the ability to learn, recognize and predict the spectrum environment, and then adaptively select the parameters and working methods to avoid interference spectrum more effectively. Such an intelligent data transmission technique may effectively improve the communication performance in a severe electromagnetic environment.

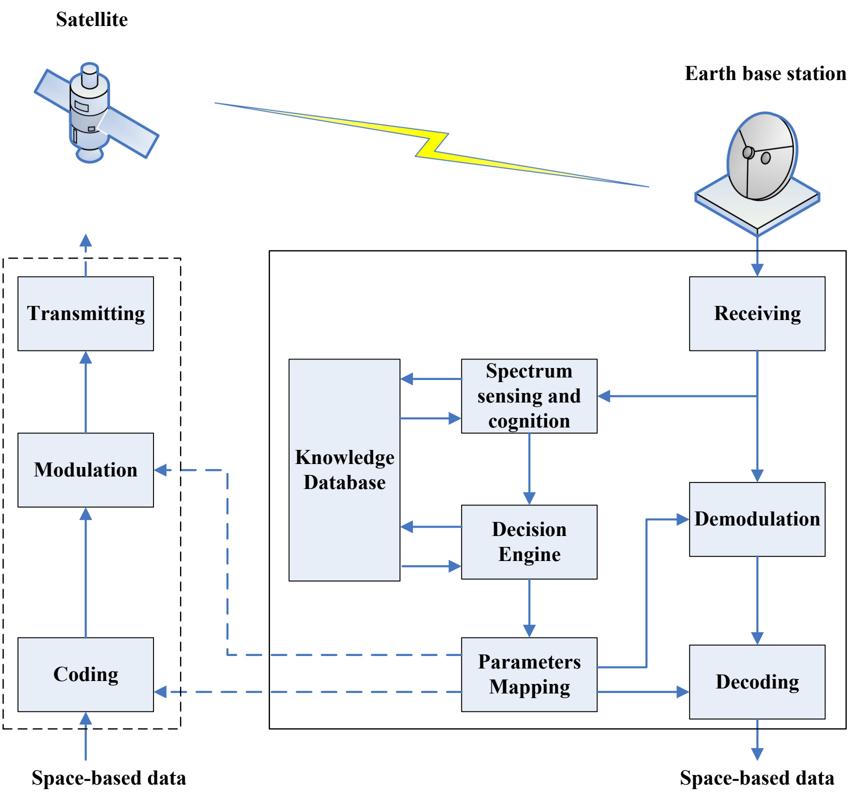


**Fig. 1.** Basic structural diagram of the intelligent data transmission technique.

Intelligent transmission of space-based information integrates the electromagnetic environment perception, the interference detection and identification, the dynamic spectrum allocation, the adaptive parameter configuration, and the intelligent decision engine into the conventional data transmission technique. A brief system structural diagram is shown in Fig. 1. Its working scheme can be summarized as follows. First, by establishing a cognitive model of the electromagnetic environment, the interference spectrum identification and the channel status identification can be realized at the ground receiving station. Second, it determines the optimal path of data transmission (using the path of the direct satellite-ground link or through a relay satellite) by analyzing the current type and amount of the data to be transmitted. Third, based on effective cases stored in the cognitive knowledge database, the intelligent decision engine dynamically determines the optimal transmission frequency bands using the reasoning and optimization methods in artificial intelligence, and adapts the transmission parameters (e.g. modulation type, coding scheme, transmission power, etc.) to reconstruct the transmission waveform. Finally, the communication parameters shall be updated synchronously with the satellite through some signaling parameters transmission channel, and then, the satellite carries out a new period of data communication based on its reconfigurable data transmission platform. The interference spectrum identification and the channel prediction module shall be optimized by continuously accumulating the spectrum sensing data and employing machine learning methods. Such an intelligent transmission technique will form an intelligent communication loop. On the one hand, it can avoid the interference spectrum. On the other hand, it can achieve the efficient use of available spectrum resources and achieve the efficient and reliable transmission of space-based information.

To realize the aforementioned intelligent data transmission system with reconfigurable parameters, it is necessary for the satellite's data transmission platform to be designed with a software-defined architecture [11]. As shown in Fig. 2, in a space-based system, the data transmission platforms of satellites for different applications (with different sensors) should be uniformly designed based on software communication architecture. This kind of data transmission platform has such capabilities including: 1) reconfigurable broadband RF front-end, so that the radio frequency part of the transmission platform covers a wide frequency band; 2) software-defined computing unit, so that the satellite can realize on-board spectrum sensing and interference identification; 3) software-defined parameters-managing unit, so that the satellite can change communication parameters as required; 4) software-defined storage unit, so that the satellite can efficiently allocate storage resources according to different tasks. With a uniformly-designed data transmission platform, the satellites for different applications could share a whole spectrum resource and actively adapt to the changing spectrum environment to ensure more efficient transmissions of space-based information.

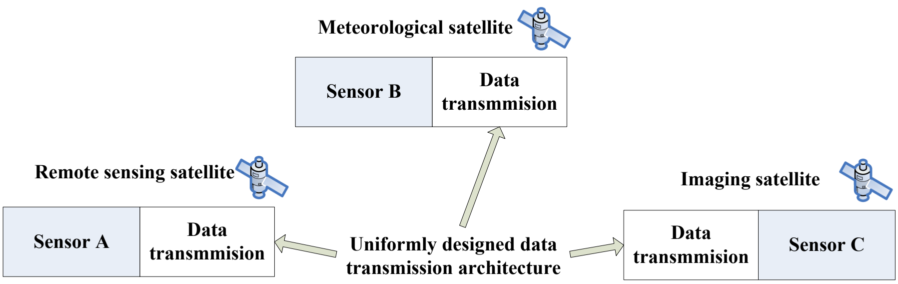


**Fig. 2.** Brief description of different satellites with uniformly designed data transmission architectures.

## 3 Key Issues of the Intelligent Data Transmission Technique

1) Spectrum sensing and cognition
Spectrum sensing and cognition is the premise and foundation of the cognitive ability of an intelligent transmission system [12–15]. It is an important way to estimate and predict the channel state. The process mainly involves modeling, detection, recognition and prediction of the interference signals. Common methods of interference signal detection include eigenvalue decomposition, cyclic spectrum detection, energy detection, etc. The main problem of the eigenvalue decomposition method is that the distribution of the interference spectrum cannot be analyzed. The main problem of the cyclic spectrum detection method is its high complexity for implementation. Since the interference detection should be able to detect the existence of interference and estimate the interference parameters, the energy detection algorithm has more advantages in this aspect. The frequency-based energy detection algorithm (e.g. the continuous mean elimination method) has the advantages of small influence to control parameters and low sensitivity to noise. To classify and identify the interference, we need to extract the features of the interference signal first. Different types of interference show different characteristics in time and frequency domains. We can classify them by extracting their features in different domains (e.g. single frequency component detection value, normalized 3dB spectrum bandwidth, spectrum flatness, etc.). By extracting the features that can reflect the interference characteristics of different categories, we can further use pattern recognition techniques to design a classifier, which use these features to classify and identify the interference types. Effective classifiers include support vector machine, extreme learning machine, artificial neural network, etc. To achieve effective interference recognition, we need to accumulate spectrum sensing data, use machine learning and big data analysis methods, and optimize the interference recognition and prediction model iteratively.
To effectively predict the channel state of a communication process, we should employ spectrum prediction techniques, which can estimate future distributions of the spectrum based on its current and historical data. Through predicting the spectrum information in the coming period, it can provide more reliable trend information for the decision engine and help to get more accurate parameter decision results. Three aspects of information are generally useful: the real time spectrum distribution information detected in the current period, the historical spectrum distribution information obtained in the past period, and the predicted spectrum distribution in the coming period. By integrating these three aspects, it is possible to get more reliable cognitive results of the spectrum distributions.
Since the historical spectrum data contains the laws and characteristics of the spectrum environment, machine learning-based methods are widely used on learning and understanding of the spectrum environment. Related machine learning methods can be divided into three categories: supervised, unsupervised, and reinforcement learning [16]. Supervised methods include k-nearest neighbors, support vector machine, artificial neural network, etc. Unsupervised methods mainly include clustering methods and principal component analysis-based methods. Two representative methods based on reinforcement learning are Q-learning and deep reinforcement learning.

The Q-learning has been used to find spectrum holes in the broadband spectrum based on achievable hardware resources [17]. DRL uses a deep neural network (DNN) to approximate the Q value table in the Q-learning algorithm. Due to the strong generalization ability of DNN, the DRL method is easier to mimic the internal laws of the spectrum environment. The DRL method treats the perception and the action as a unified solution optimization process, which will help to obtain a more suitable solution.

2) Data link waveform reconstruction
The waveform reconstruction is a key issue to realize the reconstruction ability of an intelligent transmission system. To realize it, we need to solve two main problems: dynamically allocating the spectrum and adaptively generating the parameters. The first one mainly uses the interference information obtained by the spectrum sensing module to determine the available frequency bands and select the most appropriate data transmission frequency bands. According to the processing results of the interference detection and identification, we can analyze and evaluate the interference level of different frequencies, determine the quality level of the available frequencies, evaluate the expected channel quality under special spectrum allocation rules, and formulate the optimal rule, so that the system can make the best use of the undisturbed or small interference frequency bands in the process of the whole data transmission. According to the data transmission performance requirements of the system, adaptively generating the parameters mainly deal with the modulation type (such as low-order modulation or high-order modulation type), the coding scheme (select coding scheme with different complexity according to the demand of bit error rate), the transmission power and other parameters of the data communication process.

3) Design of the intelligent decision engine
The intelligent decision engine is the core module of the intelligent transmission system. It uses decision-making optimization or learning and reasoning methods to give the optimal data transmission decision according to the historical experience and certain constraints, and then generates system parameters and reconstructs the link waveform according to the decision results. The learning and reasoning algorithm is the core algorithm for the decision engine. The genetic algorithm, reinforcement learning, case-based reasoning, neural network and other related algorithms in the field of artificial intelligence and machine learning can be used to design the intelligent decision engine. The key problem that the intelligent decision engine module needs to solve is a "multi-objective optimization" problem [9]. According to the objective decision criteria, the optimal solution will be searched and determined in a huge solution space.
It is an effective way to design the intelligent decision engine based on the case-based reasoning method. At this time, the decision engine needs the ability to store, analyze and make use of historical experience, which mainly includes two aspects: one is to perceive the external environment information through the cognitive and learning process; the other is to use the database to store and process knowledge data and dynamically adjust the communication parameters. By recording and storing the spectrum sensing result, the corresponding appropriate parameter-configuration result, and the evaluation result of the communication process, the case samples are

formed and the cognitive knowledge database is constructed. The cognitive knowledge database is a critical part of the intelligent decision engine. Through continuous communication tests, the cases in the knowledge database are constantly updated, which results in the fact that more effective communication decision cases are retained and the invalid decision cases are replaced. Then the whole intelligent decision engine is continuously optimized and updated to adapt to the changing spectrum environment and ensure more reliable data transmission. For an intelligent transmission system, the structure and organization of the knowledge database directly affect the response speed and execution efficiency of the decision engine. Designing a proper structure of the knowledge base will help to improve the performance of an intelligent communication system.

When the direct satellite-ground data transmission link is seriously interfered or the satellite beam does not cover the ground receiving station, the relay satellite can be used for indirect data transmission. Therefore, different from other communication techniques based on cognitive radios, the decision engine module of the space-based data transmission technology needs to weigh the path of the direct satellite-ground link and that of the transmission through the relay satellite according to estimating the channel state and predicting the capacity of different channels after spectrum sensing process, so as to obtain the optimal data transmission path.

4) Massive data processing

The proposed intelligent transmission technique needs to get a large amount of electromagnetic spectrum data to analyze the spectrum distributing and changing rules, so as to facilitate the intelligent decision engine to make decisions on the optimal communication parameters. The data to be processed can be divided into two parts: the first part is the spectrum sensing data, mainly including the spectrum distribution data in the relevant period; the second part is the cases data for decision-making of the communication parameters, mainly including the historical cases of the intelligent decision engine. Both the spectrum sensing and the case decision-making parts require a large amount of historical data. The decision engine needs to have the ability of self evolution to continuously accumulate data and optimize the core of the decision-making engine. Therefore, the development of the intelligent transmission technique requires the ability of high-speed storage, efficient retrieval and deep learning of massive data.

The main problem of massive data processing is to discover the laws of the data and mine the hidden information in the data [18]. The artificial intelligence-based technique is an important way to realize massive data analysis and processing. More attention should be paid to some effective methods in the research field, such as the deep learning-based data mining method and the computational intelligence-based distributed optimization method. In addition, how to take into account the real-time performance of the system as well as ensuring the effectiveness of data processing is another key issue. One potential way is to build a central data processing station as a supercomputing center on the ground, develop an integrated architecture based on the combination of cloud computing and edge computing [19], and make full use of various computing resources of the whole system. Furthermore, in order to further improve the real-time performance of the whole system, it can also make full use of the system's transmission gap period (idle period) to complete the calculation and processing of massive data. Last but not least, utilizing some predictive and pre-configured methods as auxiliary means may also be helpful for making decisions in advance.

5) The spaceborne reconfigurable transmission platform
In our concept, the data transmission subsystems of satellites for different applications should be designed with a unified architecture, that is, no matter in which application (e.g. remote sensing, imaging or navigation, etc.) the satellite is, its platform sensor load is different, but the structure of the data transmission subsystem is similar. This subsystem can be designed based on the "Software Communications Architecture", which has the ability of redefinition and reconfiguration [11]. Parameters of each satellite's data transmission subsystem, such as frequency band, communication waveform and data relay mode, are controllable and self-adaptive. In this way, different satellites' platforms of the whole space-based information system can adaptively select the best communication mode and parameters according to the electromagnetic spectrum environment, the transmitted data size, data type, timeliness requirements and other constraints. Then the ground control center can obtain the space-based data timely and effectively. This kind of satellite data transmission platform, which is based on software-defined architecture, puts forward higher requirements for effectively and reliably applying the software-defined radio technique to satellite platforms. Therefore, how to design the data transmission platform based on the software communication architecture for different types of satellites is a key challenge.
6) Reliable satellite-ground signaling parameters synchronization

Different from the conventional "parameter-fixed" data transmission architecture, an important change (or innovation) of the intelligent transmission technique is the need for signaling parameters interaction between both sides of a communication link. When the communication parameters are not suitable for the current electromagnetic spectrum environment, it is necessary to send the new parameters to the transmitter and receiver before applying new parameters for communication. It is necessary to establish a reliable signaling parameter transmission and synchronization mechanism between the satellite and the ground control center, so that each node of the communication process can synchronously update the parameters to complete the data transmission under new parameters. Reliable parameters transmission can be realized by designing a special channel, which needs low transmission rate, but high reliability, concealment and anti-interference performance. Some researchers have proposed a "transform domain communication" technique [9, 20], which improves the signal's concealment by constructing the basis function of analog noise. How to apply a similar low SNR but reliable communication technique to the signaling parameters transmission mechanism of the intelligent transmission system is another key challenge.

## 4 Conclusions

Based on discussions of space-based data transmission and cognitive radio technology, this paper studies an intelligent transmission strategy of space-based information and discusses how to improve the efficiency and reliability of the satellite-ground data link. With the development of space and information technologies, users' demand for obtaining space-based information based on satellite platforms is also growing. The contradiction between the real-time, efficient and reliable transmission of the space-based data and the insufficient data carrying capacity of the existing data transmission system is more and more prominent, and a new transmission strategy research is urgently needed. The intelligent space-based data transmission technique has potential advantages in interference spectrum avoidance and efficient utilization of the space spectrum resources. This "intelligent transmission" technique is trying to introduce the newly developed techniques in the field of communication and artificial intelligence into the transmission scheme of the space-based data. However, there are still many key issues to be studied to realize this technique. From a developing perspective, on the one hand, the evaluation of the effectiveness of this technique can be carried out by building a software simulation platform to simulate the complex interference environment between the satellite and the ground, and test its performance difference from the traditional techniques; on the other hand, after the relevant key techniques are mature and the key problems are solved, the proposed technique may be verified by an actual satellite-ground data communication test.

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