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# Anti-Interference Strategies Review of Unified Spread Spectrum Telemetry Tracking and Control System

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**Abstract:** In this study, the advanced unified spread spectrum Telemetry Tracking and Control (TT and C) system (USSTTCS) in aerospace industry is introduced and the anti-interference strategies of it are reviewed. In USSTTCS, the inherent ranging ability of pseudo-noise code and the speciality of spread spectrum modulation make the complete unification realized, including measurement of range, velocity and angle as well as telemetry, telecontrol and communication functions. With Code Division Multiple Access (CDMA) system applied, the signal and equipment of multi-target or multi-station TT and C can be unified easily in USSTTCS. In USSTTCS, there are several kinds of interference, including narrowband interference, multiple access interference, multipath interference and near-far effect and there kinds of interference affect the performance of USSTTCS greatly. In this study, several kinds of interference in USSTTCS are introduced and then the strategies which can mitigate these kinds of interference in the USSTTCS are reviewed with their performance analyzed.

**Key words:** Telemetry tracking and control, spread spectrum, code division multiple access, anti-interference, unified S-band

## INTRODUCTION

Telemetry tracking and control (TT and C) system (Gong *et al*., 2009) develops very rapidly to meet the requirements of modern complex flight texts in aerospace industry. The objectives of TT and C system are to measure the internal parameters and external trajectory of aerial vehicles (such as missile, satellite and unmanned plane) in real time and process the telemetering, range, angle and Doppler data and so as to correct the flight trajectory and control the internal equipments. TT and C system is a comprehensive electronic system, which consists of three parts that are telemetering, positioning and tracking and telecontrol. These three parts are separate and independent with each other and the radio frequencies and equipments are also different before 1969s. The large size, bad electromagnetic compatibility and vulnerability to jamming cause the separate TT and C no longer suitable and seldom used nowadays. So microwave unified TT and C system (MUTTCS) (Oleski *et al*., 2004) has been used widely since the unified S-band system was first employed in Apollo project.

Spread Spectrum (SS) technology was proposed and applied to military and secret communication in 1970s, however, it is not widely used because of its complexity and restriction by electronic devices in that time. Since the end of 1980s, because of the developments of VLSI, low power transmitting and correlation despreading techniques, the achievement of SS system with high performance and small size becomes possible. The unified spread spectrum TT and C system (USSTTCS) (Xing, 2006) is an advanced telemetering and telecontrol system developing based on the MUTTCS and it uses the SS technology to achieve the unification of different signals with different functions sharing the same carrier's frequency and transceiver.

With SS technology, the USSTTCS operates under low Signal-Noise Ratio (SNR), low threshold, low power spectrum density and wide spectrum range, so it meet the requirements of electronic warfare and electronic countermeasure, with high performance of safety, security, anti-intercept and anti-interference. Based on the Code Division Multiple Access (CDMA) system, the USSTTCS can also achieve the unification of multi-target TT and C signals and unification of multi-station TT and C signals. However, several kinds of interference still exist in the USSTTCS, such as narrowband interference, multiple access interference, multipath interference and near-far effect. These kinds of interference may decrease

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the performance of the USSTTCS and make it no longer reliable. In this study, several kinds of interference in USSTTCS are introduced and then the strategies which can mitigate these kinds of interference in the USSTTCS are reviewed with their performance analyzed.

## PRINCIPLES OF USSTTCS

The principles and advantages of the USSTTCS are as follows (Zhang and Zhang, 1996).

It is easy to realize the multi-signals, multi-target and multi-station TT and C simultaneously. The diagram of USSTTCS is shown in Fig. 1.

Based on the SS technology applied, CDMA communication systems can be implemented and the signals of different targets, signals of different stations and signals with different functions are spreaded through assigning different pseudo-noise codes, so these signals can communicate simultaneously over the same frequency band. The USSTTCS based on the CDMA system can save the spectrum resources and solve the electromagnetic compatibility problems caused by the frequency division systems used before.

Excellent anti-interference and security performance. Because the SS technology is applied in USSTTCS, the narrowband interference and broadband interference are both converted to broadband interference with low power spectral density after dispreading. At the same time, the required transmitted signal is converted from broadband to narrowband and its power spectral density becomes much higher with its transmitted power unchanged. Then most of the interference can be removed by the narrowband filter, so the anti-interference performance of USSTTCS is excellent. The acquisition and tracking of PN code is the basis to dispread SS unified signal. As the number of selectable PN codes is very large, if we have no idea about the chip duration $T_c$ and period N of the PN codes, the detection and estimation of unknown PN codes is almost impossible. Furthermore, the SS signal of USSTTCS seems to be buried in the noise because of its low power spectral density and broadband spectrum, so the USSTTCS signal is difficult to detect. Therefore in USSTTCS, the decomposition and detection of the unified signal is a very complicated procedure and the anti-intercept ability of USSTTCS is high.

High ranging ability. In USSTTCS, PN code ranging is employed and the accuracy and distance performance of the PN code is both superior to those of the sidetone ranging used in MUTTCS.

One PN code with dual purposes. In USSTTCS, a PN code can be used in both data spreading communication and ranging, taking advantage of its inherent ranging ability. The dual purposes of the PN code are widely adopted in the USSTTCS nowadays.

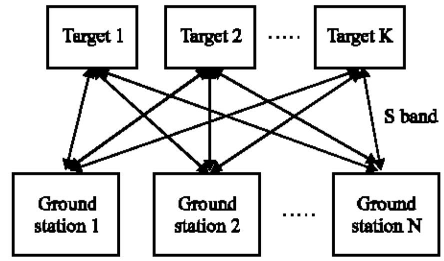


Fig. 1: The diagram of USSTTCS

Different communication systems coexist in the same channel. The power spectral density of the SS signal is low, so the CDMA communication system can coexist with other communication systems in the same channel, which means the spreaded signal and the nonspreaded signal can coexist at the same frequency of carrier and in the same frequency band. For the processing gain is relatively large, the spreaded signal can be recovered through correlation despreading. The nonspreaded signal can also be detected, because the power spectral density of the spreaded signal is low and it can be regarded as the background noise.

## ANTI-INTERFERENCE STRATEGIES OF USSTTCS

Based on CDMA system, USSTTCS can achieve total unification and its performance is excellent. However, in the channel of USSTTCS, there are several kinds of interference, which will affect its detection performance greatly. Hence, many anti-interference strategies arise recently.

Narrowband interference: Through the processing gain in SS system, the narrowband interference is spreaded to a very broad frequency band and the interference is well suppressed. Therefore, the performance in decreasing the influence of the narrowband interference in USSTTCS is perfect. However, when the power of the narrowband interference is too large or the processing gain is not big enough, the detection performance of the USSTTCS will be affected by the narrowband interference greatly. So, many strategies have been proposed to eliminate the narrowband interference in CDMA communication system and achieved satisfactory performance (Sun *et al*., 2007).

**Multiple access interference:** The USSTTCS is based on CDMA communication system and CDMA is the subject of extensive research in the field of mobile radio communications these years. This technique permits a large number of users to communicate simultaneously on the same frequency band; however, it also creates Multiple Access Interference (MAI). The MAI makes the Conventional Detector (CD), which can demodulate only one spread-spectrum signal without considering other signals, unreliable and insensitive to near-far effect in a multiuser environment. The MAI is the inherent interference in CDMA system and it should be suppressed effectively if we want to improve its performance. The strategies to reduce the influence of the MAI are as follows.

Using the PN codes with good performance. In the synchronous CDMA systems, the MAI is only caused by the noncorrelation of the PN codes and in the asynchronous CDMA systems, the noncorrelation of the PN codes is also the main cause of the MAI. So, designing PN codes with good autocorrelation and crosscorrelation performance is necessary to reduce the MAI in USSTTCS (Chen *et al*., 2008). The m and Gold sequences are by far the most popular spreading sequences in conventional CDMA systems. Even though these sequences have good correlation and balance properties, they are limited in security and are relatively small in number. In this case, increasing efforts have been devoted to ascertain the possibility of using chaotic and hyperchaotic sequences for spread spectrum: an alternative to PN sequences in recent years (Zhao *et al*., 2005; Wu *et al*., 2008). Because the chaotic sequences are very sensitive to the initial conditions, there exist a large number of available chaotic sequences with good correlation and balance properties and high security. Chaotic and hyperchaotic PN codes design will be a hot field of research in USSTTCS in the future.

Multiuser detection. Multiuser detection can reduce the MAI effectively using the information of other users in the system and it is a hot topic nowadays for CDMA systems. The Optimal Multiuser Detector (OMD) proposed by Verdu (1986) and it is shown that the OMD may be achieved by producing an estimate for the information vector transmitted based on the maximization of the logarithm of the likelihood function. The objective function of the OMD is given as:

$$b_{opt} = \arg\max \{2Y^T Ab - b^T Hb\} \quad (1)$$

However, the exponential complexity in the number of users makes it impractical to use in current CDMA systems. Therefore, research efforts have been concentrated on the development of suboptimal detectors, which exhibit good near-far effect resistant properties, have low computational complexity and achieve relatively high performance, such as Decorrelator and MMSE detector (Moshavi, 1996). Recently, as the artificial intelligence develops rapidly, many novel detectors with excellent performance have been proposed, such as Hopfield neural network detector (Liu *et al*., 2006), cellular neural network detector (Wu *et al*., 2007) and ant colony optimization detector (Ren *et al*., 2008). Among these artificial intelligence detectors, ant colony optimization detector (Wu *et al*., 2009a, 2010a; Zhao *et al*., 2010) develops fast these years and is a new field of research in multiuser detection.

**Near-far effect:** In USSTTCS, the TT and C targets are moving all the time, so the presence of strong users (near the station) exacerbates the MAI of the weaker users (far from the station). Thus, the overall effect of MAI on system performance is even more pronounced if the users' signals arrive at the receiver at different powers: weaker users may be overwhelmed by stronger users. Such a situation arises when the transmitters have different geographical locations relative to the receiver, because the signals of the closer transmitting users undergo less amplitude attenuation than the signals of users that are further away. This is known as the near-far effect.

Near-far effect will greatly increase the MAI and degrade the performance of CDMA system. The most effective method to reduce the near-far effect is the power control technique (Koskie and Gajic, 2006). The power control technique can be classified as centralized and distributed ones. In centralized power control algorithm (Grandhi *et al*., 1993), the information of all users is needed by the base station to compute optimal control actions for all users. However, significant computation and communication overhead is required, which is a drawback of the centralized scheme. Distributed power control algorithms (Skataric *et al*., 2007) have been covered in a large number of papers with only local information to decide the control actions for each user and it is widely used in practical system nowadays. The most successful distributed power control algorithms are the ones based on the Nash game theory (Koskie and Gajic, 2005), which has been extensively researched with high performance. Recently, much research effect has been focused on one type of power control algorithms that can work in different manners (Zhao *et al*., 2009), considering both the signal-to-interference ratio of the controlled user and saving the total transmitting power of the whole network.

**Multipath interference:** Multipath interference is caused by the reflection of radio waves (that are transmitted from an antenna) off structures like buildings, mountains and trees. Thus the received signal is a sum of several reflections with different delays, different phase changes and different amplitude attenuations. There are various models of the multipath interference and the most celebrated ones are Rayleigh fading and Rician fading. Multipath interference will affect the detection performance of the communication systems greatly and in MUTTCS, diversity and equalization are adopted to suppress the multipath interference, which are very complex and difficult to implement.

Because of the CDMA system used, the performance of USSTTCS in suppressing the multipath interference is much better than the former systems (Liu and Hanzo, 2007). In CDMA system, the bandwidth of the SS signal is wider than the correlated bandwidth of the channel, so the channel is under frequency selective fading. Because of the excellent correlation performance of the SS signal, the multipath interference can be regarded as broadband interference when the delay of the signal on the other paths is larger than the duration of one PN chip. The ability in suppressing the multipath interference of the USSTTCS depends on the processing gain of the SS signal. However, the inherent ability of the USSTTCS in suppressing the multipath interference does not make the best of the characteristics of the SS signal and cannot achieve reliable performance especially when the processing gain is not large enough or the power of the multipath interference is big.

A popular method to suppress the multipath interference is to use the RAKE receiver (Fulghum *et al.*, 2009). A RAKE receiver is a radio receiver designed to counter the effects of multipath fading. It does this by using several sub-receivers called fingers, that is, several correlators each assigned to a different multipath component. Each finger independently decodes a single multipath component; at a later stage the contribution of all fingers are combined in order to make the most use of the different transmission characteristics of each transmission path. Through the above procedures, the RAKE receiver can achieve superior performance in reducing the multipath interference. Another effective method to suppress the multipath interference is the multiuser detection for asynchronous CDMA systems (Yen and Hanzo, 2004). Using it, the multipath signal can be viewed as the signal of an independent asynchronous user and through this, we can use asynchronous multiuser detection to reduce the multipath interference with excellent performance.

**Multi-symbol detection for PCM/FM:** The power spectral density of the SS signal is low, so the CDMA communication system can coexist with other communication systems in the same channel in USSTTCS, which means the spreaded signal and the nonspreaded signal can coexist at the same frequency of carrier and in the same frequency band. PCM/FM system has been widely adopted as a main technique in current telemetry systems of strategic arms and launch vehicles, so it should also be accepted in USSTTCS. The PCM/FM signal in USSTTCS can be well detected, because the power spectral density of the spreaded signal is low and it can be regarded as the background noise. However, the spreaded signal still will affect the detection performance of the PCM/FM signal. Therefore the anti-interference performance of PCM/FM should be improved and a effective method is the multi-symbol detection (MSD). MSD was first proposed in 1974 (Osborne and Luntz, 1974) and in MSD, it will not be decided immediately when a symbol is received. Instead, the received signal of the following 3 to 5 symbols should be observed and all the possible transmitted waveforms over the observation interval should be correlated with the received signal, respectively and then compared to determine the sign of the symbol. Through MSD, the detection efficiency will increase by 3dB; however, the computational complexity of it is extremely large and it is difficult to implement on hardware especially when the number of observed symbols is large and the premodulation filter is applied to the baseband symbols. So a novel MSD algorithm has been proposed to reduce its computational complexity (Wu *et al.*, 2009b, 2010b) and it will be easy to implement on hardware, especially on FPGA.

## CONCLUSIONS

In this study, the USSTTCS is introduced and the basic principles and advantages of the USSTTCS are well demonstrated. Several kinds of interference in the USSTTCS are described, including narrowband interference, multiple access interference, near-far effect and multipath interference. Then the anti-interference strategies in USSTTCS are reviewed, such as designing of PN codes, multiuser detection, power control and RAKE receiver and these strategies make USSTTCS reliable to work under rather bad environment. The MSD technique for PCM/FM system is also reviewed.

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