

Research on Transmission Method of CDMA Satellite Communication System based on Time Division Duplexing¹

Xiaoyan Xu *, Jianjun Wu ^{*2}, Xi Luan *, Shubo Ren *, Haige Xiang *

* School of Electronics Engineering and Computer Science, Peking University, China

Abstract— A novel signal transmission method of asynchronous code division multiple access (CDMA) is proposed to improve the utilization of uplink timeslots for the time division duplexing (TDD) satellite communication systems. The terminals at different positions within a beam of the satellite antenna transmit their data blocks at different moments in the uplink timeslot window according to a certain rule. The uplink guard time can be reduced to one time the maximum propagation delay difference in this beam, while the uplink guard time of two times the maximum propagation delay difference was needed for the synchronous reception case in Reference [4]. Furthermore, two specific schemes are introduced to instantiate the proposed signal transmission method: transmission at discrete moments and transmission at continuous moments, and their multiple access interference (MAI) performances are analyzed and compared via simulation. It is shown that the performance of discrete transmission scheme is slightly better than the other one.

Keywords— time division duplexing; satellite communication; code division multiple access; asynchronous reception; multiple access interference

I. INTRODUCTION

In the recent past, natural disasters have happened all over the world, destroyed the terrestrial communication networks, and left millions of people isolated with no way to communicate to their families, emergency responders, or potential relief supporters. The importance of developing satellite communication networks has been highlighted unanimously. On the other hand, along with the publication of Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) and the research of TD-SCDMA Long Term Evolution Advanced (TD-LTE-A), the communication scheme based on TDD has attracted a lot of attention, especially in satellite communication system with a quite limited resource of bandwidth.

However, due to the longer transmission delays relative to its terrestrial counterpart, it is not easy to implement satellite

communication systems based on TDD. That is why most satellite communication systems do not apply TDD mode for the present, and the related references are rare^{[1]-[4]}. A solution of Half-Frequency Division Duplexing (HFDD) mode over satellite is proposed by time synchronization of the uplink and downlink frames in Reference [4]. Inspired by the time synchronization, we propose two new schemes of CDMA transmission in satellite communication system based on TDD in this article, and both schemes realize satellite asynchronous reception by pre-defining a certain guard time for different terminals in a spot beam, which means that the satellite communication systems based on TDD are feasible.

The remainder of this paper is organized as follows. Section 2 presents the CDMA satellite communication system based on TDD. Section 3 describes the CDMA transmission scheme. Section 4 presents the analysis and simulation results of multi-user performance. Section 5 concludes the paper.

II. SYSTEM DESCRIPTION

In a satellite communication system, the propagation delays are much longer than its terrestrial counterpart. As shown in Figure 1, the absolute delay from the beam center to the satellite is on the order of hundreds of milliseconds, and the differential delay to the satellite between the beam edge and the beam center varies from a fraction of a millisecond to several milliseconds, depending on the beam position. Define the longest unilateral differential delay to the satellite between the beam edge and the beam center as X , then the longest intra-beam differential delay is $2X$. Therefore, in order to avoid the overlap between the uplink subframe and the downlink subframe at the satellite receiver, the terminal should advance or retard the transmission of the uplink subframes by a certain guard time based on the intra-beam differential delay relative to the mean delay.

Reference [5] defined the frame structure for mobile satellite communication based on TDD. The basic transmission unit is a superframe, which is composed of several frames, one or zero short frame and a padding. The superframe has the length of the mean delay in the spot beam, and the i^{th} superframe from the transmitter is received at the $(i+1)^{\text{th}}$ superframe at the receiver. A frame is composed of a

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² Corresponding author is Jianjun Wu (e-mail: just@pku.edu.cn).

downlink subframe and an uplink subframe, and a downlink frame comprises several downlink time slots while an uplink frame comprises several uplink time slots and a satellite guard time. The satellite guard time is designed to deal with the differential delay to the satellite between the beam edge and the beam center and leaves room for the asynchronous arrivals of the uplink transmissions.

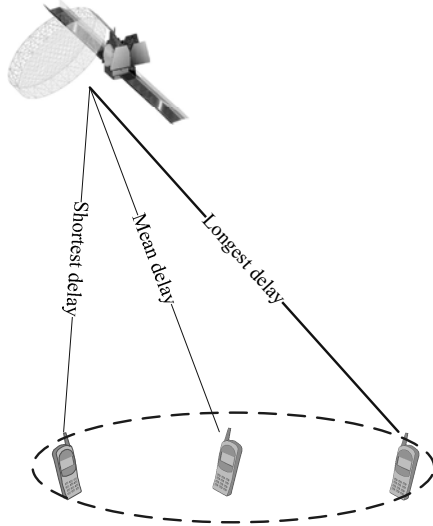


Figure 1. Different transmission delays between the terminals and the satellite in a spot beam

III. TRANSMISSION SCHEME OF CDMA SATELLITE COMMUNICATIONS SYSTEM BASED ON TDD

In CDMA satellite communication systems based on TDD, the concepts of synchronous CDMA and asynchronous CDMA are used to define satellite synchronous reception and satellite asynchronous reception, respectively.

A. Satellite synchronous reception

Satellite synchronous reception means that all the uplink signals from different terminals in a spot beam fall into the uplink reception window when they arrive at the satellite, and have the same time of arrival. This scheme can be implemented with $4X$ as satellite guard time^[4]. The signal at the satellite receiver is synchronous CDMA signal, which has minor or none multiple access interference (MAI), and the peak system capacity can be gained. The defect of satellite synchronous reception is the relative longer satellite guard time $4X$ which occupies more uplink transmission time for the terminals and decreases the uplink transmission efficiency.

B. Satellite asynchronous reception

Satellite asynchronous reception means that all the uplink signals from different terminals in a spot beam fall into the uplink reception window when they arrive at the satellite, but have different times of arrival. This scheme can be implemented with $2X$ as satellite guard time. The signal at the satellite receiver is asynchronous CDMA signal, which might have serious MAI, degrade the system performance and reduce the system capacity. However, both the uplink

transmission time for the terminals and the system efficiency are increased.

There are several different schemes to implement satellite asynchronous reception, and we only describe and analyse two schemes in the following: transmission at discrete moments, and transmission at continuous moments.

1) Transmission at discrete moments: According to the position of the terminals with different propagation delays, the scheme of transmission at discrete moments (scheme 1) divides the spot beam coverage into three zones: (1) center zone, (2) far zone, (3) near zone, as shown in Figure 2. In order to ensure that the uplink signals fall into the uplink reception window, the distances Δ_1, Δ_2 between the boundary Y_1, Y_2 and the center line are located between 0 and $X/2$. Y_1 and Y_2 are the contours for the same propagation delay, which might be curves actually.

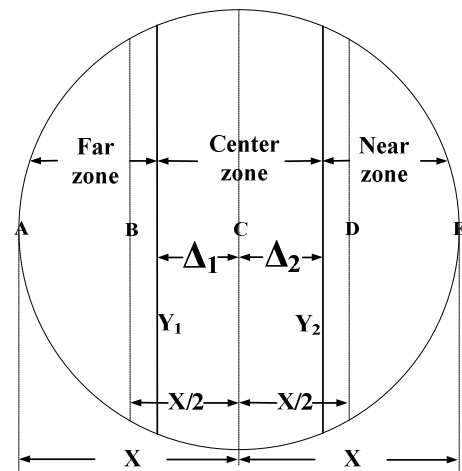
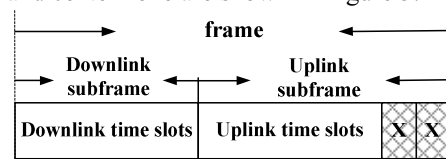
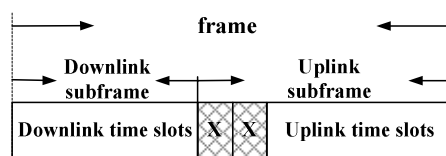


Figure 2. The division of the spot beam coverage

A stationary frame is deployed for each zone in the spot beam. The frame structures for the terminals in the far zone, near zone and center zone are shown in Figure 3.



(a) The frame structure for the terminals in the far zone



(b) The frame structure for the terminals in the near zone

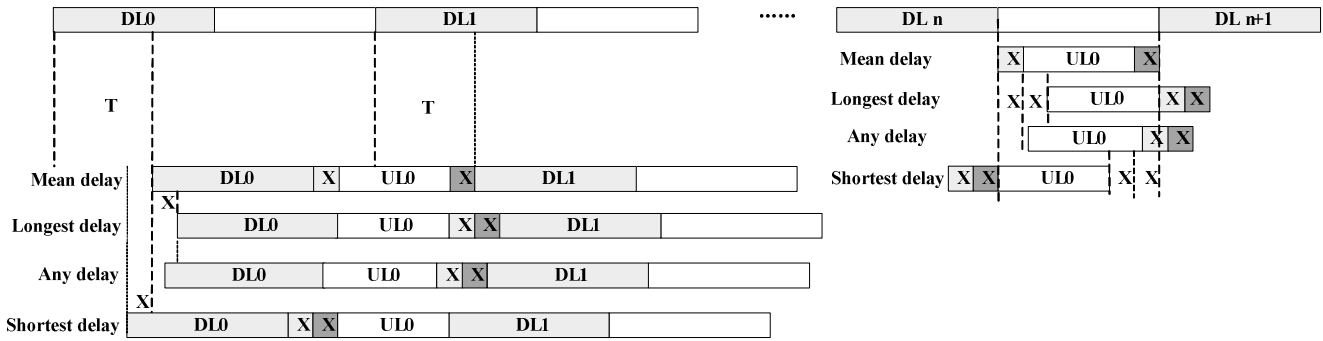
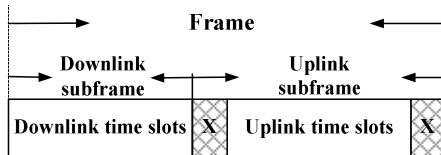


Figure 4. Transmission at discrete moments



(c) The frame structure for the terminals in the center zone

Figure 3. The frame structures for the three zones

By ranging or positioning, the terminal determines its zone, and utilizes the corresponding frame structure to transmit its signals. When the terminal finishes the reception of the downlink subframe, it begins the uplink transmission according to the uplink subframe. With the transmission arrangement, the satellite asynchronous reception is shown in Figure 4. The terminal with the mean delay is in the center zone, and thus transmits using the frame structure in Figure 3(c) so that the uplink data arrives in the middle of the uplink reception window; the terminal with the longest delay is in the far zone, and thus transmits using the frame structure in Figure 3(a) so that the uplink data arrives in the rear of the uplink reception window; the terminal with the shortest delay is in the near zone, and thus transmits using the frame structure in Figure 3(b) so that the uplink data arrives in the head of the uplink reception window.

The advantage of Scheme 1 is that the start time of the uplink transmission for the terminal is the end time of the downlink reception. Therefore, accurate satellite clock timing is not needed and the demand for terminal clock accuracy is reduced.

2) Transmission at continuous moments: The scheme of

transmission at continuous moments (scheme 2) has a common transmission start time T_1 for all the terminals in a spot beam to realize satellite asynchronous reception, as shown in Figure 5. The transmission of all terminals starts at time T_1 and ends at time T_2 , and because of the different transmission delays, the uplink signals fall into the uplink reception window at the satellite naturally.

The advantage of Scheme 2 is that the start time of uplink transmission is determined by the satellite, which means that the ranging and positioning operations of the terminal are skipped and the complexity is reduced accordingly.

There are only three positions in a spot beam which have the same uplink reception time at the satellite receiver both in Scheme 1 and Scheme 2: the positions of the longest delay, the shortest delay and the mean delay. Other positions apart from these three have different uplink reception time at the satellite receiver in Scheme 1 and Scheme 2.

IV. ANALYSIS AND SIMULATION OF THE SATELLITE ASYNCHRONOUS RECEPTION PERFORMANCE

The performances of Scheme 1 and Scheme 2 are compared in this section. Suppose the longest propagation delay in a spot beam is D_1 , the length of uplink subframe is T_0 , then the shortest delay is $D_1 - 2X$, the mean delay is $D_1 - X$, the delay at any position is $D_1 - \Delta$, and the effective uplink transmission time is $T_0 - 2X$ in satellite asynchronous reception.

Suppose A and B are two positions apart from the longest delay, the shortest delay and the mean delay in a spot beam,



Figure 5. Transmission at continuous moments

and the propagation delay of A and B are $D_1 - \Delta_1$ and $D_1 - \Delta_2$, respectively. The length of the overlapping piece between transmissions from A and B at the satellite receiver is $T_0 - 2X - 2|\Delta_1 - \Delta_2|$ in Scheme 1, and $T_0 - 2X - |\Delta_1 - \Delta_2|$ in Scheme 2, which results in different multiuser interference. For example, suppose $T_0 = 5ms$, $2X = 1.3ms$, $|\Delta_1 - \Delta_2| = 1ms$, the overlapping length is 1.7ms in Scheme 1 and 2.7ms in Scheme 2.

The spreading codes that are employed in the system also affect the multiuser interference level. Suppose there are two terminals in the coverage of a spot beam, and BPSK is used without channel coding or interleaving. The additive white Gaussian noise (AWGN) channel model is employed. The bit error (BER) curve of satellite synchronous reception has been added to the simulation results to compare.

1) Suppose $T_0 = 5ms$, $2X = 1.3ms$, $|\Delta_1 - \Delta_2| = 1ms$, the overlapping length is 1.7ms in Scheme 1 and 2.7ms in Scheme 2. The orthogonal variable spreading factor (OVSF) codes with spreading factor 16 are employed. The average BER performance of the two schemes with single user detection is shown in Figure 6.

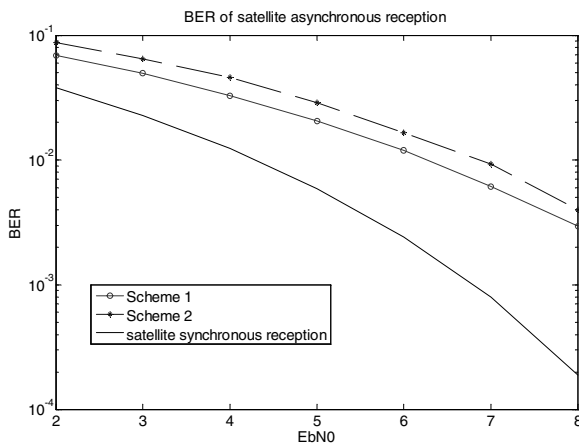


Figure 6. The BER performance of satellite asynchronous reception 1

Because the cross correlation of OVSF codes is zero, the BER of satellite synchronous reception is the ideal AWGN BER. The average BER of satellite asynchronous reception is worse than that of satellite synchronous reception, and the average BER of Scheme 1 is slightly better than Scheme 2 when OVSF codes with spreading factor 16 are employed.

2) Suppose $T_0 = 5ms$, $2X = 1.3ms$, $|\Delta_1 - \Delta_2| = 1ms$, the overlapping length is 1.7ms in Scheme 1 and 2.7ms in Scheme 2. The Gold codes with code length 31 are employed. The average BER performance of the two schemes with single user detection is shown in Figure 7.

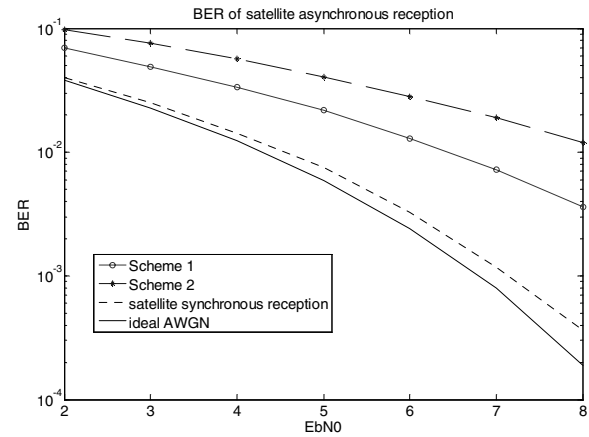


Figure 7. The BER performance of satellite asynchronous reception 2

Because the cross correlation of Gold codes is not zero, the BER of satellite synchronous reception is not the ideal AWGN BER. The average BER of satellite asynchronous reception is worse than that of satellite synchronous reception, and the average BER of Scheme 1 is slightly better than Scheme 2 when Gold codes with code length 31 are employed.

To sum up, CDMA satellite communications based on TDD with satellite asynchronous reception are affected by multiuser interference, which is related to both the overlapping length and the cross correlation of the spreading codes. Single user detection under this circumstance will result in poor BER, and the performance improvement is limited and slow as the signal to noise ratio (SNR) at the detection point increases. Therefore, multiuser detection is necessary when satellite asynchronous reception is employed, and minimum mean square error (MMSE) criterion or maximum likelihood (ML) criterion can be used to suppress the multiuser interference^{[6]-[8]}. The complexity of optimal multiuser detection is quite high, and some simplified suboptimal multiuser detection can be used to achieve a compromise between performance and complexity. The next object is to find such a multiuser detection method which applies to TDD satellite asynchronous reception and has a good compromise between performance and complexity. In addition, if channel coding and interleaving have been used, the average BER of satellite asynchronous reception could be improved a lot.

V. CONCLUSIONS

A new asynchronous transmission method is proposed to improve the utilization rate of uplink timeslots in CDMA satellite communication systems based on TDD. Different terminals in a beam transmit their data block at different moments in the uplink window according to a certain rule, and the uplink guard time can be reduced to one time the maximum differential propagation delay in the beam. The utilization rate of uplink timeslots is improved compared with two times the maximum differential propagation delay needed for the transmission of synchronous reception in Reference [4].

Furthermore, two schemes are proposed to verify the feasibility of the proposed method: transmission at discrete moments and transmission at continuous moments, and multiuser interference of asynchronous code division multiple access reception is analysed and compared. Simulation results show that the performance of transmission at discrete moments is better and help prepare for the application of CDMA satellite communication systems based on TDD.

REFERENCES

- [1] Wolfgang Kogler, et al., "Timing Synchronization in MF-TDMA Systems for Geostationary Satellites," *IEEE Communications Magazine*, Dec. 2007.
- [2] Hulbert, et al., "A Method of Communication in a Time Division Duplex (TDD) Satellite Communication System," EU Patent EP 1 698 075 B1, Jan. 2008.
- [3] Rec. ITU-R M.1457-6, "Detailed Specifications of the Radio Interfaces of International Mobile Telecommunications-2000 (IMT-2000)," 2006.M. Wegmuller, J. P. von der Weid, P. Oberson, and N. Gisin, "High resolution fiber distributed measurements with coherent OFDR," *Proc. ECOC'00, 2000*, paper 11.3.4, p. 109.
- [4] Arif Ansari, et al., "S-WiMAX: Adaptation of IEEE 802.16e for Mobile Satellite Services," *IEEE Communications Magazine*, Jun. 2009.
- [5] JianJun Wu, et al., "Transmission based on Time Division Duplexing in Mobile Satellite Communications", CN 201010186304.3, 2010.
- [6] Xie Hong, "Research on Anti-jamming Technology of CDMA Communicate System," Ph.D. dissertation, Harbin Engineering University, Dec. 2005.
- [7] Ni Liang fang, Zheng Bao yu, Wu Xin yu, "The application investigation of hybrid genetic algorithm for multi-user detection with diversity reception in asynchronous CDMA mobile communications," *Journal of China Institute of Communications*, 2003, 24(2): 27-36.
- [8] Wang An yi, Li Xu hong, "Space-time Multiuser Detection in Asynchronous Multi-path CDMA Systems," *Signal Processing*, 18(4): 331-335, 2002.