

Research on Adaptive Transmission of Time Division Duplex Physical Frame in Mobile Satellite System¹

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Abstract— An adaptive adjustment strategy in the transmission of physical frame is proposed for a satellite communication system based on time division duplexing. The proposed strategy adaptively adjusts both superframe length and uplink synchronization time according to the subregion determined by the positions of all active users. Meanwhile, a transition procedure for physical frame adjustment is also designed. Since the proposed strategy not only improves transmission efficiency as high as possible but also ensures data reliability, it establishes a foundation for the application of time division duplexing in satellite communication systems.

Keywords—Multi-beam satellite system, geosynchronous satellite, propagation delay, Time Division Duplex, adaptive radio frame

I. INTRODUCTION

No matter how quickly wireless communications develop, seamless coverage can't be realized without satellite system especially in the areas such as forests, mountains and deserts. Meanwhile, satellite plays an important role in emergency communication when natural disasters occur.

Recently, satellite communication has gained enormous attention in the wake of third-generation (3G) wireless communications. However, because of the long propagation delay—the round trip time is about 270ms in GEO satellite system—which may lead to quite a number of problems for the realization of satellite system based on Time Division Duplex (TDD) mode, most of the researchers concentrate on the satellite system being compatible with Frequency Division Duplex (FDD) mode. Studies on TDD satellite system are quite few. [4]-[7] proposed some methods to solve timing synchronization issues, but there is no practically feasible solutions for radio frame design.

However, TDD is an optional mode for 3GPP UMTS and utilizes the spectrum more efficiently and flexible than FDD mode. Aiming to cope with the long propagation delay and large differential propagation delay within one beam, Patent [8] introduces the concept of superframe and uplink window and

can be taken as a solution of TDD satellite system. However, the efficiency of this method is low especially in areas where users are quite few such as forest, seas and so on. The main reason is that the uplink synchronization time in uplink window is fixed to be the largest value for all cases and leads to unnecessary waste.

Based on the design of [8], we propose an adaptation strategy for physical frame which can adjust the uplink synchronization time adaptively according to users' positions in one beam, which can enhance transmission efficiency in some special areas.

The paper is organized as following: the physical frame structure in patent [8] is displayed in Section II. Section III explains the adaptation design and handover process. In Section IV, some explanation and analysis is presented and Section V concludes the paper.

II. SYSTEM MODEL

Patent [8] has proposed a kind of frame structure for TDD satellite system, which is suitable for various multiple access technologies, see Figure 1. The biggest unit of physical frame is superframe, which consists of one or several normal frames, one or zero short frame and a filled field without any useful information in it. The length of superframe is decided by the mean propagation delay between satellite and user. Each normal frame consists of a downlink block and an uplink window as opposed to short frame consisting only uplink window. Another important difference between this frame structure and the one defined in 3GPP standard is the uplink synchronization time set in uplink windows, which is decided by maximum differential propagation delay within a beam. Patent [8] has only proposed the basic structure to realize TDD satellite system.

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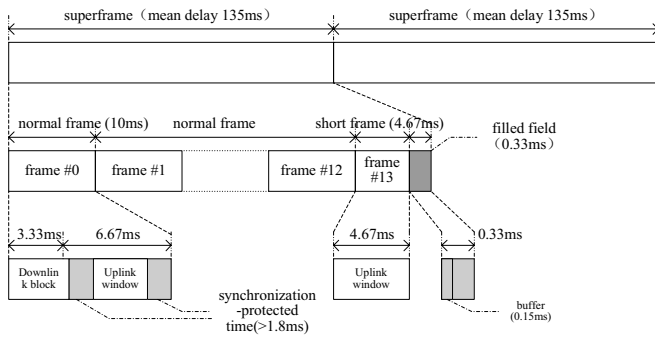


Figure 1. The physical frame structure for TDD satellite system

III. ADAPTIVE PHYSICAL FRAME TRANSMISSION

In Figure 1, the uplink synchronization time is decided by maximum differential propagation delay within a beam, but for some region where the users are relatively concentrated, the unified uplink synchronization time might be a waste. Therefore, the transmission efficiency can be improved by adaptive superframe structure.

Now, we define an adaptive subregion which is the smallest circular region covering all the active users in a beam, as shown in Figure 2. The uplink synchronization time is adjusted according to the range of the subregion in order to enhance transmission efficiency. When a new user turns up, or the user on the edge of the adaptive subregion moves outside, the adaptive subregion enlarges, as shown in Figure 2(a); when the user on the edge of the adaptive subregion turns down or moves inside, the adaptive subregion shrinks, as in Figure 2(b); otherwise the adaptive subregion stays the same. Because the maximum differential propagation delay determined by the active users is shorter than the counterpart within a beam, the uplink synchronization time can be reduced and the uplink transmission efficiency can be improved.

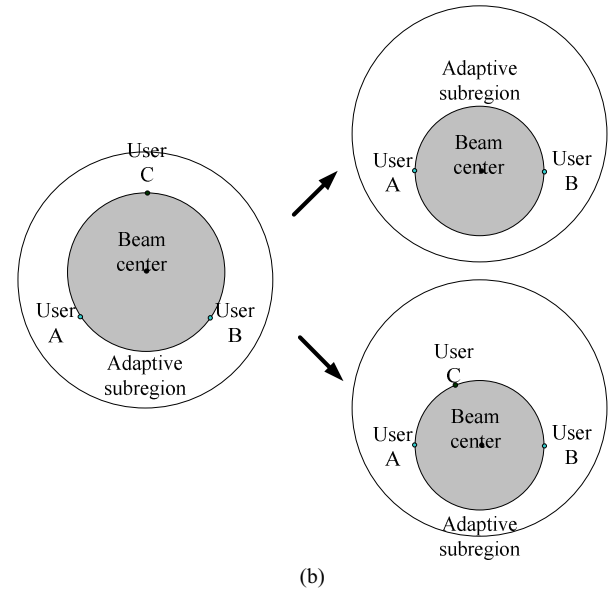
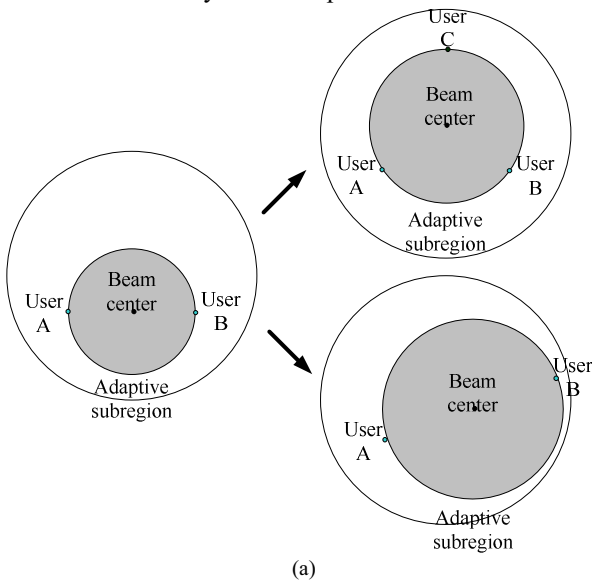


Figure 2. The adjustment of the adaptive subregion

The changes of center and coverage of the adaptive subregion can separately affect the maximum differential propagation delay and mean propagation delay in a beam, therefore, the lengths of superframe and uplink synchronization time within the adaptive subregion should also change correspondingly. The corresponding handover process is needed to ensure the reliability of data transmission during the adjustment.

An example of the adjustment process is given in the following subsections. Suppose there is more than one user in the beam coverage, and the initial users determine an initial subregion.

A. When the adaptive subregion enlarges as in Figure 2(a), the adjustment process of the superframe length is described in Figure 3.

(1) In Slot i , the adjustment message is sent by the satellite, but the subregion center and the superframe length stay the same.

(2) In Slot $i+1$, the adjustment message is received at the user terminal, and the superframe length of Slot $i+1$ is increased accordingly.

(3) In Slot $i+1$, the short frame length of Slot $i+1$ is increased by the satellite, and the subregion center is changed accordingly. The adjustment is finished.

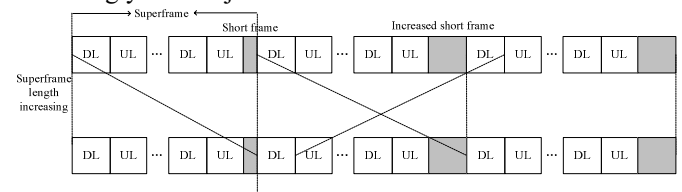


Figure 3. The adjustment process when the superframe length increases

B. When the adaptive subregion enlarges as in Figure 2(a), the adjustment process of the uplink synchronization time is described in Figure 4.

(1) In Slot i , the adjustment message is sent by the satellite, but the subregion coverage and the uplink synchronization time stay the same.

(2) In Slot $i+1$, the adjustment message is received at the user terminal, and the uplink synchronization time of Slot $i+1$ is increased accordingly.

(3) In Slot $i+1$, the uplink synchronization time of Slot $i+1$ is increased by the satellite, and the subregion coverage is changed accordingly. The adjustment is finished.

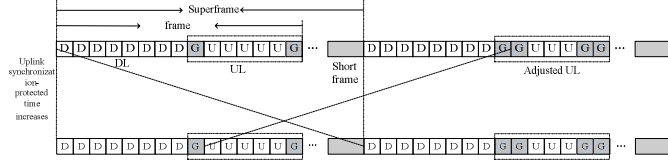


Figure 4. The adjustment process when the uplink synchronization time increases

C. When the adaptive subregion shrinks as in Figure 2(b), the adjustment process of the superframe length is described in Figure 5.

(1) In Slot i , the adjustment message is sent by the satellite, but the subregion center and the superframe length stay the same.

(2) In Slot $i+1$, the adjustment message is received at the user terminal, and the superframe length of Slot $i+1$ is decreased accordingly.

(3) In Slot $i+1$, the short frame length of Slot $i+1$ is decreased by the satellite, and the subregion center is changed accordingly. The adjustment is finished.

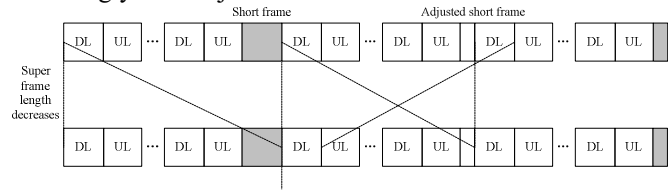


Figure 5. The adjustment process when the superframe length decreases

D. When the adaptive subregion enlarges as in Figure 2(b), the adjustment process of the uplink synchronization time is described in Figure 6.

(1) In Slot i , the adjustment message is sent by the satellite, but the subregion coverage and the uplink synchronization time stay the same.

(2) In Slot $i+1$, the adjustment message is received at the user terminal, and the uplink synchronization time of Slot $i+1$ is decreased accordingly.

(3) In Slot $i+1$, uplink synchronization time of Slot $i+1$ is decreased by the satellite, and the subregion coverage is changed accordingly. The adjustment is finished.

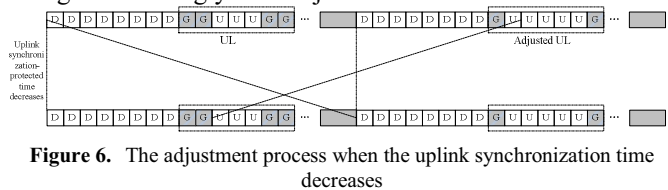


Figure 6. The adjustment process when the uplink synchronization time decreases

IV. RESULT ANALYSIS

The adaptation scheme proposed in section 3 shows that all active users can determine an adaptive subregion in a beam and adjusting the uplink synchronization time according to the range of the subregion can enhance transmission efficiency. In some special areas, such as forest, seas and mountains, users in a beam are quite few, and therefore it is more suitable to apply this adaptive scheme.

Take a simple case in China as an example: if the radius of the subregion becomes half of its belonging beam by using this scheme, $R_a = 1/2R_0$, we can calculate the change of maximum differential propagation delay in the subregion by space geometric model, shown as figure 7. We focus on the beams near Kashgar area in Sinkiang province. If assume that the actual beam radius is 200km and the longitude of GEO satellite is 115.5° E, the maximum differential propagation delay changes from 1.167ms to 0.5834ms with the reduce of the subregion area. Therefore, the uplink synchronization time can become much shorter than before (0.5836ms). Moreover, the length of superframe is not changed (129.019ms) in this case. Thus the transmission efficiency in radio frame can be obtain by

$$\eta = \frac{(T_f - T_\Delta) \lfloor T_{sf} / T_f \rfloor}{T_{sf}} \quad (1)$$

where T_{sf} , T_f , T_Δ are the length of superframe, normal radio frame and uplink synchronization time.

The enhancement of transmission efficiency in this case is 5.4%.

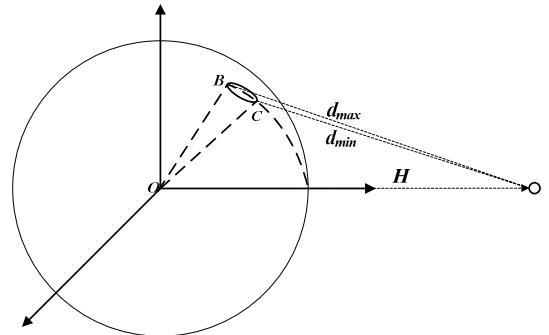


Figure 7. Calculation of the maximum differential propagation delay

Though transmission efficiency can be increased by adopting this adaptive scheme, the change of the position or the number of active users also leads to the change of superframe. Because of the long propagation delay, the data sent before adaptation will be destroyed or lost if there is no handover-protected method when the length of superframe and uplink synchronization time changes. The handover process proposed in section III provides a solution for this problem. It can guarantee the reliability of data transmission in the process of radio frame adaptation and is a crucial step to realize the adaptive transmission.

However, the performance of this scheme in areas with numbers of users is not very good because the subregion may be almost the same with great probability. In these cases, this adaptation scheme can't increase system efficiency obviously.

Moreover, the subregion will be continuously changing if the users at the edge of subregion are moving at a high speed. The radio frame in this case will also be continuously changing accordingly and the whole system is always in the handover process which will lead to tremendous waste of system resources. Therefore, the frequency of adaptation is a considerable factor in the future.

V. CONCLUSION

Adaptive transmission of physical frame has been researched in satellite system based on TDD mode. In order to enhance transmission efficiency, a new subregion within a beam is defined which is decided by all active users' positions in this beam. The length of superframe and uplink synchronization time changes with the real-time change of the subregion. Based on the subregion, adaptive handover process is proposed in order to guarantee the transmission reliability when adaption of physical frame is ongoing. This research may play an important role in implementing TDD satellite system in the future.

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