

An Uplink Timing Synchronization Method for GEO Mobile SAT-LTE System

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Abstract—In this paper, we investigate uplink timing synchronization problem in GEO mobile SAT-LTE system. Firstly, we introduce a two-hop GEO multi-beam satellite communication model, and simply analyze the issues of existed timing synchronization methods. After that, we set the round trip delay (RTD) of furthest point in a beam as the timing reference (TR), with this reference, an available uplink timing synchronization method named modified frame alignment (MFA) is proposed, which take into consideration of LTE signalling and minimum scheduling unit. In the end, the simulation result demonstrates that the proposed method has higher system efficiency, better Qos performance for delay sensitive services, and higher degree of commonality with the terrestrial LTE networks.

Keywords—Uplink timing synchronization, GEO mobile satellite communication, LTE.

I. INTRODUCTION

With the development of information technology in human life, the demands for mobile communication are increasing rapidly. Long Term Evolution (LTE) often called 4G can support low to high-mobility applications and a wide range of data in accordance with user and service demands [1]. The terrestrial wireless network based on LTE specifications has been constructed in some countries and regions. As an important part of mobile communication field, mobile satellite communication can offer services in the regions outside terrestrial coverage, including physically isolated regions, and areas where terrestrial network collapses due to disaster. In order to provide the seamless service in a global coverage, it is a critical issue to design a satellite radio interface, which should have a high degree of commonality with the terrestrial LTE networks.

Based on the consideration above, ITU-R calls for proposals for the satellite component for LTE-Advanced FDD, and provides the satellite requirements in Sep 2012 [2]. ETSI also publishes its technique report ETSI TR 101 542, which compares the OFDM and WCDMA performances as satellite radio interface in Jul 2013 [3]. As a result, many initiatives have been carried out [4]–[7] for the design of a satellite air interface that maximizes the commonalities with the LTE. However, not much attention has been paid to the study on the adaptive technique named uplink timing synchronization, which is a key scheme in air interface design. The main role of uplink timing synchronization is to hold the orthogonality between users within a beam at the receivers, if users are not synchronized, they will interfere with each other, and therefore

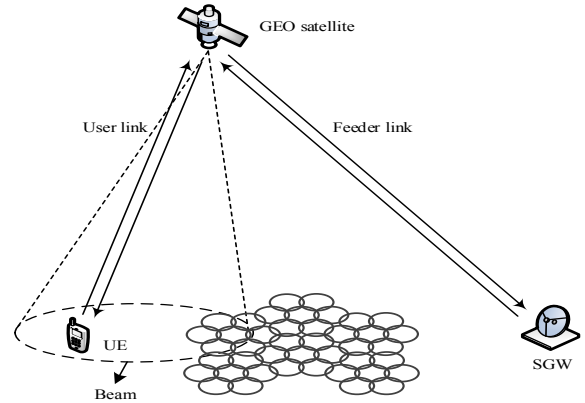


Fig. 1. Two-hop GEO multi-beam satellite communication model.

the satellite will not be able to recover individual signal of each user. Hence, all users should arrive at the satellite gateway (SGW) at the same time with a high timing accuracy.

In the terrestrial LTE wireless network, to ensure such receiver-side time alignment, LTE includes a mechanism for transmit-timing advance. In essence, timing advance (TA) is a negative offset between the start of received downlink signals and transmitted uplink signals [8]. It is infeasible in mobile satellite communication adopting the terrestrial approach. We should make some modifications from terrestrial radio interface to adapt to the satellite characteristics, such as large differential delays between users within the beam. Three kinds of timing synchronization schemes are proposed in [9] and [10], which are named subframe alignment (SFA), timeslot alignment (TSA) and symbol alignment (SYA) respectively, but they don't consider LTE signalling and scheduling unit. Thus, it is necessary to investigate uplink timing synchronization for GEO mobile SAT-LTE system in detail.

II. SYSTEM MODEL

The two-hop satellite communication system is shown in Fig. 1, which consists of GEO satellite, satellite gateway (SGW), user equipments (UEs). The GEO satellite is a transparent bent pipe, that is to say, signals can't be processed and switched onboard. There are two links in this model, one is UE-satellite link named user link, and the other is SGW-satellite link, which is referred to as feeder link. The user link

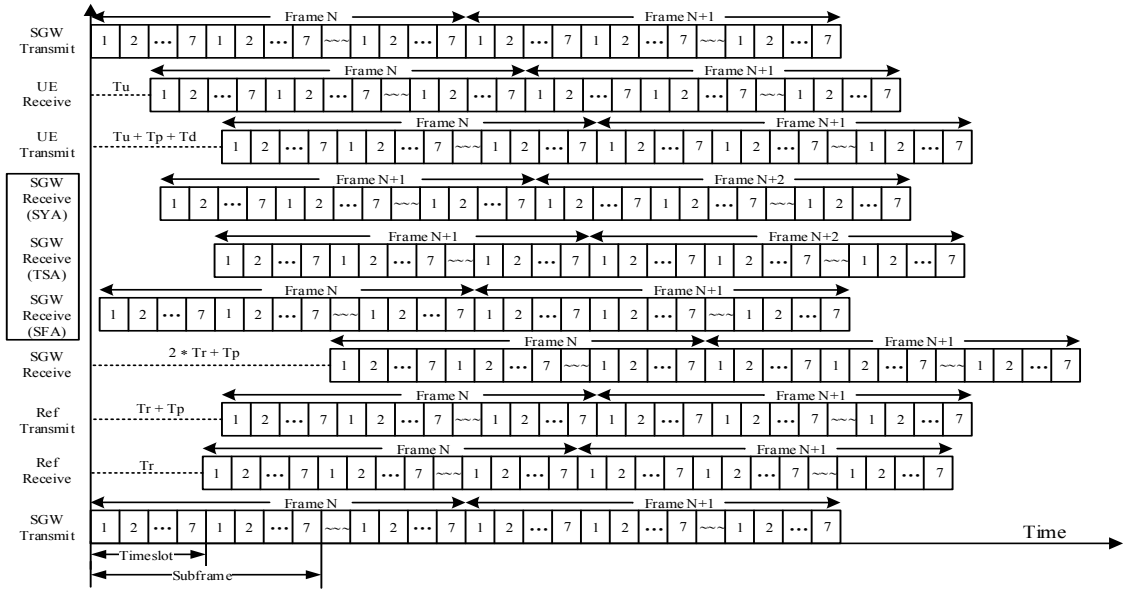


Fig. 2. The existed timing synchronization methods (SFA, TSA and SYA).

is specified based on LTE specifications, which is research emphasis in satellite air interface design. The objective of user link interface design is to keep similar or even the same as those of the terrestrial part, which can minimize the chipset cost by using the mature industry chain.

In multi-beam satellite communications system, the focused areas are divided into numbers of spot beams, which are formed by beamforming technology. Because there is an elevation angle for each beam, different users may have different propagation delay characteristic within the same beam. In this paper, we set the RTD of furthest point as the TR in one beam. With this TR, the differences of propagation delay relative to TR for UEs can be calculated according to the method in [11]. On the basis of analysis results in [11], the difference is mainly determined by the geographic coordinate of UE and the beam size.

In terrestrial wireless network, uplink timing synchronization is achieved by frame alignment scheme (FA). However, the difference of the delay within a beam in GEO satellite communication is very long compared to terrestrial network. It is waste of time resources seriously, if we solve the problem using the same timing synchronization procedure as in the conventional LTE. In addition, the maximum value possible for TA is $0.67ms$, corresponding to a terminal-to-base-station distance of slightly no more than $100km$, which can't meet the timing demand in GEO mobile satellite communication.

III. TIMING SYNCHRONIZATION METHOD

Aiming at solving this problem, Hee Wook Kim et al. propose three kinds of timing synchronization methods, which are SFA, TSA and SYA. In this section, these existed methods are analyzed and we propose a timing synchronization method

taking into LTE signalling and minimum scheduling unit consideration.

A. Existed timing synchronization method

The existed synchronization methods have minor difference in essence, the only difference is time unit in alignment. Three alignment methods are shown in Fig. 2, where Ref represents reference UE, which is located at the furthest point in the beam. T_r is the propagation delay between reference UE and SGW via satellite. T_p is the processing delay at UE, which is the same for all of UEs in this beam. The propagation delay between any user and SGW can be indicated by T_u . T_d is the transmission delay for any UE. From Fig. 2, we can see that the transmission delay for UE can be reduced to one subframe, one timeslot, and one symbol for SFA, TSA and SYA respectively. Although these existed methods make full use of time resource, it also has some issues in uplink timing synchronization for losing sight of LTE signalling and minimum scheduling unit.

The basic resource block is defined over one slot in LTE. In fact, in order to enhance the time and frequency diversity, the minimum scheduling unit, consisting of two time-consecutive resource blocks within one subframe, can be referred to as a resource block pair. For TSA and SYA, the scheduler can make the received uplink signal at SGW suffer from harmful co-channel interference (i.e., we can see from Fig. 2 that the 2th slot of frame $N + 2$ in the UE may interfere with the 1th slot of frame $N + 1$ in reference for TSA), and it will decrease the system throughput. Thus, the scheduler has little abilities to allocate resource block pair for UE in that slot. This problem also exists in SYA. In addition, all of UEs can be reached timing synchronization at SGW-side by random access process. SGW can estimate the transmission delay, and return the value to each UE. However, the maximum value

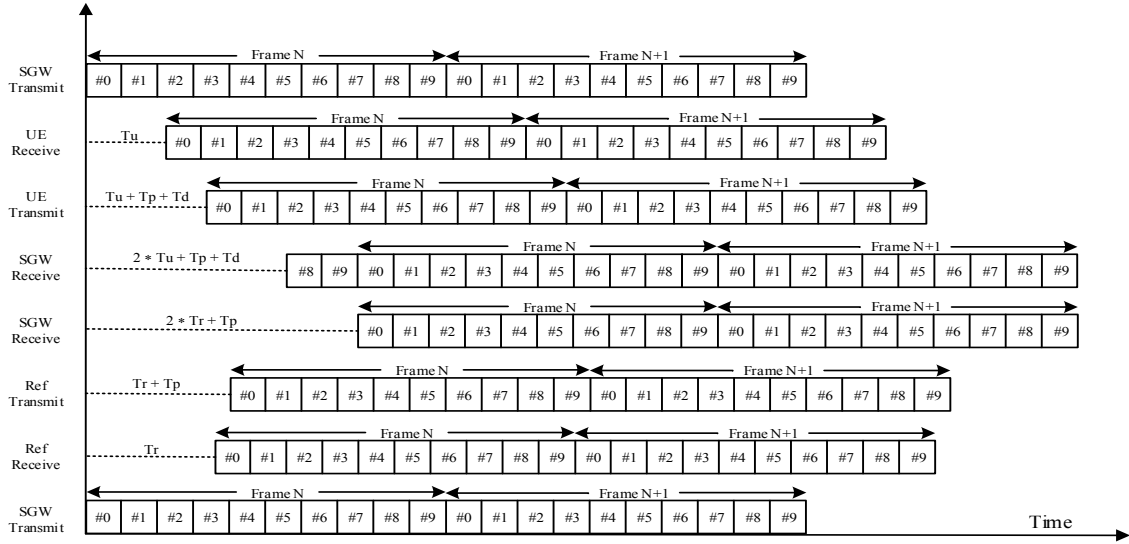


Fig. 3. The proposed timing synchronization method (MFA).

possible for LTE signalling is $0.67ms$, which can't meet the demand for timing in SFA since it requires at least $1ms$.

B. Proposed timing synchronization method

Aiming at the issues of existed timing synchronization methods, we propose an uplink timing synchronization method, which is called modified frame alignment (MFA) as shown in Fig. 3. In this method, we use the same timing synchronization procedure as FA in terrestrial LTE network, and only modify resource allocation scheme in the first several subframe. From Fig. 3, we can see that once the Ref receives the random access response signal, it will process and acquire the scheduling information, and then Ref transmits the uplink signal in specific resource block pair after T_p . On the other hand, we apply a different resource allocation scheme for UE. In fact, SGW can estimate the difference of RTD for UE relative to Ref accurately, and the minimum scheduling unit in LTE specification is $1ms$. It means that the uplink scheduler can allocate the specific resources to UEs simultaneously in order to maintain the orthogonal for UEs at receive-side if SGW receives the random access response signal within $1ms$. As shown in Fig 3, UE receives the random access response signal from SGW after T_u , and only delays $2 \times (T_r - T_u) - n \times T_{sub}$ for transmitting uplink signals according to proposed method, where n is able to keep the delay within $1ms$. Meanwhile, UE can use these n subframe to bearer previous data, and data will be framing from $n + 1$ subframe, the procedure is just the same as in the conventional LTE later. By this way, we can keep the high degree of commonality with the LTE system in physical layer. Moreover, MFA is similar to SFA, and the only difference is resource scheduling type. LTE supports three scheduling types, which are dynamic, semi-persistent, and fixed scheduling [12]. However, scheduler can

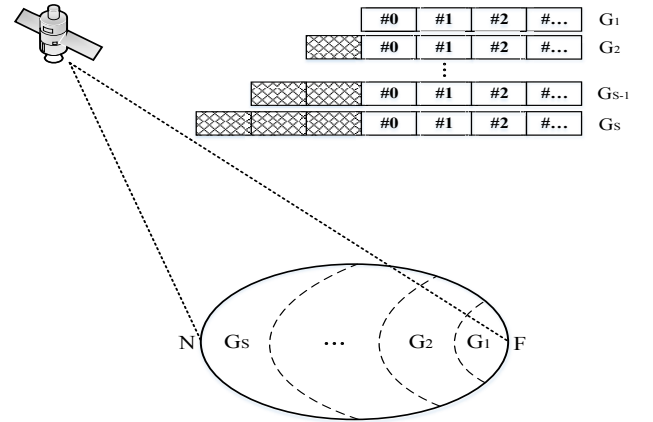


Fig. 4. The procedure of MFA.

only employ dynamic scheduling in SFA because the subframe number is continuous misplaced. On the contrary, dynamic scheduling is only carried out in the first n subframe in MFA, three kinds of scheduling types can be applied based on service type from $n + 1$ subframe.

It is assumed that a set of M UEs ($UE_i, i = 1, 2, \dots, M$) have already obtained downlink synchronization via Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS), and they want to achieve uplink synchronization by random access procedure. The complete procedure of the proposed timing synchronization method can be illustrated as follows, which is shown in Fig. 4:

- *Step I:* UE_i calculates the difference Δt_i of RTD with respect to TR. All of UEs are divided into S groups based

on Δt , (i.e., UE_i will be categorized into group G_j ($j = 1, 2, \dots, S$), when $(j-1)T_{sub} \leq \Delta t_i \leq jT_{sub}$, where T_{sub} is subframe length in LTE equals to $1ms$).

- *Step II*: UE_i initiates random access request. The request signal arrives SGW via satellite, and SGW obtains the accurate differences of RTD for UE_i (T_{acc}) based on the method as terrestrial network (the details is beyond the scope of this paper).
- *Step III*: SGW calculates the coarse differences of RTD for UE_i (T_{coa}) according to its position information and beam size, and returns the differences (T_{dif}) between T_{acc} and T_{coa} , which is loaded in TA signalling. In addition, a scheduling grant, indicating resources those group UEs will use for the transmission of the message is also delivered by random access response.
- *Step IV*: Once UE_i receives the random access response signals, the transmission delay (T_d) can be achieved by means of $T_d = T_{coa} + T_{dif} - (j-1)T_{sub}$. Which resource block is assigned to UE_i for transmission can be know over scheduling grant.

Note that the uplink scheduler transmits scheduling information in each $1ms$. Specifically, resources are scheduled to the group of G_S UEs during the first scheduling period (SP) equals to $1ms$, in the next SP, the scheduler allocates resources to the group of G_S and G_{S-1} , and the like, resources will be assigned to all of M UEs of this beam.

IV. NUMERICAL RESULTS

In this section, we compare the performance between existed and proposed uplink timing synchronization methods. From Fig. 5, we can see that the transmission delay at a UE is increased by the difference between UE and reference or the beam size, if we apply the conventional synchronization procedure FA. In this case, it can bring the system efficiency to be decreased, and it is difficulty to support delay sensitive services such as voice over IP. Although the transmission delay can be reduced into $0.5ms$ and $0.0667ms$ for TSA and SYA respectively, co-channel interference may be induced to the system, which could result in total throughput decreasing seriously. SFA is available in SAT-LTE system, and has same performance with the proposed method MFA except for flexibility in resource scheduling. Therefore, MFA not only improve the transmission efficiency by saving time resources, but also enhance the Qos of delay sensitive services by reducing end-to-end latency. In addition, we can keep the maximum physical layer commonality with the terrestrial radio interface by a minor modification of higher layer procedure.

V. CONCLUSION

This paper presents a method of uplink timing synchronization named MFA in GEO mobile SAT-LTE system. We set the RTD of furthest point in a beam as the timing reference. With this reference, UEs are divided several groups according to their difference of propagation delays. Combined with resource scheduling, all of UEs achieve time alignment at SGW-side. From simulation result, we can see that the proposed method has higher system throughput and lower latency, and only

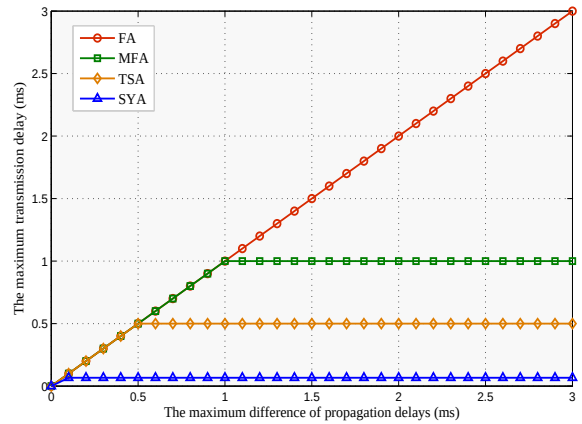


Fig. 5. The maximum transmission delays for different timing synchronization method.

needs minor modification of resource allocation scheme in the first several subframe.

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