TDD Mode on NTN Direct to Satellite Service

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Abstract

Though the Time Division Duplex (TDD) is a typical mode in the terrestrial communication, it was seldom applied in the satellite communication. With the increasing requirements on Direct to Satellite Service (D2SS), TDD is expected to solve the problems of low frequency shortages suitable for handheld terminals. This paper tries to discuss TDD mode on Non-Terrestrial Network (NTN) to support D2SS, including advantages and disadvantages, technical challenges and also potential solutions for TDD mode.

1. Introduction

In recent years, with the rapid development of mobile communication, electronic components, satellite engineering and other technologies, satellite communication systems have basically solved the problems of user access, call quality, data transmission and construction costs. On one hand, with the technologies of multiple satellites launching within one rocket and also recoverable launching vehicle, the cost of satellite development is getting lower and lower. On the other hand, the configuration of mobile phone is getting more and more advanced. These improvements have provided opportunities for mobile phone Direct to Satellite Service (D2SS), which is also becoming a hot topic in the industry.

From the perspective of industry discussion, there are mainly three technical routes for mobile phone D2SS. The first route uses traditional satellite phone with specific communication protocols and frequency bands, typical constellations include Iridium, Globalstar, Inmarsat, etc. The second route requires satellite to take all technical difficulties to make no change to existing mobile phones, typical companies include AST Space Mobile [1] and Lynk [2]. The third route mainly refers to the 3GPP Non-Terrestrial Network (NTN) [3-5] standard, where both the network and terminals are required to do enhancement to adapt to specific characteristics of the satellite link, and further some advanced features are being introduced to support the integrated satellite-terrestrial communication toward 6G [6-7]. At present, more and more satellite operators and terrestrial mobile operators are cooperating together to realize D2SS with the third route. It is expected that a user will use a unified terminal communicating with a satellite or a terrestrial base station without feeling the serving difference.

For terrestrial mobile networks, both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) are regarded as popular modes. However, for satellite networks, FDD mode is relatively popular, while TDD mode is seldom applied. At present, the only commercial satellite system with TDD mode is Iridium. Therefore, in order to facilitate satellite-terrestrial integration and also seamless switching between satellite and terrestrial base station, TDD mode needs to be developed for mobile phone D2SS in the future. Till current stage, only FDD is standardized for NTN in 3GPP and there is absent study about TDD, so this paper hopes to discuss TDD mode on NTN, including technical advantages and disadvantages, technical challenges and potential technical solutions.

2. Advantages and Disadvantages of TDD mode on NTN

TDD mode has been regarded as a main branch in terrestrial mobile communication standards since the third generation (3G) [8]. A series of advantages can be achieved if TDD is applied into the fifth generation (5G) NTN standard. First, TDD can simplify the designs of both satellite and terminals, since only one set of antenna is required for transmitter and receiver (TRx), while usually two sets of antennas are required for FDD with one set for transmitter (Tx) and the other for receiver (Rx). Especially, when the frequency gap between Tx and Rx is small, it’s very difficult to realize the signal separation between uplink (UL) and downlink (DL). Second, TDD can bring flexible and efficient frequency usage, since it does not require symmetrical frequency bands as FDD requires, which is very difficult to get at low frequency area. Third, supporting TDD will make satellite communication compatible with terrestrial mobile communication.

Of course, there also have some disadvantages for TDD compared with FDD. For example, the frame structure, synchronization, timing and even the interference problem will be more complex. The system overhead may be more serious due to large transmission delay.

Comparisons on the difference of TDD and FDD for 5G NTN are detailed in Table 1.

key factors	characters of TDD	characters of FDD
Frequency allocation	It does not need symmetrical frequency and can save frequency resources.	It requires symmetrical frequency bands.

Antenna architeture	Tx and Rx can share the same antenna array.	Since the frequency gap between Tx and Rx is big better, it's difficult to use the same antenna array.
Frame structure	Guard period is required to saparate uplink and downlink, which may bring resource waste.	There is no requirement for guard period between uplink and downlink.
Scheduling timing	The scheduling timing is rigorous since the uplink or downlink time slots is not continuous.	The scheduling timing is simple since the uplink or downlink time slots is continuous.
Interference management	Interference may exist between uplink signal and downlink signal.	In case of big frequency interval between Tx and Rx, there will be no interference between uplink signal and downlink signal.
Latency	Due to resource constraints, TDD has bigger latency than FDD in the process of accessing and data transmission.	
coverage	Compared with FDD, the coverage capability is weaker for TDD since its discontinuous signal transmission.	
Data rate	Since the timeslot resources available to TDD are divided into uplink and downlink, if the frequency bandwidth is equal in one-way transmission, TDD has lower data rate than FDD.	

Table 1. Difference of TDD and FDD for 5G NTN

3. Challenges of TDD mode on NTN

Since the TDD mode shares the same radio frequency for DL and UL, it means the satellite and terminals only work at one state (namely UL or DL) at the same time. Compared with terrestrial communication, the transmission distance in satellite communication is so far away that the transmission delay is rather large. Even for the low earth orbit (LEO) satellite, the round trip delay (RTT) will extend from OFDM symbol level to slot level. Such a large transmission delay has a great impact on UL and DL synchronization timing. Therefore, a series of challenges should be considered in TDD system design.

First issue is about the influence on the guard period (GP) and TDD frame structure. In TDD mode, the satellite transceiver works in a time-sharing manner. After the satellite sents the signal, it enters the reception mode. At this time, a time interval (TI) needs to be added between the transceiver. If there is no TI, it may cause interference between DL and UL. Therefore, under the perspective of terminals within the same satellite beam, it is necessary to add a GP to avoid mutual interference between UL and DL. However, for NTN scenarios, larger GP would degrade the system performance significantly due to long time resource wasting.

Second issue is about interference management. In satellite system, the interference situation is more complicated for TDD than for FDD. For TDD mode, the total interferences may include inter-terminal interference, inter-satellite interference and mutual interference between terminal and satellite. While for FDD mode, only single-way directional interference such as DL only or UL only interference for inter-satellite and inter-terminal need to be considered.

Third issue is about the impact on service scheduling time. For TDD mode, since UL and DL are sent in time sharing, the timeslots of service scheduling need to avoid mutual interference between UL and DL. In addition, since DL and UL can't work simultaneously, the latency would be increased inevitably due to longer propagation from satellite to ground.

Forth issue is about the impact on hybrid auto repetition request (HARQ). Due to the large transmission delay, there may be much less number of processes for HARQ in TDD mode. Moreover, HARQ feedback and scheduling timing should be carefully designed to assign suitable time resource and keep effective transmission operations. So there should have enhancement for HARQ scheme.

Therefore, in order to improve the flexibility of spectrum use, on the basis of 5G TDD frame structure, TDD mode for 5G NTN should consider further improvement design, including TDD frame structure, UL and DL timing relationship, time-frequency synchronization [9], interference management, HARQ scheme, and coverage enhancement [10], etc.

4. Potential solutions of TDD mode on NTN

To ensure the validity of TDD mode on NTN system, potential solutions are considered to address related issues. In Table 2, there shows some mapping relationship between challenging issues and potential solutions.

Challenges issues	**Potential solutions**
Interference management	1. Dedicated guard period and TDD frame configuration 2. Interference suppression with assisted information
Timing and HARQ	Specific timing parameters design based on RTT variation
Overhead due to guard period	Extend TDD frame strucure configuration
Coverage	Repetition and data segementation

Table 2. Challenging issues and potential solutions for TDD NTN system

In the following paragraphs, detailed investigation is given for TDD mode on NTN systems, including TDD frame structure design and interference management.

A. TDD frame structure design

As illustrated in Figure 1, in the TDD frame structure, the symbols of each time slot include three types: DL symbol, UL symbol and GP symbol. A satellite base station or a terminal can receive signals only at its DL timeslots or symbols, and transmit signals only at its UL timeslots or symbols. The key point of TDD mode is to solve the problem of UL and DL switching point.

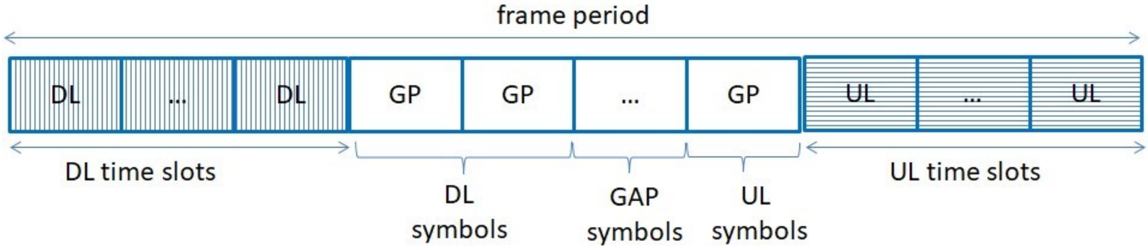

Figure 1: TDD frame structure for 5G NTN.

Take a LEO satellite constellation as an example, assuming the maximum link distance between a satellite and a terminal is 900km, then the maximum transmission delay is 3ms. In this case, since the RTT is 6ms, the GP of TDD system should be at least 6ms to avoid interference between UL time slots and DL time slots. If the 10ms frame structure is adopted as traditional, the time available for data transmission in each frame is only 4ms by maximum, and the effective transmission time is less than 40%. The system efficiency is quite low. Therefore, it is necessary to enhance the frame structure to improve the system efficiency.

The first solution is to reduce the GP. Normally, the GP should be adapted to the propagation delay of satellite-to-ground transmission. Then one basic assumption is that the GP should be configurable depending on the orbit height. If the orbit height is large, the overhead of GP is a big headache. In order to mitigate the impact, one simple method is to set one reference point. The UL timing advance (TA) can be performed with differential TA method which is based on the common reference point. In this case, UE is not expected to compensate the whole propagation delay of satellite-to-ground transmission. But the common propagation delay still requires the resource reservation of the satellite side. Then further optimization is to let UE transmit the signal with bigger TA, but this will cause additional interference between DL and UL at the UE side. When carefully scheduling is conducted, the UL to DL interference can be avoided for different UEs within one beam.

The second solution is to extend the frame length. The main motivation is to dilute the impact for GP. When the longer frame configuration is used, the overhead of GP can be acceptable. Considering that the satellite system should reserve a long protection interval to separate UL timeslot from DL timeslot, the TDD system can set longer frame length. Here shows an example of 20ms frame structure configuration. With the subcarrier interval is 30KHz, each subframe includes 2 time slots with each time slot adopting 0.5 ms and including totally 14 symbols. Thus there have totally 20 subframes and 40 time slots, including 8 DL subframes with timeslot number 0 to 15, 6 GP subframes with timeslot number 16 to 27, and 6 UL subframes with timeslot number 28 to 39. In this case, the system efficiency can approach 70%, much bigger than the value 40% in the case of 10ms frame structure.

B. TDD interference management

In the view of UEs within the same beam, GP can be used to remove the interference between DL and UL. Effective scheduling mechanism can further suppress the interference between DL and UL via adaptive GP configuration and spatial division multiplexing. However, there are other interferences as the bottlenecks to restrict the TDD mode, as shown in Figure 2.

Similar as terrestrial mobile system, different satellites should align the TDD configuration to mitigate the inter-satellite interference. In some cases, even if the same DL or UL configuration is applied, the remote interference from the neighboring satellite still exists. In this case, the interference suppression can consider beam-space isolation, and another method is to use assisted signal to do successive interference cancellation.

Regarding the UE to satellite interference at the UL, for directional UE, this is not a big problem due to the accurate beam pointing. But for handheld UE, the interference is unavoidable. In this case, UL receiving beam isolation should be carefully designed. For different direction, satellite beam response should be smartly boosted or restricted.

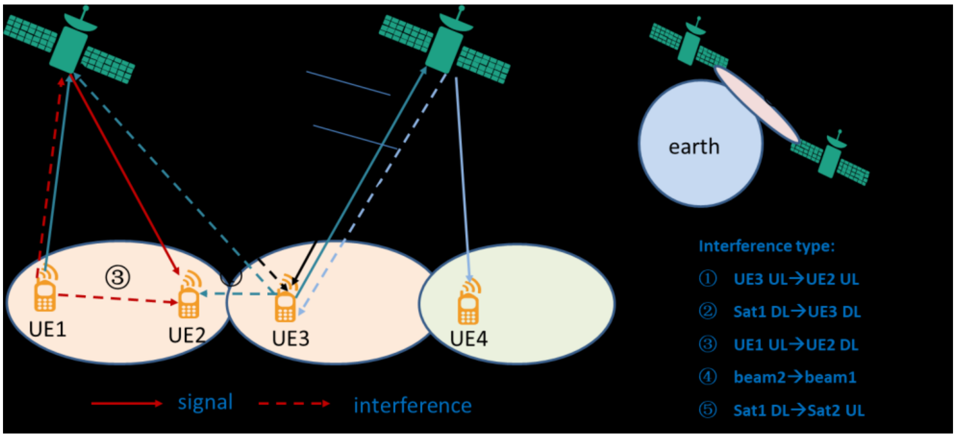

Figure 2: Illustration of interference from TDD mode in NTN system.

5. Conclusions

To meet the communication requirement of mobile phone D2SS, the terminal needs to work in the low frequency band. In case of increasing shortage of frequency resources, TDD mode will be a suitable choice. However, at present, organizations like 3GPP have not yet carried out TDD research and standardization for satellite communications which means poor integration of satellite-terrestrial communication and poor support of global mobile phone industry chain. This paper discusses the advantages, disadvantages and technical challenges of TDD mode on 5G NTN, and also gives potential TDD frame structure design and interference management scheme to reduce the system overhead. In the future, it is necessary to set up TDD on NTN projects in R19 of 3GPP, promoting the design and standardization of globally unified NTN TDD system.

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