A Spread Spectrum Communication Method Based on GNSS Positioning and Timing System

Jie Zhang, Zhaorui Wang and Qingtao Wan

Abstract Application of spread spectrum technology can effectively solve the problem of power constraints in satellite communication. A difficulty of spread spectrum communication is fast acquisition of spread spectrum signal. For the lack of priori information, code phase and frequency offset are both random quantities, it usually takes a long time in signal acquisition, which would reduce the efficiency of the communication especially for the burst communication. Traditional methods realized spread spectrum signal fast acquisition at the expense of acquisition algorithm complexity and hardware resources cost. This article presents a low cost new code phase and carrier frequency of spread spectrum signal correction method that is easy to implement based on GNSS positioning and timing system. In order to correct the frequency offset and code phase difference, position and time information given by GNSS system are used to build the network-wide time synchronization system and indirect loopback correction system in ground station. At the same time, with the aid of satellite timing, the influence of clock error is eliminated in the way of DDS. With the above measures, the spread spectrum signal fast acquisition could be realized in the network-wide time synchronization system.

Keywords Spread spectrum communication · Timing · Time synchronization

1 Introduction

Due to the high orbit satellite, propagation loss of satellite communication system, especially in the GEO satellite communication system is great. Meanwhile, in order to avoid interference between satellite and ground communication systems, low satellite antenna EIRP and weak signal power reaching the ground are obstacles to terminal miniaturization and communication capacity expansion. The spread spectrum technology can effectively solve the problem of limited power in satellite

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communication channel with sufficient bandwidth. To comply with International Telecommunication Union (ITU) regulations on signal strength (see [1]), spread spectrum communication technology is used to reduce the wave flux density in the unit band by broadening signal bandwidth for the power. At the same time, the spread spectrum communication has the advantage of confidential, and strong antijamming capability.

Synchronization is a key problem for spread spectrum signal receiving processing. PN code and carrier, at both transmitting and receiving ends should be kept under synchronization, including the synchronization of phase and frequency. At the receiving end, the rough code phase and carrier frequency offset estimation are given by capturing and coarse synchronization. Then the results of coarse synchronization are used to initialize tracking loop and precise synchronization, finally restore the information. As a result, the capture of the spread spectrum signal with high rate and long PN code period is very difficult in high dynamic, low SNR environments.

There are several capture normal methods [2, 3]: sliding correlator, capture time is proportional to the square of PN code period; matching filter, with a short capturing time at great hardware expense. These two methods are 2-D search for code phase and carrier frequency, and affected by the frequency offset. Besides the above two methods, FFT based on carrier frequency is able to overcome the frequency offset on the influence of PN code, but adaptive threshold adjustment for large signal strength varies and increases the complexity of the system.

From the above, for the lack of prior information, the capture of PN code phase and frequency offset value which is random costs a large amount of computation and hardware resources, repeated threshold judgement and adjustment are necessary for the probability of signal capture. Therefore, capture process with a long time reduces the communication efficiency especially for burst communication.

In this study, a new PN code phase and carrier frequency offset correction method based on the link of "Ground station—GEO satellite—Remote station" is proposed. In order to spread spectrum signal fast acquisition, the code phase difference, carrier Doppler frequency offset and clock error are corrected with the aid of GNSS satellite navigation system positioning and timing functions.

2 Construction of Network-Wide Time Synchronization System

In order to improve communication efficiency and user management, network-wide time synchronization technology has been widely used in ground-based 3G and 4G mobile communication system. Time synchronization between the base station (BS) is achieved by GPS or IEEE 1588v2 time transfer technology [4]. The mobile station (MS) achieves time synchronization with BS by time correction parameter in synchronous channel. The 3G and 4G mobile communication networks' time

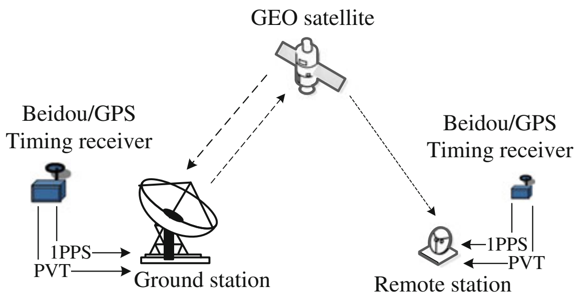

Fig. 1 Network-wide time synchronization system

synchronization precision index is only for μs [4], which is inadequate for the military and security spread spectrum communication with high spreading gain and PN code rate (Mcps). Timing function of Beidou/GPS satellite navigation system with the precision of 20–100 ns could be used as a unified time reference. The signal is transmitted and received under the unified time reference (1PPS). The capture process is accelerated by PVT (position, velocity, time) parameters. The original ground station and remote station are equipped with Beidou/GPS timing receivers to construct the network-wide time synchronization system (Fig. 1).

3 Synchronization of Spread Spectrum Signal

Prerequisites for spread spectrum communication are carrier and PN code synchronization, which means synchronization of both frequency and phase. Code phase, carrier frequency offset, and clock error are corrected, respectively, based on Beidou/GPS positioning and timing system.

3.1 Correction of PN Code Phase Offset

Code phase consists mainly of link propagation delay and equipment delay, which is corrected in different ways, respectively, at ground station and remote station.

3.1.1 Code Clock Round-Trip Link Indirect Correction in Ground Station

In Fig. 1, an example of a communication link composed of "Ground station—GEO satellite—Remote station", round-trip correction link consists of transceiver baseband, RF equipments at ground station, (up/down converter, PA, LNA, and antenna) and GEO satellite, as shown in Fig. 2.

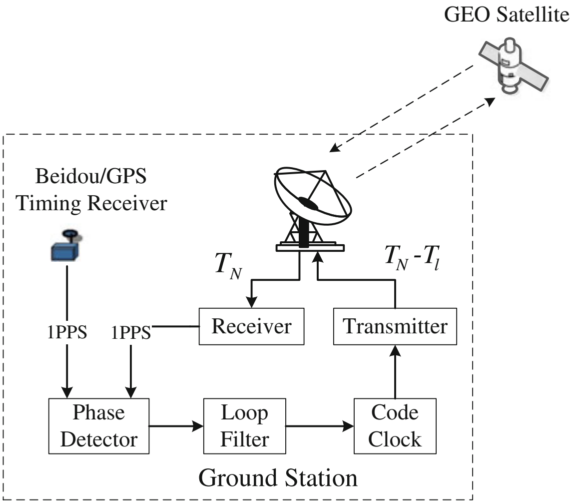

Fig. 2 Principle of code clock indirect loop back correction

The ground station transmits the spread spectrum signal and then receives the signal through the round-trip link. The receiver baseband output 1PPS on the start rising at the edge of each 1 s frame. The phase difference between 1PPS of Beidou/GPS receiver and 1PPS the receiver output is given by phase detector, which is used to feedback the correction of transmitting code clock after loop filter. Through the above indirect adjustment method, data transmitted from the ground station arrives at the receiving end on the rising edge of 1PPS, which means that the data transmitted at the time of $T_N - T_l$ arrives at T_N through round-trip link (T_N is integer second, T_l is the link propagation and equipment delay).

The experiments based on satellite ground link composed of equipments in Fig. 1 verify the above program. The Beidou/GPS timing receiver HM-1103C from Hwa Create Corporation [5]; the ground station located in navigation and communication central station of National Astronomical Observatory in Wuqing district, Tianjin; GEO satellite is a retired commercial satellite. The measured results of 1PPS synchronization precision in actual satellite ground round-trip link are shown in Fig. 3.

The 1PPS synchronization error that is corrected by the ground-satellite round-trip loop gradually converges with 1σ error of 34 ns.

3.1.2 Code Phase Correction in Remote Station

For the communication system in Fig. 1, the 1PPS in the ground-satellite round-trip loop is synchronized with Beidou/GPS 1PPS, but for signal transmitted from the ground station, there is time difference (ΔT) between the time arriving at the ground station and the remote station as the two different down links (“satellite—ground station” and “satellite—remote station”).

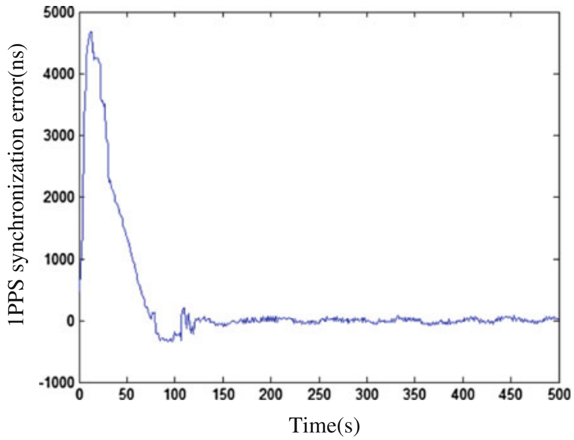

Fig. 3 Receiver-Beiou/GPS output 1PPS synchronization error of the round-trip link

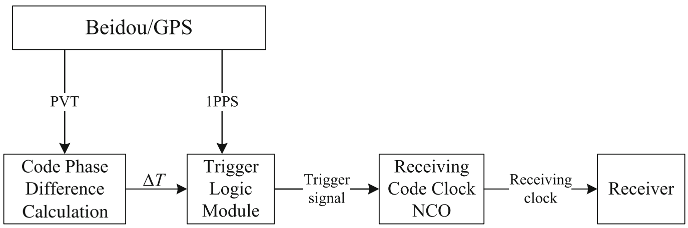

Fig. 4 Correction of propagation time delay difference correction

According to the output of the Beidou/GPS timing receiver position coordinates, precise satellite ephemeris parameters and ground station coordinates, the remote station can calculate the down link propagation delay difference ΔT.

Modules for propagation delay difference correction are shown in Fig. 4.

The propagation time delay difference ΔT can be calculated by real-time computing with Beidou/GPS 1PPS output. The work timing sequence is shown in Fig. 5. The ground station transmits the signal at the time of $T_N - T_l$ (T_N is integer second, T_l is the ground-satellite round-trip propagation and equipment delay), the remote station starts receiving the clock to correlate at the time of $T_N + \Delta T$.

For the "Ground station—GEO satellite—Remote station" link, the code phase difference correction of whole link consists of the above two processes. The remote station code clock starts at a fixed time to receive, so as to, improve the efficiency without signal acquisition process.

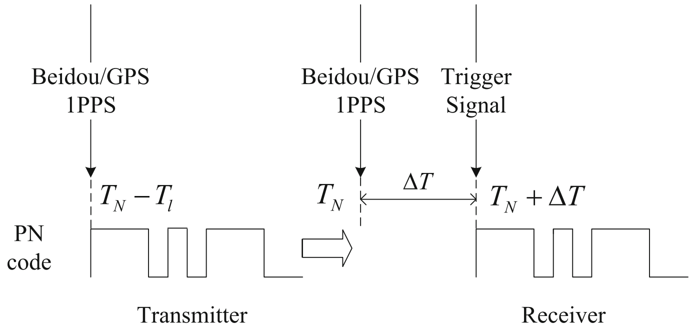

Fig. 5 Propagation time delay difference correction of remote station

3.1.3 Total Code Phase Error

Total code phase error ΔT_s is composed of timing error caused by Beidou/GPS positioning error ΔT_p and 1PPS synchronization error of ground-satellite round-trip link loop ΔT_l. Beidou/GPS positioning precision ΔP is about 10–20 m, c is propagation velocity of electromagnetic wave, then

$$\Delta T_p = \Delta P/c \tag{1}$$

According to the test results, 1PPS synchronization error of ground-satellite round-trip link loop ΔT_l is 34 ns, and the total code phase error is as follows:

$$\Delta T_s = \sqrt{\left(\Delta T_p\right)^2 + \left(\Delta T_l\right)^2} \tag{2}$$

According to Eq. (2), total code phase correction error ΔT_s is 50–70 ns. The code phase synchronization error should be within $\frac{1}{2}$ code chip for the capture of the PN code. Thus, this program meets the highest code rate 10 Mcps spread spectrum communication capture requirements.

3.2 *Carrier Frequency Offset Correction*

Carrier frequency offset is composed of Doppler, transformer, and clock error.

3.2.1 Frequency Offset Correction in Ground-Satellite Round-Trip Link

The same way as the code phase correction in Fig. 2, the frequency offset of the forward link is corrected in the ground-satellite round-trip link. In order to keep the

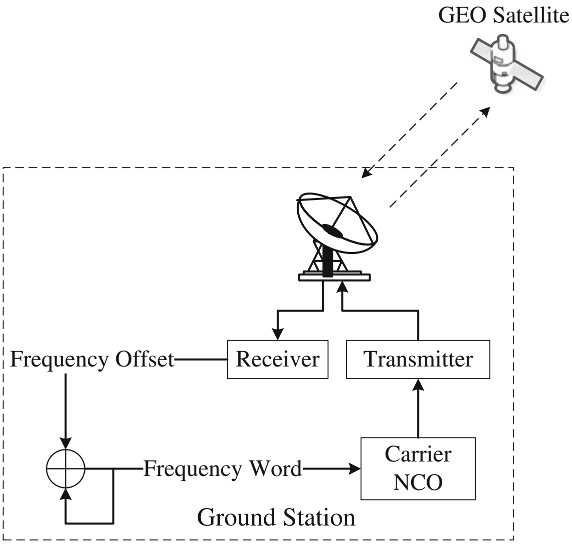

Fig. 6 Principle of frequency offset correction

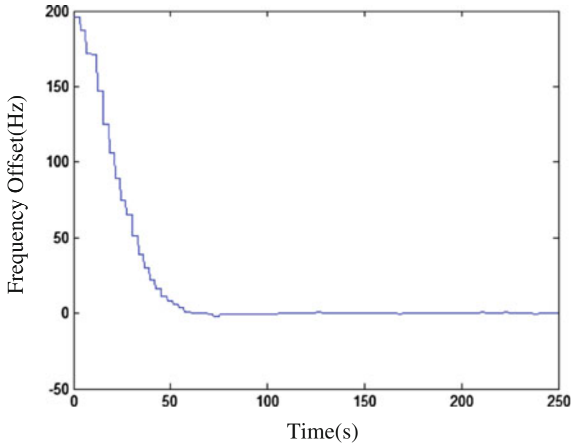

Fig. 7 Results of frequency offset correction

down link frequency at nominal value, as shown in Fig. 6, the receiver outputs the frequency offset to the transmitter for transmitting frequency pre-bias by the closed loop correction.

The results of frequency offset round-trip loop correction finally converge to 0 Hz, as shown in Fig. 7:

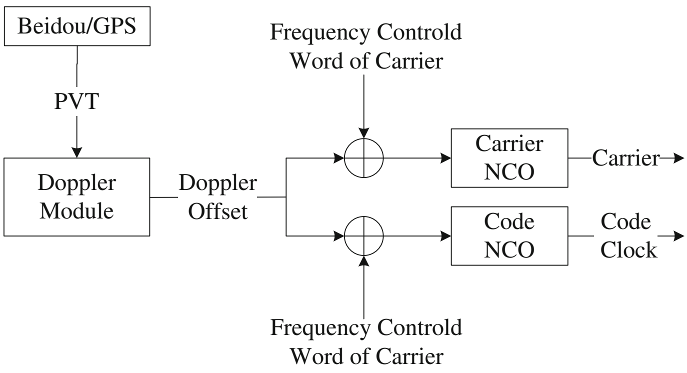

Fig. 8 Consisting of Doppler frequency offset correction

3.2.2 Frequency Doppler Correction in Remote Station

Doppler frequency offset is derived from the relative motion of the carrier. For "Ground station—GEO Satellite—Remote Station" the relative motion of the carrier including the remote station motion and satellite drift can result in frequency offset of the carrier and the code clock.

According to the location coordinates velocity of Beidou/GPS timing receiver output, Doppler carrier and code frequency offset Δf could be calculated, and then, Δf and precise satellite ephemeris are used to frequency pre-bias of carrier and code NCO. The Doppler carrier and code frequency offset Δf is calculated as follows: [6]:

$$\Delta f = -f_T \frac{\left(\overrightarrow{v_d} \cdot \overrightarrow{a}\right)}{c} \tag{3}$$

f_T, nominal frequency of the transmitted signal; $\overrightarrow{v_d}$, relative velocity vector of the transmitting and receiving ends.

$$\overrightarrow{v_d} = \overrightarrow{v_t} - \overrightarrow{v_r} \tag{4}$$

$\overrightarrow{v_t}$, velocity vector of the transmitting end; $\overrightarrow{v_r}$, velocity vector of the receiving end; $\overrightarrow{a}$, unit vector along the straight line from the receiving end to the transmitting end.

$$\overrightarrow{a} = \left(\overrightarrow{u_t} - \overrightarrow{u_r}\right) / \left\| \overrightarrow{u_t} - \overrightarrow{u_r} \right\| \tag{5}$$

$\overrightarrow{u_t}$, location vector of the transmitting end; $\overrightarrow{u_r}$, location vector of the receiving end; $\|\cdot\|$, distance between transmitting and receiving ends; $\overrightarrow{v_d} \cdot \overrightarrow{a}$, radial component of relative velocity vector along the straight line from the receiving end to the transmitting end; c, propagation velocity of electromagnetic wave.

The structure of the Doppler frequency offset correction module as shown in Fig. 8.

For the “Ground station—GEO Satellite—Remote Station” link, frequency of uplink and downlink are as follows:

$$f'_u = f_u + \Delta f_u \tag{6}$$

$$f'_d = f_d + \Delta f_d \tag{7}$$

f_u, nominal frequency of uplink; f_d, nominal frequency of downlink; Δf_u, frequency offset of uplink; Δf_d, frequency offset of downlink. Frequency of uplink is corrected to nominal value f_u frequency pre-bias at the transmitting end; Frequency of downlink is corrected to actual value f'_d at the receiving end.

The above methods apply to “Ground station—GEO Satellite—Remote Station” link, for the reverse link, the code phase difference and frequency offset can be calculated according to PVT parameters at remote station.

3.2.3 Clock Error Correction

Clock error of oscillator at transceiver both ends is also an important cause of frequency offset besides Doppler motion. OCXO is of high stability, but higher cost is not suitable for the terminal equipment. TCXO is of short-term stability but frequency drift for long time, while GNSS timing short-term stability is poor, but of high long-term stability. Therefore, combining the advantages of both TCXO and GNSS timing can be used to the frequency offset correction, which is “discipline”. The principle of “discipline” is to adjust the local oscillator according to the frequency error of clock signal generated by local oscillator and determined frequency signal, for both short-term and long-term stability [7, 8].

In this study, a correction method of low cost based on direct digital synthesizer (DDS) with aid of satellite timing is proposed. Specific as follows: GNSS output 1PPS as gating signals, the local clock error Δx of the actual and nominal value could be estimated according to the clock cycles between the two adjacent 1PPS. Then code clock and carrier frequency offset caused by clock error Δx could be corrected by pre-bias. Principle of DDS is as follows [9]:

$$\mathrm{FTW} = \frac{f_o}{2^M}\left(f_{\mathrm{sys}} + \Delta x\right) \tag{8}$$

FTW, the frequency tuning word; f_o, the output frequency; M, the length of the phase accumulator; f_{sys}, nominal frequency of the oscillator.

Structure of clock error correction module is shown in Fig. 9: the local clock error Δx could be estimated according to the clock cycles between gating Beidou/GPS 1PPS signals. In order to avoid the short-term unstability of Beidou/GPS 1PPS, filter the counting results using weighted filtering algorithm. The principle of weighted filtering algorithm is as follows [10]:

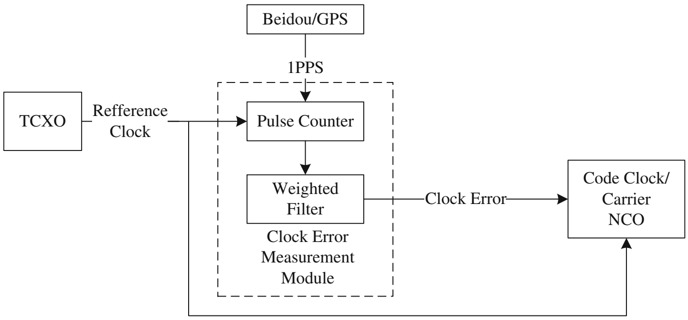

Fig. 9 Consisting of clock error correction

$$\hat{x} = \sum_{i=0}^{n-1} W_i(n) x_{n-i} \tag{9}$$

x_{n-i}, 1PPS count number; $W_i(n)$, weight coefficient; n, length of measurement window, the longer the length, the higher the precision.

4 Conclusions

In this study, a new spread spectrum code phase and carrier frequency correction method based on Beidou/GPS timing is proposed. For the key of spread spectrum signal acquisition: code phase and carrier frequency offset, network-wide time synchronization system is constructed and to correct from three aspects based on Beidou/GPS timing: code phase error, carrier frequency offset, and clock error. The acquisition of spread spectrum signal is greatly accelerated due to the correction of code phase and carrier frequency. The method of this paper is simple with low cost, not only for satellite spread spectrum communication system, also can be applied to other ground mobile or fixed station communications.

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