Time synchronisation for multi-static radar via microwave and troposcatter

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Abstract: Time synchronisation is one of the key issues to realise remote detection for multi-static radar. With the condition that the receivers are commonly located at different distances from the transmitter, a high-precision time synchronisation scheme for multi-static radar with mixed microwave and troposcatter channels is proposed. In order to prove the feasibility of transmitting pulse signals in microwave channel, the jitter of the signals has been tested, and the transmission loss of the troposcatter channel has been calculated. Finally, the accuracy of the proposed model is analysed, which shows that the proposed scheme is feasible and can be a backup for time synchronisation for multi-static radar.

1 Introduction

Multi-static radar has good capability against active directional jamming and anti-radiation missile, which has received considerable theoretical interest in recent years. However, the transmitters and receivers of multi-static radar are far apart, which leads to unique complexity and technical problems, and the most important is the synchronisation problem between various bases. Therefore, it is necessary to seek a high-precision time synchronisation method. Two-way time transfer (TWTSF) is one of the highest precision time synchronisation methods at present [1], and commonly used communication channels are satellites and cables. However, cables links are limited by terrain during mobile operations and the satellite channel has intrinsic limitations due to capacity problems at regions with low satellite coverage.

In [2], TWTSF via troposcatter channel was proposed, which can overcome the constrains of terrain for beyond line-of-sight time synchronisation in emergency communication. However, it is not suitable for receivers near transmitters utilising troposcatter communication channel, while microwave signals transmitted at the same frequency range is more suitable for near field communication. Therefore, in this letter, we propose a TWTSF via microwave and troposcatter (TWTTMT) for multi-static radar time synchronisation, which can meet the requirements of different distance communications. The jitter of pulse signals in microwave channel and the transmission loss of troposcatter channel have been analysed, along with the feasibility of the proposed scheme. We get that the proposed scheme can achieve high-precision synchronisation for multi-static radar.

2 TWTSF via microwave and troposcatter

TWTTMT system consists of a master station and a slave station. The block diagram of TWTTMT is shown in Fig. 1. The master station is equipped with omnidirectional antennas, and the directional antennas are arranged at the slave stations. A plurality of slave stations is arranged around the master station according to their needs. If the slave station is within 20 km from the master station and no barrier is covered, the microwave synchronisation scheme may be used; otherwise, the troposcatter synchronisation scheme is adopted. In the master station, the time signal one-pulse-per-second (1PPS) generated by the rubidium clock is transmitted to the time interval counter (TIC), and TIC is started by the leading edge of 1PPS. Meanwhile, the same 1PPS signal is delivered to the modern unit, and after the phase modulation processing, the signal is modulated onto the station’s intermediate frequency signal. Then after error correction coding processing, the signal is up-converted to the radio frequency. Via the wireless channel, the signal arrives at the directional antenna of the slave station. Signal transmission from the slave to the master is similar to the transmission from the master to the slave, and multiple slave stations are transmitted simultaneously at different frequencies. After the data acquisition and computer processing, the time bias between the master station and the slave station can be attained.

3 Jitter of pulse signals in microwave channel

The receiver of microwave communication is susceptible to noise, interference and other effects caused by jitter. In order to evaluate the magnitude of jitter, the transmission performance of the calibration pulse signal through a high frequency channel in a microwave communication system is tested. The jitter range is measured by changing the attenuation level to get different reception levels. The result can be observed by the digital oscilloscope. Fig. 2 represents the jitter edge when the reception level is ~30 dBm. It can be seen from Fig. 2 that the jitter is ~4 ns. Therefore, the results suggest that the time synchronisation system can transmit the calibration pulse signals with good accuracy via microwave link.

4 Transmission loss

As the complex and time-varying air turbulence of the tropospheric link, it is quite important to model the transmission loss. According to [2, 3], the transmission loss can be estimated using the ray tracing method. The parameters used are as follows: antenna gain $G_a = 41.5\, \text{dB}$, beam-width $dw = 1^\circ$. Beam elevations of the antennas and communication distance are critical in troposcatter system. Figs. 3 and 4 illustrate the relationship of transmission loss with beam elevation and communication distance at different frequencies, respectively.

It can be indicated from Fig. 3 that 1° increase in the elevation angle can result in 10 dB decrease in the received power. The reason may be that as the beam elevations increase, the path lengths becomes longer and the height of common volume becomes larger, which leads to the higher transmission loss. Fig. 4 shows the transmission loss with communication distance for different frequencies. As can be seen, 100 km increase in the distance can result in 2 dB decrease in the received power. The conclusions can be obtained from both Figs. 3 and 4, that with the frequency increase the transmission loss becomes larger correspondingly. Therefore, when design time pulse signal for TWTSWT system, the beam elevation angle, communication...
distance and frequency bandwidth must be seriously taken into account. According to results, to get better performance of TWTSWT, the beam elevation angle of troposcatter system should be $<5^\circ$ and the communication distance should be 20–300 km.

5 System accuracy assessment

In order to adapt to different distances and adopt different communication methods, we propose a hybrid time synchronisation approach. For the microwave and troposcatter channel, the TWTSF expression is different, as shown in Fig. 5.

For the troposcatter channel, TIC reading of two sites is as follows:

$$t_{TICA} = D_t + t_{TXB} + t_{Btropo} + t_{tropoA} + t_{RXA}$$
$$t_{TICB} = -D_t - t_{TXA} + t_{Atropo} + t_{tropoB} + t_{RXB}$$

(1)

$$\Delta t = \left[ (t_{TICA} - t_{TICB}) + (t_{TXA} - t_{TXB}) + (t_{RXB} - t_{RXA}) + (t_{Atropo} - t_{Btropo}) + (t_{tropoB} - t_{tropoA}) \right] / 2$$

(2)

where $\Delta t$ is the time difference between the two sites. $t_{TXA,B}$ and $t_{RXA,B}$ are the delays of the transmit and receive parts of stations, respectively. These delays have to be measured individually or to be calibrated by means of some kind of transfer standard [4]. $t_{A,Btropo}$ and $t_{tropoA,B}$ are the signal delays for the two directions. These delays may equal with each other and can be offset, when the same frequency is used for both stations. Otherwise, the difference of the delays must be estimated.

For the microwave channel, TIC reading of two sites is as follows:

$$t_{TICA} = \Delta t + t_{TXB} + t_{BA} + t_{RXA}$$
$$t_{TICB} = -\Delta t + t_{TXA} + t_{AB} + t_{RXB}$$

(3)

$$\Delta t = \left[ (t_{TICA} - t_{TICB}) + (t_{TXA} - t_{TXB}) + (t_{RXB} - t_{RXA}) + (t_{AB} - t_{BA}) \right] / 2$$

(4)

where $t_{AB}$ and $t_{BA}$ are the signal delays of microwave links for the two directions.

From (2) and (4), we can conclude that the accuracy of TWTTMT depends on the equipment delay errors and transmission path delay errors. Equipment delay errors mainly include the modem errors and errors caused by different temperature of receiving and sending equipment. As for transmission path delay errors, most path delay can be offset due to TWTSF.

6 Actual channel test

The station A, B are set in Xi’an, China, of which station A is fixed, station B is a mobile station. The distance between A and B station is 23 km. The time interval measuring instrument is placed in the fixed station (station A). The start of measurement is the signal transmission from the fixed station to the mobile station.
The mobile station will send the received signal back to the fixed station. When the fixed station receives the return pulse, it is used as the close signal of time interval measuring instrument. The time interval measuring instrument can measure calibration pulse through the two-way transmission time interval $t_{ABA}$. Measurements are performed $m$ times, and $m$ is the number of second pulses transmitted during calibration. Through the statistical data processing system, we can get pulse transmission time jitter root mean square of the microwave transmission distance.

Fig. 6 shows the long distance microwave transmission test curve. The abscissa is the number of measurements, and the ordinate is the time interval. It can be calculated that the average value is 3.4 ns. The variance is 1.4 ns. The results show that the root mean square error of the calibrated pulse transmission is <2 ns.

As for troposcatter channel, the experiment has not been conducted. We can only calculate the theoretical accuracy. In [4], the path delay for troposcatter links is analysed. The results suggest that max delay is 24.94–45.37 m in a single way. In TWTSF, when the delay can counteract 90 or 95%, time delay is 3.1–5.7 ns or 1.5–2.9 ns.

When considering multiple simultaneous stations, Hongwei and Imae [5] indicate that the accuracy of the multi-directional time synchronisation is $\sqrt{2/n}$ of the accuracy synchronisation of TWTSF.

7 Conclusion

We propose a high-precision time synchronisation scheme for multi-static radar with mixed microwave and troposcatter channels. The jitter of pulse signals in the microwave channel is tested, and the transmission loss of the troposcatter channel is calculated to prove the feasibility of system. Finally, the accuracy of the proposed scheme is analysed, which shows that the proposed scheme is feasible.

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9 References

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