Novel National High-Precision Time Synchronization Network Architecture and First Field Trial with 2150km Span for 5G Communication

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Abstract *This paper reports a novel national high-precision time synchronization network with distributed common-view backbone time transfer and TDM-based metro synchronization. Field trial results confirm excellent national synchronization over commercial optical networks with <10ns time accuracy between regions across 3 provinces and 2150km for 5G stations.*

Introduction

Synchronization is an essential issue in various applications such as telecommunication, electric power system, financial trading, and industrial control. In 5G communication, stringent time synchronization is needed for Time Division Duplexing (TDD) system [1-3]. Synchronization via transport networks using PTP (precision time protocol) is a promising solution and has been gradually developed [4]. PTP network has a shortcoming that its coverage scale is limited since the number of network hops will affect time accuracy. In order to maintain high accuracy, the PTP network has to be divided into domains [5]. Independent time sources are used for each time network domain, making it difficult to achieve a nationwide time network.

In order to realize a nationwide unified time network, advanced time transfer method over dedicated fiber/wavelength is researched, which may provide sufficient precision over long distances. It has recently achieved time transfer across a distance of 1085km [5-7]. However, the complexity and high cost of dedicated fibers and devices limit the practical application of this method.

Because unified and accurate time is essential for 5G wireless and emerging new services, e.g., 5G positioning service [8], national large scale high-precision time network is strongly desired. New high-precision time transfer technologies must be further studied and developed.

In this paper, we propose novel national high-precision time network architecture. The backbone network adopts a proposed distributed common-view (DCV) time transfer solution via satellite and internet connection. The metro networks adopt a TDM-based time transport to enhance the accuracy. Any regional time server can be flexibly set as the national primary time source and track each other via a centralized datacenter. Based on this novel architecture and solution, we report the

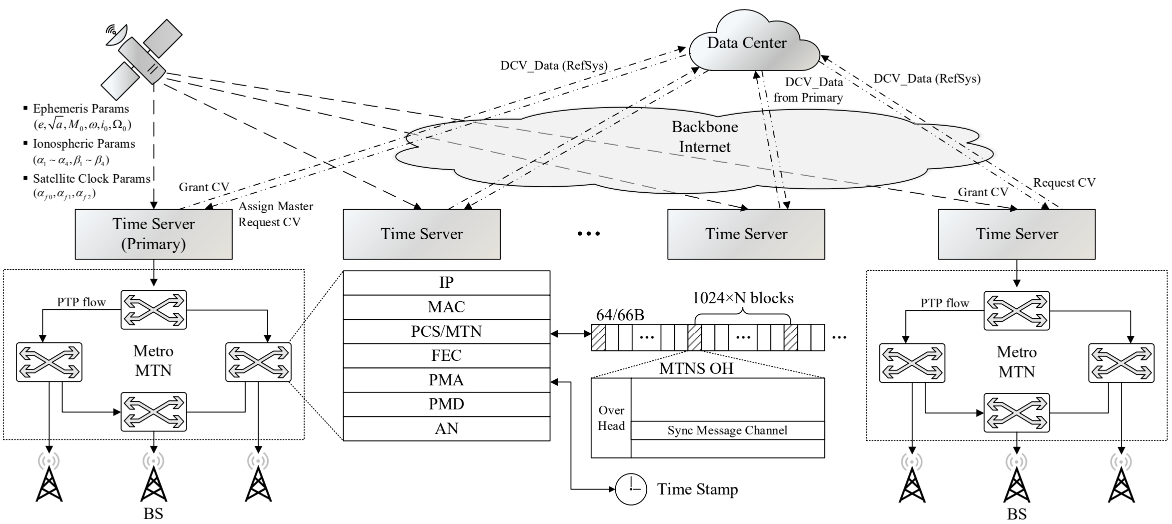

Fig. 1: Architecture of the national high-precision time synchronization network

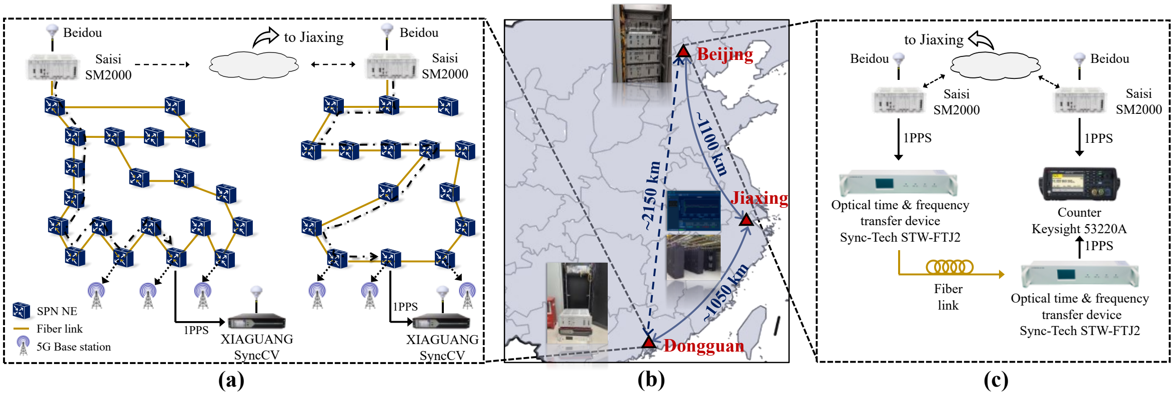

Fig. 2: Field trial setup

successful field trial for the first time across 3 provinces/cities and 2150km with an end-to-end time accuracy of 36ns. The relative time difference between regions is improved to less than 10ns.

Time Synchronization Network Architecture

The novel national synchronization network is organized into backbone synchronization network and metro synchronization network, as shown in Fig. 1.

Backbone synchronization mechanism

Time servers are synchronized via the new concept called distributed common-view (DCV). The time servers obtain the Keplerian elements, ionospheric parameters, and clock bias correction coefficient from their separate Global Navigation Satellite System (GNSS) receivers [9-10]. Then the time servers report the DCV data (Refsys) to a centralized datacenter via internet. Refsys is the time difference between local time and system time during observation track. The datacenter will determine which regional time server to be the national primary time source and broadcast the DCV Refsys of the primary time server to any other time servers. By comparing the received Refsys and its own, the regional time server could calculate the relative deviation of time and adjust its time. Then all the time servers will reach the synchronization to the selected primary time server.

The DCV architecture, which is composed of a centralized datacenter and distributed time servers, brings at least the following advantages:

a) Long-distance and high-precision time transfer is realized. Additionally, the national time performance data can be collected and monitored at the datacenter.

b) Flexible to set and change the national primary source relationship at the datacenter without affecting the network topology.

c) The processing and response of non-real-time data is performed by the datacenter, which significantly enhances the synchronization processing capability and network scalability. The datacenter can support >2000 DCV message interactions per second, which means supporting thousands of metro networks.

Metro synchronization mechanism

TDM-based time synchronization is introduced into the metro transport network. In the traditional PTP via Ethernet, the reference point and instability of packet-based timestamp limit the accuracy.

In order to improve the accuracy, the PTP protocol is enhanced in the TDM-based Metro Transport Network (MTN) technology.

a) The PTP messages are carried by MTN overhead frame instead of Ethernet packet. The message timestamp point for a PTP event message shall be the start of the MTN overhead multi-frame. The first byte of the PTP message can be inserted in the overhead of any frame of this multi-frame. A PTP message may cross the multi-frame boundary. The deterministic nature of the TDM frame format ensures the certainty of the timestamp.

b) MTN timestamps are generated within the lower PHY in the protocol stack. After the start of the MTNS overhead multi-frame is detected, the position is marked. The marking of that position is carried through the PHY functions. The timestamps are generated when the markers are detected at the lower PMA position within PHY.

Field Trial Setup

We conducted the first field trial using the proposed novel time network architecture. Fig. 2 shows the map of national backbone synchronization network and the topologies of metro networks. The testbed covers 3 cities of Jiaxing, Beijing, and Dongguan at 3 provinces in China with the longest 2150km transport. Two Saisi SM2000 time servers are set up for each

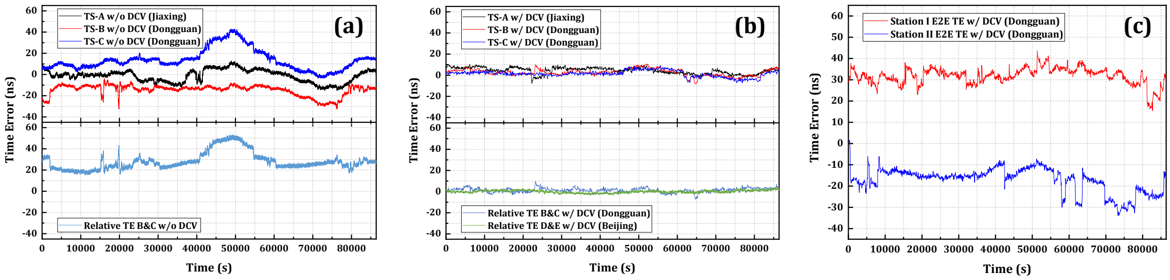

Fig. 3: Field trial results (a) the traditional time error performance without proposed DCV scheme; (b) the time error performance with the proposed new scheme; (c) national end-to-end time error to the 5G base stations.

city with the Beidou receiver (at B1I 1561.098MHz) and an internal rubidium oscillator. The synchronization datacenter is employed at Jiaxing and one time server at Jiaxing is designated as the primary source. Each time server in different cities exchanges information with the datacenter via the CMNet IP network. DCV Refsys data and negotiation messages are exchanged at 16 packets-per-second. The datacenter has an APP interface that can display real-time monitoring data curves.

At Dongguan, the time servers are connected with the commercial MTN network via GE interface. MTN network from Huawei SPN980 equipments forms 50G/100G ring topologies. For time accuracy measurements, time pulse-per-second (PPS) signals from time servers and MTN equipments are outputted to time analyzers from Xiaguang. The time analyzers obtain the UTC time reference from China National Time Service Center (NTSC).

At Beijing, the time output of one time server is transferred over 40km fiber via bi-direction transport. Then the time from the two servers are directly compared by connecting to a Keysight 53220A time interval counter.

Results

The ability of the novel national high-precision time network and that of the traditional multi-domain PTP network are compared.

When using the proposed DCV solution, the time accuracy of time servers at Jiaxing, Dongguan, and Beijing is recorded with an observation time of 24 hours, as shown in Fig. 3(b). The time error is -7.7~10.3ns, -8.1~10.6ns, and -7.3~9.3ns, respectively. It can be seen that the trend of accuracy curves shows the obvious consistency. The relative time difference between two servers at Dongguan is calculated, which is -7.0~9.9ns. The time difference between two servers at Beijing measured via Keysight 53220A is -182~41ps. This proves the excellent synchronization performance between different regions using the new scheme.

As a comparison, we test the traditional performance without DCV, as shown in Fig. 3(a). The outputs of various time servers using Beidou receivers show randomness and irrelevance. The difference between Dongguan servers without DCV is 15~53ns, which is much larger than the new scheme.

The end-to-end time error of the national time networks to the 5G base stations is measured. We select two remote MTN nodes to measure time output with 10 hops of metro transport. Within an observation time of 24 hours, one output is from 15.4ns to 43.6ns with the peak-to-peak value of 28.2ns, another is from -34.0ns to 2.0ns with the peak-to-peak value of 36.0ns, as shown in Fig. 3(c). The TDM-based MTN node provides a higher precision of <+/-5ns per hop. It can satisfy the most stringent requirements of 5G communication.

Conclusions

Time synchronization networks are becoming one of the most important infrastructures for a wide range of applications. We demonstrated the world's first national time synchronization network using distributed common-view backbone transfer and TDM-based metro networks. Any regional time server can be flexibly designated as the national primary time source in this architecture. The field trial network covers 3 cities in 3 provinces in China with the longest 2150km span. An excellent end-to-end accuracy of 36ns and relative accuracy of <10ns between regions is realized for the 5G base stations. Results confirm successful ten-nanosecond national time synchronization over large-scale transport networks. The proposed solution can be applied to future network and applications requiring high-precision time synchronization.

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