Trends in Standardization of High-precision Time- and Frequency-synchronization Technology for Creating a 5G Mobile Network

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Abstract

High-precision time- and frequency-synchronization technology has received worldwide attention in recent years for its importance in creating a future fifth-generation (5G) mobile network. Consequently, standardization of this technology is underway by ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) Study Group 15. This article introduces the function of time- and frequency-synchronization technology in 5G mobile networks and describes standardization trends concerning technical requirements such as synchronization-network architecture and synchronization accuracy.

Keywords: 5G, time synchronization, PTP

1. Time-synchronization technology in mobile communication

Synchronization technology is essential for data transmission between communication systems and has been introduced into many telecommunication operators' networks. Conventionally, network carriers offering services such as telephones and leased lines have established synchronous networks and have synchronized the clock frequencies of the devices, thereby multiplexing and separating data and providing high-quality services. Synchronization technology has been important even for packet-based asynchronous networks and is required for efficient data communication for fourth-generation (4G) and 5G mobile networks. Thus, synchronization technology is important in mobile communication as well as in fixed communication and is one of the basic technologies in realizing the network services of telecommunication operators.

Synchronization technology is mainly classified as frequency synchronization and phase/time synchronization. The state in which the clock frequencies of different systems match is called frequency synchronization, and the state in which the timings between the clocks agree is called phase synchronization. In particular, when the clock timing is synchronized with Coordinated Universal Time (UTC),*1 that state is defined as time synchronization. Time-synchronization technology for communication services is currently used for time-division multiplex communication based on Long-Term Evolution (LTE), and fixing the time synchronization between UTC and mobile base stations contributes to improving the utilization efficiency of the frequency band at the base stations.

In the 5G era, more efficient use of bandwidth is necessary to handle the increasing amounts of data traffic, and advanced communication methods for improving communication quality are required in

*1 UTC: Time managed to continuously maintain the difference between global time (based on the earth's rotation) and international atomic time (based on the time standards of the standards agencies of each country) within 0.9 seconds by inserting leap seconds, etc.

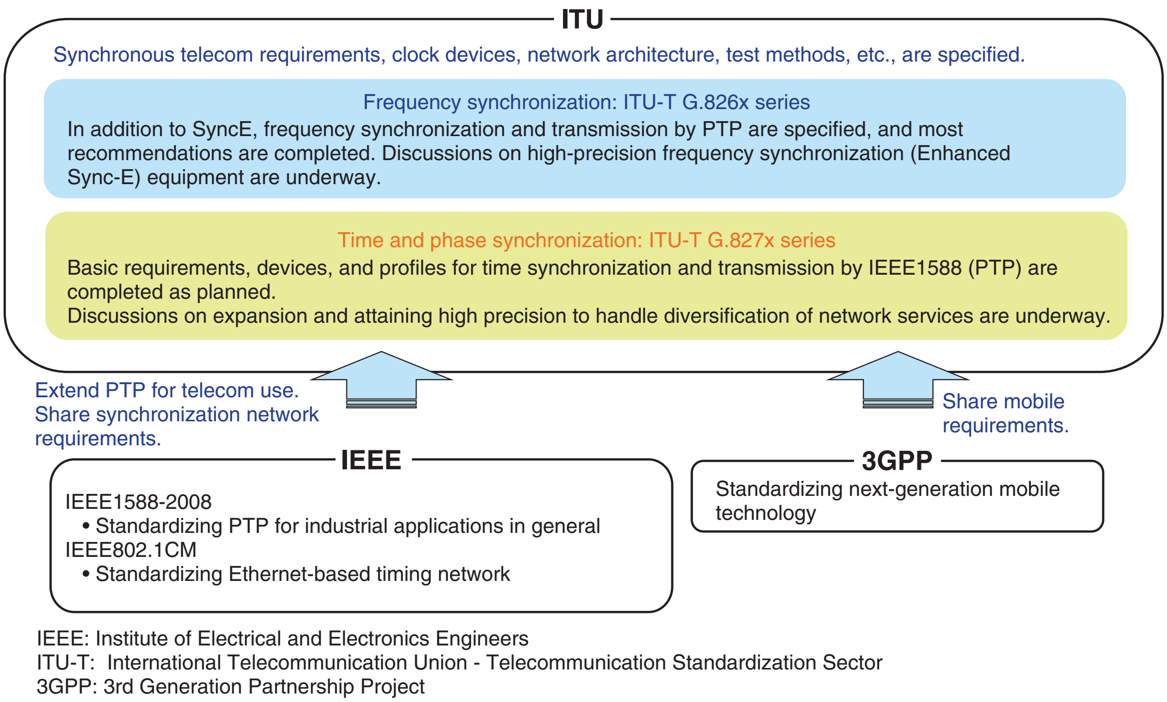


Fig. 1. Relationships between standardization organizations concerning synchronization technology.

order to address the diversification of end applications. High-precision time synchronization for temporal coordination and control between base stations is also required. Representative example technologies are dual connectivity (i.e., communicating by using multiple base stations) and carrier aggregation (i.e., bundling a large number of carrier frequencies as one channel). Together with the standardization of such mobile technologies, standardization of the synchronization technologies that support them is under discussion.

2. Technology for achieving high-precision time/frequency synchronization

Precision Time Protocol (PTP)*2 is a protocol for achieving time synchronization based on time-stamp information stamped on packets [1]. PTP has attracted attention in recent years because time synchronization with UTC is possible with microsecond- to nanosecond-order precision. Therefore, standardization of PTP as a candidate protocol for time synchronization of future 5G mobile networks is underway. PTP generally uses UTC information received from a global navigation satellite system (GNSS), typified by the GPS (Global Positioning System), as the time reference. It is possible to transmit and synchronize that time information—with the installation site of the GNSS antenna as the reference point—by utilizing the network.

Frequency synchronization, represented by Synchronous Ethernet (Sync-E) [2], is also commonly used as a backup for time synchronization. If PTP packets are missing (due to network congestion, etc.), and time synchronization is not possible, time synchronization can be maintained for a certain period of time by applying frequency synchronization.

3. Relationships between standardization organizations in terms of time/frequency-synchronization technology

Standardization bodies are addressing various issues related to frequency-, phase-, and time-synchronization technologies including PTP, and the relationships between these organizations in terms of these technologies are shown in **Fig. 1**. Study Group

*2 PTP: A protocol to calculate the time shift of a slave (subordinate device) relative to a master (superior device) based on time-stamp information and round-trip-delay information stamped in a dedicated time-synchronization packet and synchronize the calculated time with the master clock.

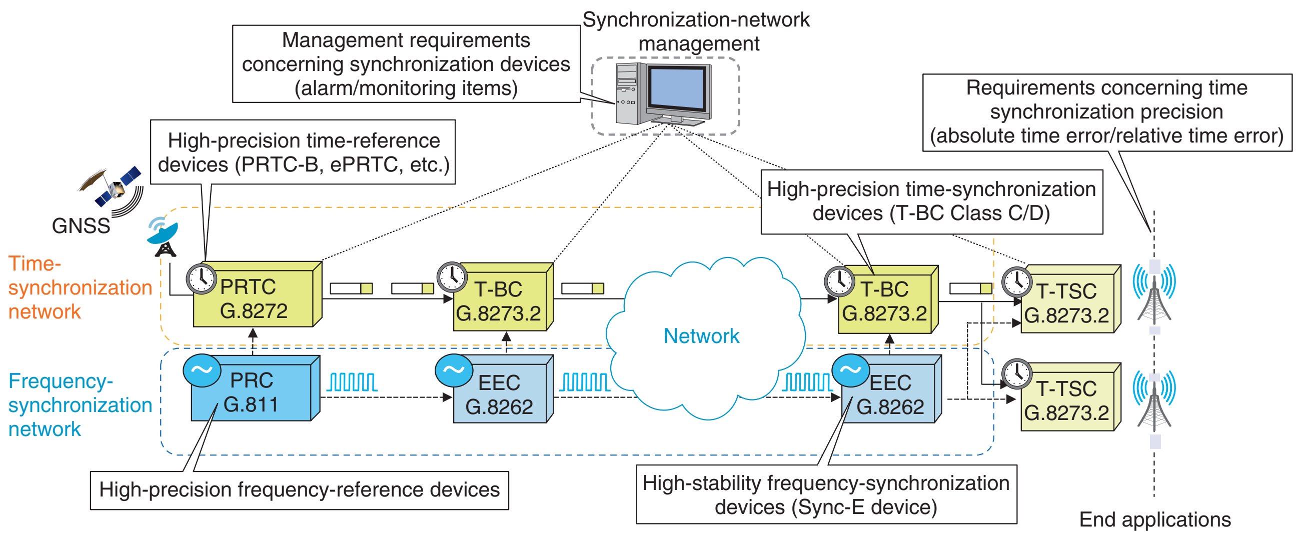


Fig. 2. Configuration of synchronization network and main standardization topics.

(SG)15 of the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) is standardizing specifications for frequency-synchronization technology such as Sync-E (ITU-T G.826x series) as well as time-synchronization technology that extends PTP (IEEE1588-2008, prescribed for general industrial applications by the Institute of Electrical and Electronics Engineers (IEEE)) to telecommunication operators (ITU-T G.827x series). The 3rd Generation Partnership Project (3GPP) has been specifying the technological requirements of the mobile field, and this information is being fed back to the ITU-T for their discussions. In addition, the ITU-T is standardizing synchronization equipment while referring to the draft timing requirements (IEEE802.1CM: Time-Sensitive Network for Fronthaul) for the Ethernet-based mobile fronthaul being discussed by IEEE.

4. Requirements concerning time and frequency synchronization for 5G mobile communication

At the ITU-T SG15 meeting in February 2018, a technical report (GSTR-TN5G) on transport networks for 5G was given consent. That report also includes network architecture and accuracy requirements concerning time- and frequency-synchronization technologies. The discussion topics concerning general network configurations and standardization for time and frequency synchronization are shown in **Fig. 2**. The time-synchronization network is configured with a primary reference time clock (PRTC)—a time-reference device that receives time from a GNSS, a telecom-boundary clock (T-BC)*3 for receiving, synchronizing, and transmitting time information from the PRTC, and a telecom-time slave clock (T-TSC)*4 for supplying the time from the T-BC to the end application.

The frequency-synchronization network supporting time synchronization consists of a primary reference clock (PRC)—a frequency-reference device—and a synchronous Ethernet equipment clock (EEC), which synchronizes and distributes frequency by Sync-E. In addition, the synchronization-network management system monitors and controls these time- and frequency-synchronization devices.

Accuracy is cited as the main requirement of time synchronization [3]. In addition to the absolute time error defined in terms of error with respect to UTC, in

*3 T-BC: A device that calculates time information from PTP packets and attains time synchronization. The time information can then be relayed from a time source.

*4 T-TSC: A device that terminates PTP packets and supplies time information to the end application.

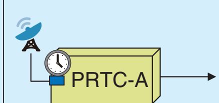
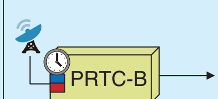
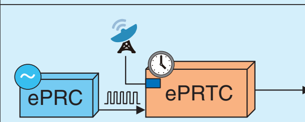
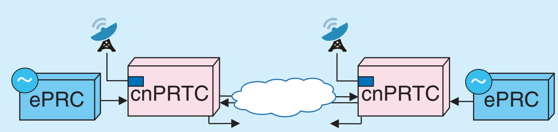
Table 1. Requirements concerning mobile applications and time-synchronization accuracy.

Category	Applications	Time alignment error
A+	MIMO or TX diversity transmission, at each carrier frequency	65 ns
A	Intra-band contiguous carrier aggregation with or without MIMO or TX diversity	130 ns
B	Intra-band non-contiguous carrier aggregation with or without MIMO or TX diversity, and inter-band carrier aggregation, with or without MIMO or TX diversity	260 ns
C	TD-LTE	3 µs

Source: IEEE802.1CM Draft 2.2; Draft standard for local and metropolitan area networks—excerpt from Time-Sensitive Networking for Fronthaul

MIMO: multiple-input multiple-output
TD-LTE: time-division duplexing LTE
TX diversity: transmit diversity

Table 2. Classes of PRTC.

PRTC type	Performance	Device configuration
PRTC-A (G.8272)	Maximum time error: 100 ns	
PRTC-B (G.8272)	Maximum time error: 40 ns Error reduction of GNSS signal reception by high-precision receiver	
enhanced PRTC (ePRTC) (G.8272.1)	Maximum time error: 30 ns Time synchronization is maintained when GNSS reception is impossible by frequency-reference device (ePRC) (within 100 ns over 14 days).	
coherent network PRTC (cnPRTC) (G.8275 et al.) Under discussion	Maximum time error: ? Reliability improved by mutual monitoring and comparison through the network High precision achieved by mutual synchronization	

recent years, relative time error between base stations is also being considered under the assumption of 5G applications. The time-synchronization accuracy requirements of major mobile applications being discussed and regulated by the 3GPP and IEEE are listed in **Table 1**. Up to now, standardization has been advanced with the aim of achieving absolute time-synchronization accuracy of 3 µs for TD-LTE (time-division duplexing LTE) [4]. However, in recent years, higher precision (namely, a minimum of 65 ns) is being required as a relative time error for carrier aggregation and other technologies. Therefore, to ensure high-precision and stable operation of various synchronous devices for providing time information to base stations, high reliability as well as management capabilities are required. In the following section, standardization trends concerning these topics are introduced.

5. Quality improvement of time-synchronization devices

Here, we report on efforts to improve the quality of time-reference and time-synchronization devices.

5.1 Time-reference device (PRTC)

Currently, the ITU-T specifies multiple types of PRTC, which is a device that receives time from a GNSS, according to the levels of accuracy and reliability as listed in **Table 2**. In contrast to PRTC-A

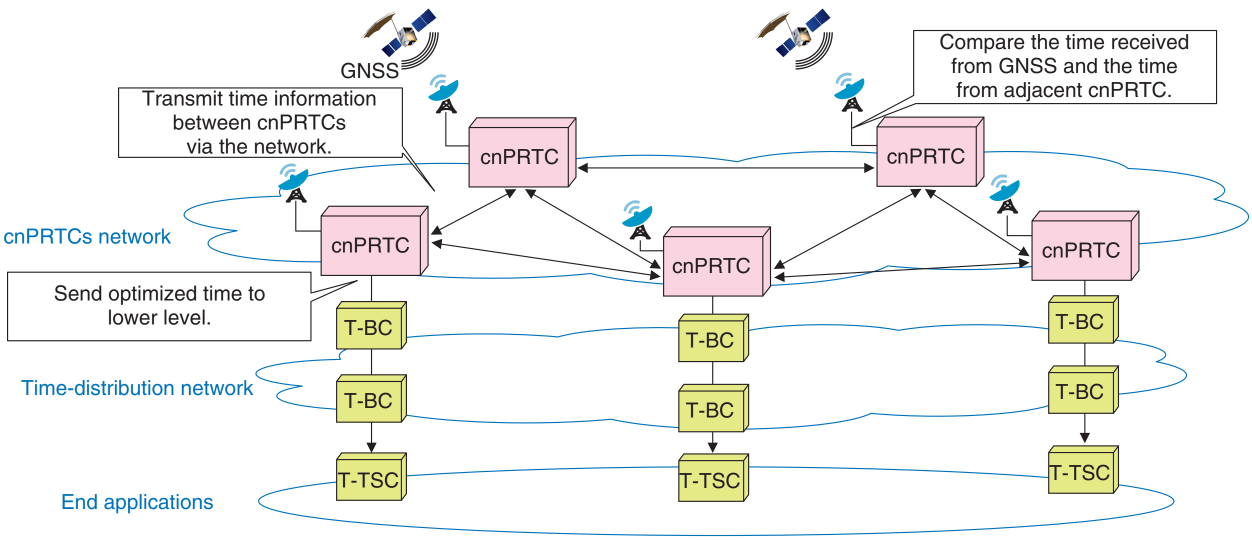


Fig. 3. Concept of cnPRTC.

(G.8272), which specifies a maximum time error in relation to UTC of 100 ns, PRTC-B (G.8272), for which a highly accurate receiver is mounted, specifies a reduced error of 40 ns. In addition, ePRTC (enhanced PRTC, G8272.1) has a function for maintaining time synchronization (*holdover*) with high precision by using a frequency-reference device (PRC) when a GNSS signal cannot be received. Currently, the specified holdover requirement is that time synchronization must be maintained within 100 ns over two weeks.

More recently, discussions have begun on a device concept called coherent network PRTC (cnPRTC) as a solution utilizing networks to minimize the effect when a GNSS signal cannot be received. As shown in **Fig. 3**, a cnPRTC optimizes error while comparing time information from a GNSS received from its own base station and information from neighboring devices, synchronizing those bits of information, and detecting abnormalities in GNSS reception. Details of the monitoring network architecture and mutual comparison methods will be discussed from now onwards. To improve the reliability and quality of future synchronization networks, NTT also proposes concepts concerning equipment in cooperation with other telecommunication operators.

A PRTC is an important device in a time-synchronization network. However, depending on the environmental disturbance and antenna installation conditions, the desired quality may not be able to be secured, especially when the GNSS signal is received as a reference. Consequently, developing a method for achieving stable reception of the GNSS signal has become a major issue among ITU-T participants. Therefore, the ITU-T is working on creating a technical report (GNSS-TR) on basic know-how and general measures against error factors concerning GNSS—to be published in the future.

5.2 Time-synchronization device (T-BC)

The T-BC (G.8273.2) receives time information from a PRTC and transmits and synchronizes it, and the issue of reducing the time error per device is being discussed. The ITU-T specifies the maximum absolute time error per device as a performance index of a T-BC, and that error is classified according to the accuracy class of the device, as listed in **Table 3**. Currently, although Class B is specified, new classes must correspond to the high accuracy requirement for 5G. At the ITU-T SG15 meeting in February 2018, agreement was reached on specifying the new classes of C and D. It was agreed at the meeting in October 2018 to specify the maximum time error per node to 30 ns for Class C. Opinions were expressed that class D should be set to 15 ns per node, and the specification of numerical values is planned from the viewpoints of both use cases of telecommunication operators and performance of the equipment. Specific requirements are also being fine-tuned in cooperation with other telecommunication operators based on the functionality and performance of a new clock-supply module for high-accuracy time synchronization

Table 3. Maximum absolute time error per node of T-BC (October 2018).

Class	Maximum absolute time error (ns)	
A	100 ns	
B	70 ns	
C	30 ns	Newly agreed
D	15 ns?	Under discussion

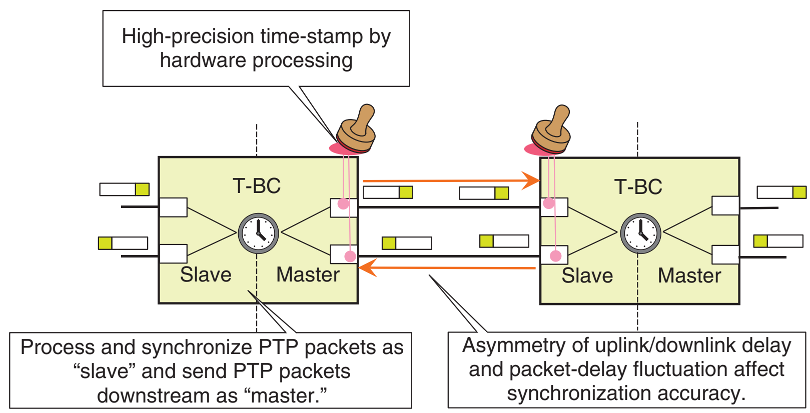


Fig. 4. Function of T-BC.

developed by NTT [5].

Also, the performance of the PTP itself within the T-BC is being studied with the aim of improving time-synchronization accuracy. As shown in **Fig. 4**, the error factors of the PTP for the T-BC include time-stamp-embossing error caused by internal clock frequency and asymmetry in uplink and downlink delay.

As an example of a time-stamp-embossing error, when the internal clock frequency of the device is 125 MHz, the error of one time-stamp becomes a maximum of 8 ns. Therefore, in the case of T-BC class D (equivalent to the level of several nanoseconds), it is necessary to improve the time-stamp performance within the device.

The delay asymmetry of the uplink and downlink is being considered in order to achieve high accuracy from the viewpoints of intra-device delay and fiber-transmission delay. With regard to intra-device delay, although the PTP has a function for eliminating delay fluctuation in the device by means of a hardware time-stamp function, ways to further improve synchronization accuracy by taking into account the delay-fluctuation factor at the device level are being discussed. However, in the current situation, intra-device delay primarily depends on the implementation, and specifying the delay values as standards is an important task facing the ITU-T. Regarding fiber-transmission delay, parameters of optical fibers (such as wavelength dispersion) have been discussed by ITU-T SG15 in cooperation with members studying issues related to optical fiber, and the goal is to promote understanding with the participants responsible for synchronous systems.

6. Quality improvement of frequency-synchronization devices

Efforts are underway to increase the accuracy of frequency synchronization by improving the quality of the relevant devices. Those efforts are described in this section.

6.1 Frequency-reference device (PRC)

When the time-synchronization signal is interrupted, it is necessary to keep the time according to the frequency-synchronization signal and internal clock. Frequency-synchronization accuracy is determined by the performance of the PRC (shown in Fig. 2). The conventional PRC (G.811) recommendation is intended for use with synchronous network services such as telephone and leased lines, and it was last updated in 1997. However, in anticipation of the use of frequency synchronization in the mobile field, based on the latest technology of clock devices such as atomic clocks, enhanced PRC (ePRC) was given consent as a new recommendation (G.811.1) in June 2017. The frequency accuracy of an ePRC was specified to be improved tenfold over that achieved by a conventional PRC. For example, if the frequency accuracy is increased tenfold by switching from PRC to ePRC, the holding time when the time signal is interrupted is also extended tenfold, so sufficient time is available to restore the time signal.

6.2 Frequency-synchronization device (EEC)

An EEC (G.8262) is a frequency-synchronization device equipped with Sync-E, and discussions have been held on developing a high-quality enhanced EEC (eEEC). Consent was obtained for the new recommendation (G.8262.1) at the meeting in October 2018. The stability of timing devices such as oscillators incorporated in the eEEC was the main issue being discussed, and the eEEC was being considered in reference to the effects of the temperature characteristics of an actual device. As a result, the holdover performance when the input signal of frequency synchronization is lost was specified to be more stable than the conventional EEC.

7. Enhancement of synchronization network management

In addition to the synchronization devices described above, the management of synchronous networks has also been a recent topic of discussion. The ITU-T has already standardized the OAM (operations, administration, and maintenance) of main-signal systems such as Ethernet. However, with the recent increased importance of time-synchronization technology, the need for stable maintenance and operation of synchronization-system devices is increasing. The ITU-T discusses specific quality-monitoring items, measurement items, as well as alarms and events regarding synchronization devices based on maintenance requirements received from telecommunication operators. In addition to developing the new clock-supply module [5], NTT has also proposed technologies (such as ones for quality monitoring and alarms) included with the developed equipment and has reflected those technologies in the relevant document. That document is scheduled to be prepared as an auxiliary document (G.Suppl.SyncOAM) for the recommendations of existing synchronization technologies.

8. Future development

Time-synchronization technology is an important technology for the 5G era, and it is necessary to keep track of standardization trends in the future in a timely manner. NTT will continue to actively contribute to standardization activities while advancing research and development of high-accuracy synchronization technology.

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