High-precision Time Synchronization | TD-LTE | UTC

Technology Reports

Special Articles on Introducing the 3.5-GHz Band

High-precision Clock-time-synchronization Network Equipment for Introduction of 3.5-GHz band TD-LTE

In December 2014, the MIC approved "Establishment Plan of Specified Base Stations for Introduction of Fourth-generation Mobile Communication Systems," and it thus became possible to utilize the 3.5-GHz frequency band in Japan. NTT DOCOMO has introduced TD-LTE using this band—combined with the existing FDD bands by means of CA—and communication services with a maximum data rate of 370 Mbps were launched to evolve our service called "PREMIUM 4G" in June 2016. This article summarizes technologies and describes characteristic features in regard to high-accuracy time-synchronization networks—a required future technology—for providing services based on the TDD method (which is being introduced by NTT DOCOMO for the first time).

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1. Introduction

In December 2014, the MIC allocated the 3.5-GHz frequency band to NTT DOCOMO. In accordance with a requirement for utilization of that band, the Time Division Duplex (TDD)*1 method must be used. Accordingly, when introducing the 3.5-GHz frequency band, NTT DOCOMO adopted TD-LTE standard technology (which is one version of the LTE standard).

As for TD-LTE, the frequency band can be used to the full because the frequencies of the uplink and downlink channels do not have to be separated. On the other hand, if the signals of the uplink and downlink channels are sent at the same time, radiowave interference can be generated. Extremely accurate clock-time synchronization—between not only our base stations but also those of other communication carriers—is thus necessary.

The accuracy of that clock-time synchronization is specified in the International Telecommunication Union-Telecommunication Standardization sector (ITU-T) Recommendation G.8271*2 as a time-synchronization error between

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*1 **TDD:** A bidirectional transmit/receive scheme that achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions that use the same frequency.

base-station-equipment time and Coordinated Universal Time (UTC)[*3] that must be kept to 1.5 μs or below (**Figure 1**). High-accuracy time synchronization can be achieved by directly receiving radiowaves (such as GPS signals) at base-station equipment, deriving UTC, and using that time. However, at base stations that cannot receive radiowaves like GPS signals (such as underground base stations), time-synchronization methods using Ethernet transmission are adopted.

The Network Time Protocol (NTP)[*4] commonly used for time synchronization, however, it cannot be utilized as the time-synchronization method for TD-LTE, even if stratum-3[*5] is applied, because time-synchronization error in relation to UTC is in the order of milliseconds, namely, time-synchronization accuracy is low. Consequently, a high-accuracy time-synchronization protocol called Precision Time Protocol (PTP) is applied (**Table 1**).

As for PTP, using a highly versatile Ethernet transmission path makes it basically possible to transmit stabilized time with high accuracy to base-station equipment without dependence on distance. Networks adopting PTP are configured with components called Grand-Master Clock (GMC)[*6] and Boundary Clock (BC)[*7]. In this article, a high-accuracy time-synchronization network adapting TD-LTE using these components is described [1] [2].

2. Time-synchronization Method

Two kinds of time-synchronization methods using Ethernet transmission paths are specified by the ITU-T: "full-on path support" and "assisted partial timing support." Each method is summarized below (**Figure 2**).

"Full-on path support" achieves high-accuracy time transmission because all equipment on paths from GPS transmitters to base-station equipment supports BC capability (which corrects and re-sends timing errors by statistical processing) and transmits PTP packets.

"Assisted partial timing support" achieves time synchronization in a configuration including equipment in the paths that is incompatible with BC capability. While existing Ethernet networks can be utilized, the influence of factors such as processing delay of non-BC-compatible equipment is significant; therefore, it is not always possible to assure time-synchronization accuracy with this configuration. Assisted partial timing support is prescribed for use as a backup method to be used in the

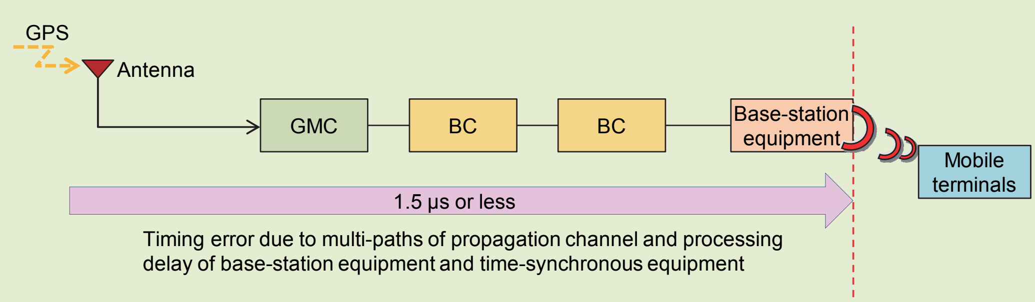


Figure 1 Condition of clock-time error in the case of TD-LTE

Table 1 Time-synchronization protocol

Protocol	Synchronization accuracy	Synchronization method
NTP	Approx.1 ms	In reference to a time standard maintained by a server, times are synchronized according to requests from clients.
PTP	1.5 μs or less	Times are synchronized by exchanging messages between equipment taking the roles of master and slave.

*2 **ITU-T Recommendation G.8271:** An ITU-T recommendation that defines clock time and phase synchronization for packet networks.

*3 **UTC:** Time on which standard time around the world is based.

*4 **NTP:** A communication protocol for correcting the internal clock of computers via networks.

*5 **Stratum-3:** Devices on the third stratum—in regard to UTC—in an NTP-hierarchical structure. Clock time is generally delivered to a client from stratum-3.

*6 **GMC:** UTC-time information is extracted from signals (such as GPS signals) and delivered to downlink equipment as packets. The GMC is located at the apex of the PTP communication structure.

case that base-station equipment receives direct radiowaves (such as GPS signals).

NTT DOCOMO is expanding TD-LTE so that it can also be used in places that cannot receive GPS signals (such as underground). Accordingly, as a time-synchronization method, full-on path support was adopted instead of assisted partial timing support—which is presupposed to be used as a backup method.

3. Mechanism of High-accuracy Time Synchronization

As shown in **Figure 3**, a time-synchronization network is configured with a GMC at its apex. In each link of this configuration, the downlink port of uplink equipment plays the role of "master," and the uplink port of downlink equipment plays the role of "slave." Messages are exchanged between the master and slave in accordance with the PTP sequence described in the following (**Figure 4**). Moreover, providing an action that cancels delay within equipment makes it possible to achieve high-accuracy time synchronization.

3.1 PTP Message Type

The PTP messages are generally classified as "announce" or "event" messages.

1) Announce Message

Announce messages are used for communication of information about session*8 establishment and time synchronization by sending messages from master to slave.

2) Event Message

- Sync: A message sent from master to slave. It records the time the message was sent from the master.
- Delay_Req: A message returned to the master from the slave that received the Sync message.
- Delay_Resp: A message sent from the master to the slave. It records the time the Delay_Req message was received by the master.

3.2 PTP Sequence

Time correction can be achieved by

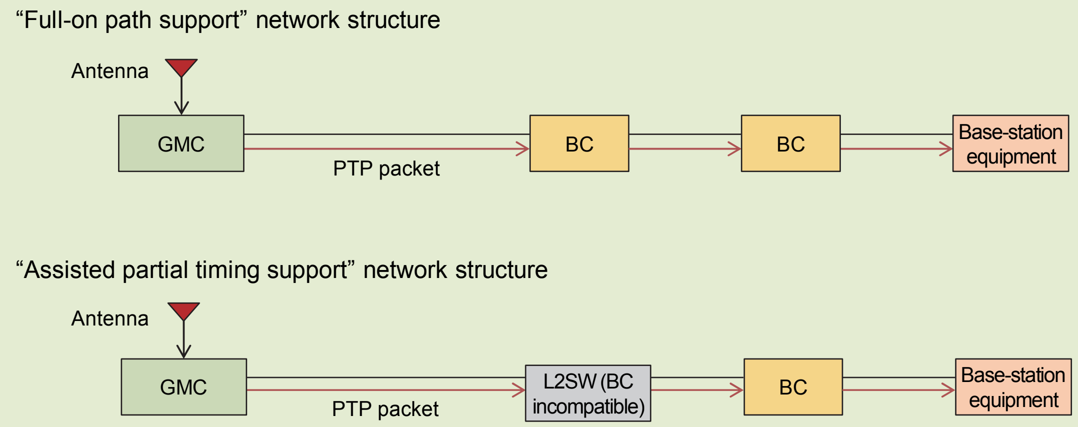


Figure 2 Time synchronization

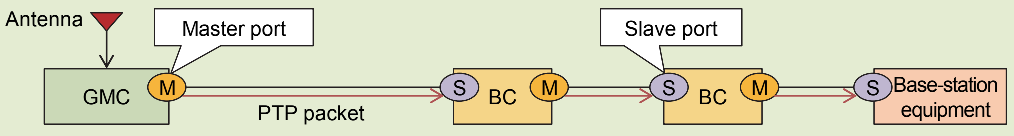


Figure 3 Configuration of time-synchronization network

*7 **BC:** A component that re-sends clock time from uplink equipment to downlink equipment after correcting it.

*8 **Session:** A virtual communication path for transmitting data or the transmission of data itself.

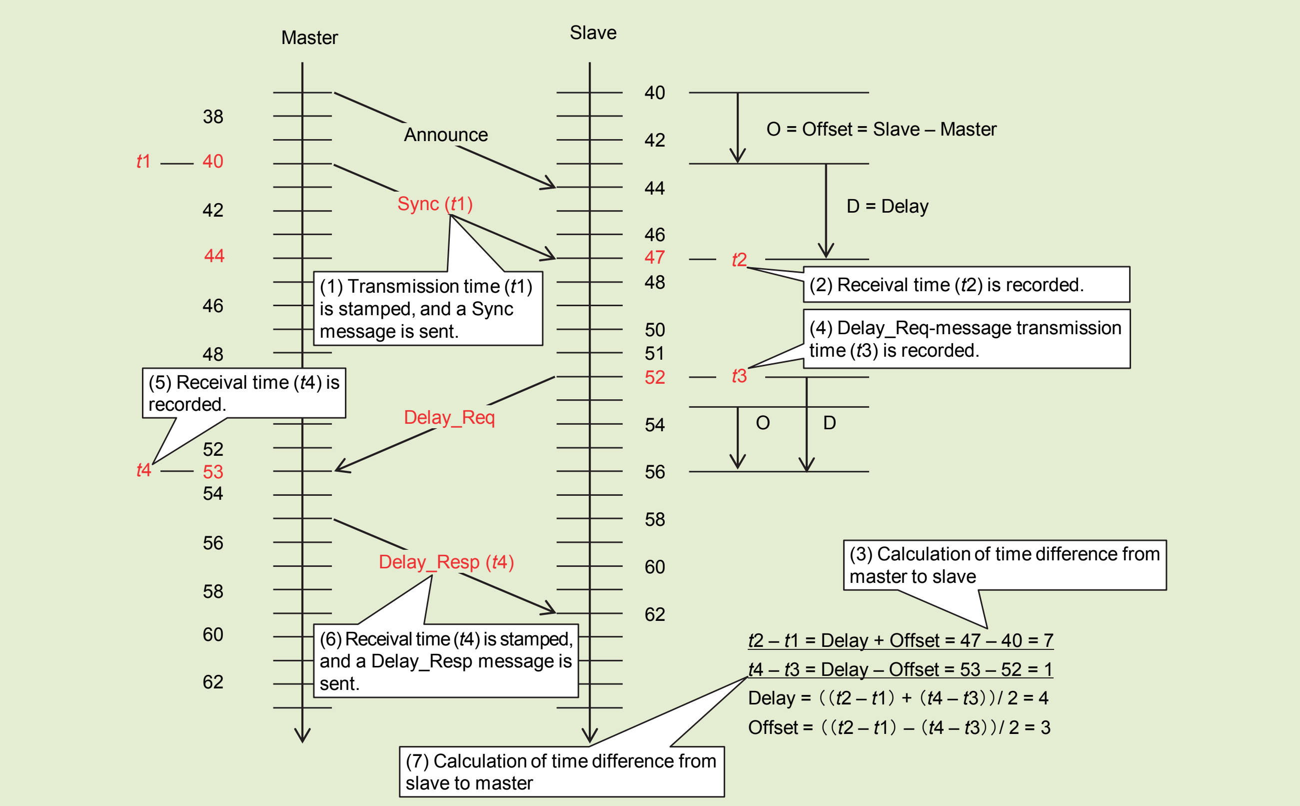


Figure 4　PTP sequence

determining the time difference between the master and slave and calculating the transmission-path delay and time lag (hereinafter referred to as "offset") between equipment (Fig. 4).

1) Calculation of Time Difference from Master to Slave

(1) The master sends a Sync message [stamped with the time it was sent ($t1$)] to the slave.

(2) The slave records the time ($t2$) that it received the Sync message.

(3) The slave determines the time difference from the master to the slave from $t1$ and $t2$ (i.e., 47 – 40 = 7, as shown in the middle of Fig. 4).

2) Calculation of Time Difference from Slave to Master

(4) The slave sends a Delay_Req message to the master, and it records the time ($t3$) that the message was sent.

(5) The master receives the Delay_Req message and records the time ($t4$) it receives the message.

(6) The master sends a Delay_Resp message (stamped with $t4$) to the slave.

(7) The slave receives the Delay_Resp message and determines the difference between $t4$ and $t3$ (i.e., $t4 - t3 = 53 - 52 = 1$, as shown in the middle of Fig. 4).

3) Calculation of Transmission-path Delay and Offset

Transmission-path delay and offset are calculated on the basis of a precondition under which the transmission-path delay time between the master and slave is symmetrical as follows:

- transmission-path delay = $\{(t2 - t1) + (t4 - t3)\}/2 = (7 + 1)/2 = 4$
- offset = $\{(t2 - t1) - (t4 - t3)\}/2 = (7 - 1)/2 = 3$

In the case that transmission-path distances from the master to the slave and from the slave to the master are symmetric, arrival times at the master and slave will be consistent. Calculating the total of the transmission-path delay and offset and dividing that value in two therefore gives the transmission-path delay time. And dividing the difference in those values in two gives the offset. The slave always performs time correction within the equipment in which it is installed on the basis of the transmission-path delay time and offset. As a result, high-accuracy time synchronization between each session of PTP equipment (GMC and BC) is accomplished.

3.3 Cancellation of Internal Equipment Delay

To correct delay occurring within equipment, a correction field*9 including PTP packets is used. Adding a correction value to the event message sent by the master allows the slave to cancel the internal delay of the master (**Figure 5**).

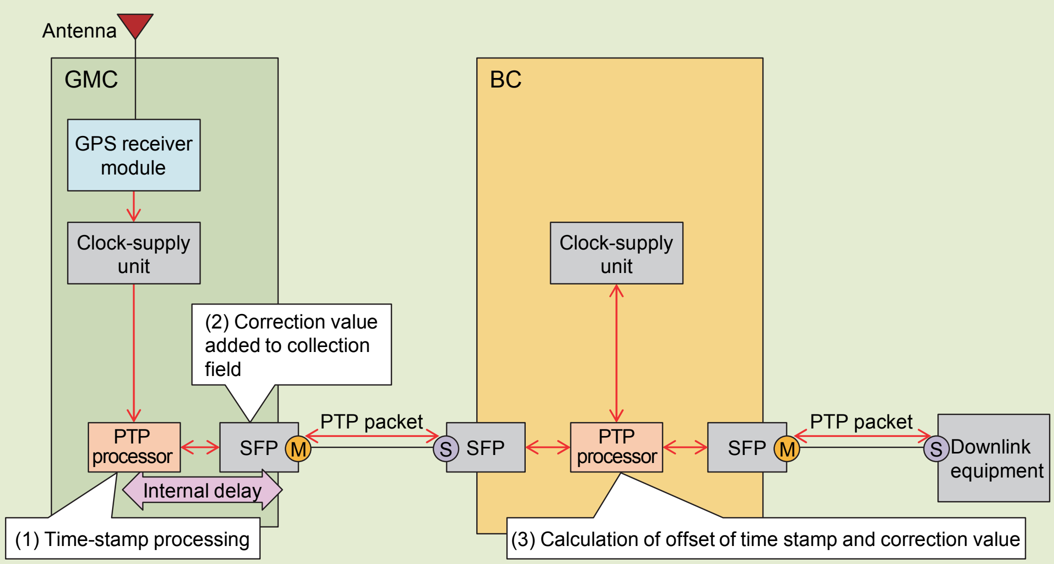
4. Outline of Functions of PTP Equipment

4.1 Functional Block

As shown in **Figure 6**, the GMC has a GPS receiver module (for receiving signals like GPS ones and extracting time information from them), a clock-supply unit (which houses a Sync-E*10 processing block) for storing that information as the system clock of the equipment in question. It also has a PTP processing block (for generating and embedding time stamps from the clock-supply block in PTP packets) and a PPS processing block for sending 1 Pulse Per Second (1PPS)*11 signals. In contrast to the functional blocks of the GMC, those of the BC do not include a GPS receiver module.

4.2 Combined Use with Sync-E

Although time synchronization is executed under the assumption that frequency synchronization*12 is imposed, frequency synchronization under PTP executed on Ethernet networks is independent in terms of each piece of equipment, and the whole network is asynchronous. On the other hand, Sync-E operates on a physical layer; therefore, frequency synchronization can be performed with high accuracy regardless of fluctuations in communication volume, and the whole network is synchronous. Under those circumstances, NTT DOCOMO judged that combined use of PTP and Sync-E would be



Small Form-factor Pluggable (SFP): A removable module that can be installed in equipment in accordance with the communication standards in use.

Figure 5 Mechanism of internal-delay cancellation for GMC and BC equipment

*9 **Correction field:** A field including PTP packets used for transmitting internal equipment delay.

*10 **Sync-E:** A method for synchronizing frequencies on the physical layer. All equipment on a transmission route performing synchronization must handle Sync-E.

*11 **1PPS:** A pulse signal sent once per second.

*12 **Frequency synchronization:** A condition under which the speed at which time is kept is consistent from one piece of equipment to the next.

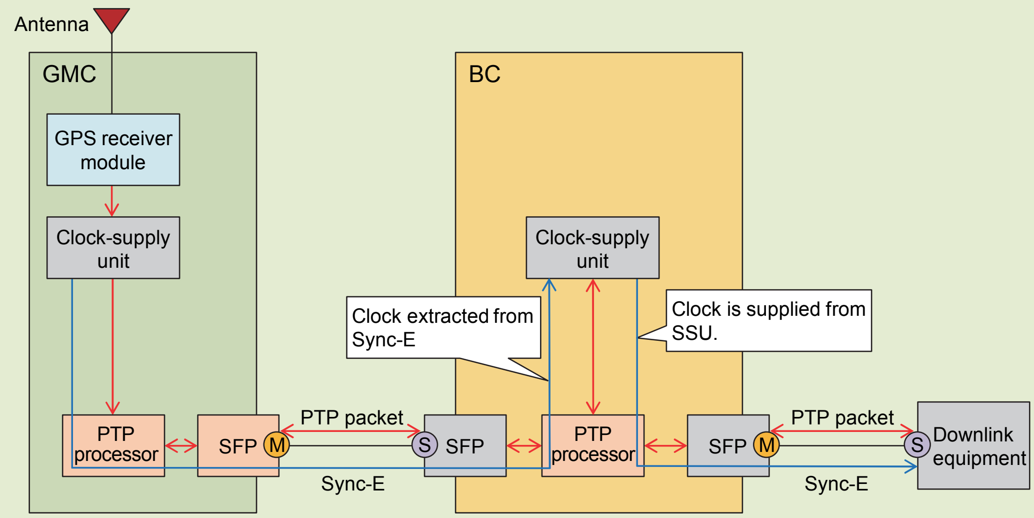


Figure 6 Functional blocks of GMC and BC

effective for the high-accuracy time synchronization required by TD-LTE, so we adopted a method combining PTP and Sync-E. Combining PTP and Sync-E in this manner for all equipment of a time-synchronization network makes it possible to improve the time-synchronization accuracy along a whole ("end-to-end") communication route because the times for processing PTP packets are consistent.

4.3 BMCA

To handle failures, BC equipment can combine a maximum of two uplink PTP units in a redundant configuration by applying a function called a Best-Master Clock Algorithm (BMCA). This function is accomplished as a result of the master recording the performance value of its own time information in the announce message and regularly communicating with the slave. The slave can receive time information from two masters, judge the masters on the basis of their performance values, and select the BMC accordingly. Which of the two pieces of received time information to use for synchronization is judged by means of a "BMCA sequence" (as shown in **Figure 7**). Furthermore, although synchronization is performed with the selected BMC, if communication with that BMC fails, time synchronization is performed with the other master. The performance value included in the time information received from the masters is classified as one of the following six kinds (and the master with the highest value is selected).

(1) Priority 1

A priority 1 value indicates the unconditional priority of GMCs. It is a set value specified in IEEE1588-2008*13 and cannot be changed. In the case of BC, priority 1 is passed down to downlink equipment.

(2) Clock Class

"Clock Class" is a value that indicates the synchronization state between UTC and the time sent from the master (as shown in **Table 2**). In the case that the two are synchronized, a Clock Class "6" (hereinafter referred to as "CC6") is sent.

(3) Clock Accuracy

"Clock Accuracy" is a value that indicates the accuracy of time. The values handled by NTT DOCOMO's PTP equipment are shown in **Table 3**.

(4) Offset Scaled log Variance

"Offset Scaled log variance" indicates the stability of clock-synchronization accuracy as shown in **Table 4**.

(5) Priority 2

"Priority 2" is a value that indicates the unconditional priority of GMCs. However, unlike priority 1, it can be varied; that is, by setting

*13 **IEEE1588-2008:** An IEEE standard that defines a protocol for high-accuracy clock-time synchronization used for financial and communication systems.

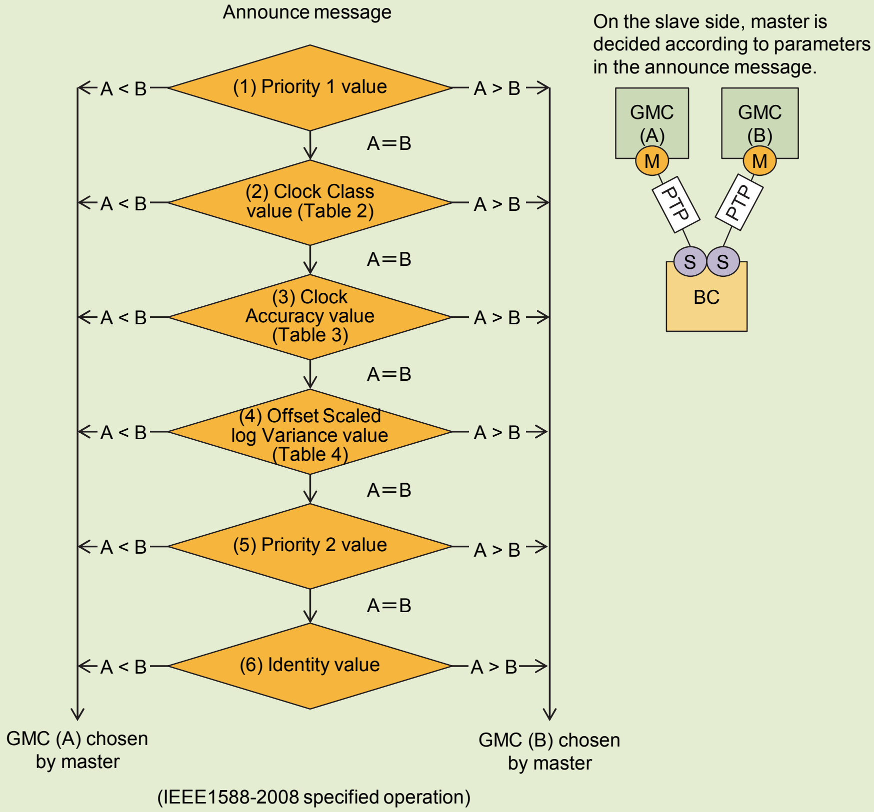


Figure 7 BMCA sequence

Priority 2, the user can select the BMC that must be synchronized.

(6) Identity

"Identity" is a value calculated from the Media Access Control (MAC) address*14 of equipment as a unique value allocated to each piece of equipment.

5. Aiming to Provide Stable Services

5.1 Improvement of Operation of PTP Equipment

When the GMC is synchronized with UTC, delivery of clock time (along with CC6) to downlinks starts.

Table 2 Clock Class

Value (hexadecimal notation)	Explanation of condition
6	Synchronization with UTC
140, 150, 160	GMC is hold over.
165	BC is not synchronized with master.
248	GMC: During initial start-up operation or hold-over BC: During initial start-up operation

Table 3 Clock Accuracy

Value (hexadecimal notation)	Explanation of condition
21	Time accuracy within 100 ns
FE	unknown

Table 4 Offset Scaled log Variance

Value (hexadecimal notation)	Explanation of condition
4E5D	Synchronization with UTC
FFFF	Not synchronized with UTC

*14 **MAC address:** A 12-digit fixed physical address allocated to an Ethernet board.

On the other hand, due to periodic failures of time-synchronization networks, even under the condition that an error between the system clock and UTC occurs, if CC6 is received, clock time is delivered to subordinate equipment. As a result, it has been typically necessary to periodically stop services delivered on the basis of TD-LTE. As a countermeasure against that necessity, by reviewing the behavior of clock-time error convergence and significantly shortening the time required for convergence, it is possible to shorten the time that failures effect services (**Figure 8**).

5.2 Influence of Multipaths

Radiowaves (like GPS signals) can be categorized as direct waves or reflected waves according to the surrounding environment (**Figure 9**). With reflected waves referred to as "multipath waves," in regard to accurate clock-time synchronization, clock-time error is increased (**Figures 10** and **11**). At present, it is impossible to completely exclude multipath waves; accordingly, at NTT DOCOMO, while considering increase in clock-time error due to the influence of multipath waves, we are

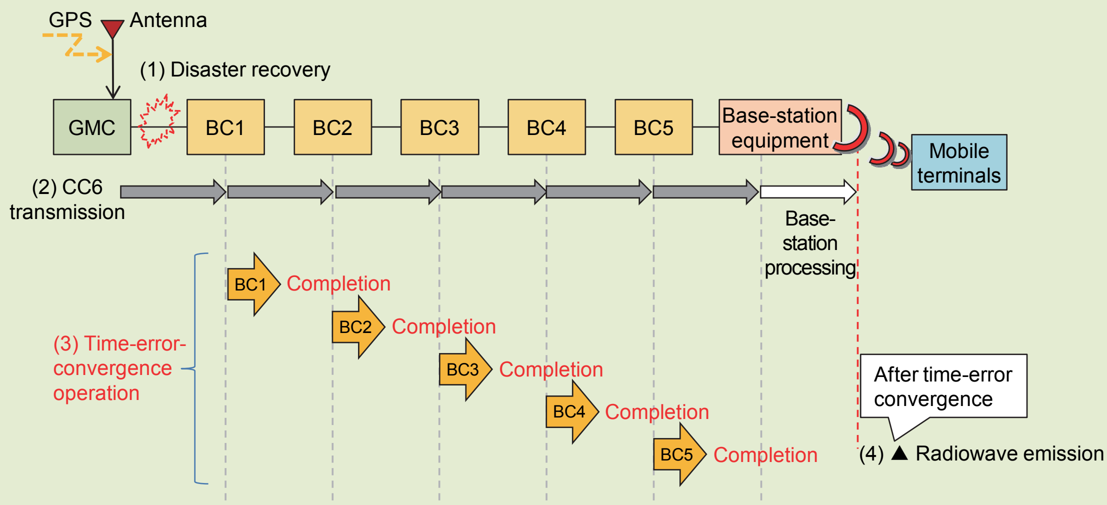


Figure 8 Convergence of time errors

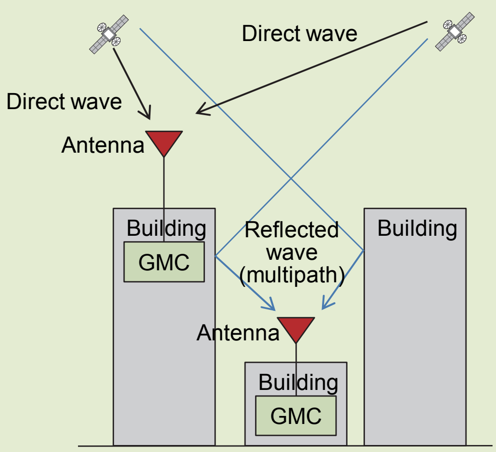


Figure 9 Direct waves and multipath waves

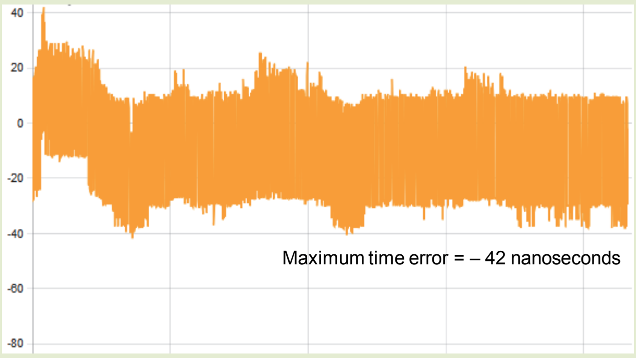


Figure 10 Maximum time error in an environment with numerous direct waves

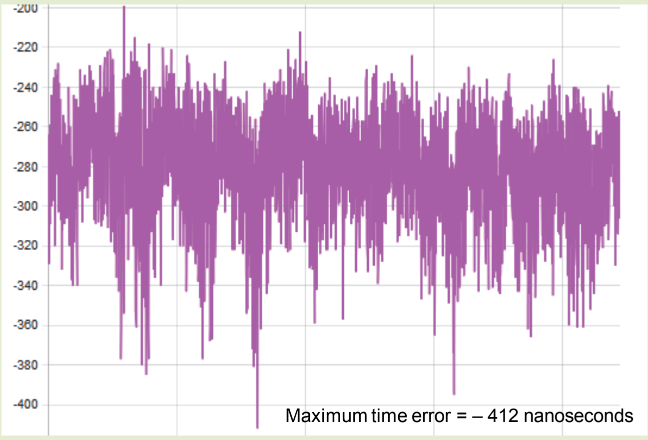


Figure 11 Maximum time error in an environment with numerous multipaths

building networks with a limited number of BC stages connected to downlink equipment of GMC.

6. Conclusion

In this article, standard specifications and operations in regard to equipment composing high-accuracy time-synchronization networks targeting introduction of 3.5-GHz-band TD-LTE are explained. At present, standardization of, for example, operation during failures is progressing, and while considering this trend, we will continue to apply this standardized technology to NTT DOCOMO networks as necessary.

References

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[2] M. Fujii et al.: "Base-station Equipment with the Aim of Introducing 3.5-GHz Band TD-LTE," NTT DOCOMO Technical Journal, Vol.18, No.2, pp.8-13, Oct. 2016.