TIME CONCURRENCY / PHASE-TIME SYNCHRONIZATION IN DIGITAL COMMUNICATIONS NETWORKS

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Abstract

Digital communications networks have the intrinsic capability of time synchronization which makes it possible for networks to supply time signals to some applications and services.

A practical estimation method for the time concurrency in terrestrial networks is presented. By using this method, time concurrency capability of the NTT (Nippon Telegraph and Telephone corporation) digital communications network is estimated to be better than 300 ns rms at a advanced level, and 20 ns rms at final level.

INTRODUCTION

In current digital telecommunication networks, highly stable frequency signals are distributed as a standard frequency. Master-slave synchronization is generally adopted to synchronize all nodes in these networks. A unique master node and other slave nodes compose a hierarchically topological tree structure which is gradually growing with the expansion of digital networks. In master-slave synchronization, however, this growth causes the extension of logical depth, namely an increase in the number of links. Consequently, the purity and stability of standard frequencies are being degraded.

There are two effective ways to prevent such degradation. One is a new standard frequency distribution system named the Primary Reference Clock developed by AT&T that receives GPS signals and can distribute a highly stable reference [1]. This system can reduce the number of links in a synchronization hierarchy since reference signals are regenerated in nodes dispersed throughout the U.S.

The other way is the phase-time synchronization described here. Traditional master-slave synchronization is actually syntonization, even though phase-locked loop systems are used in slave nodes. We suggest a new system which can provide true synchronization in both phase-time synchronization and time concurrency through reference time signal distribution.

Such distribution to all telephone offices and subscriber sites can also provide time concurrency for certain aspects of systems which are improved by accurate time signals, such as time management in network operation systems, time stamping in distributed computer systems, and navigation in digital mobile systems.

We assume that the present network synchronization (i.e. frequency synchronization) is being changed to accommodate time synchronization, in which reference time signals will be distributed over digital paths composed of optical transmission and digital radio systems. The high capability of the terrestrial digital network for time transfer is presented here.

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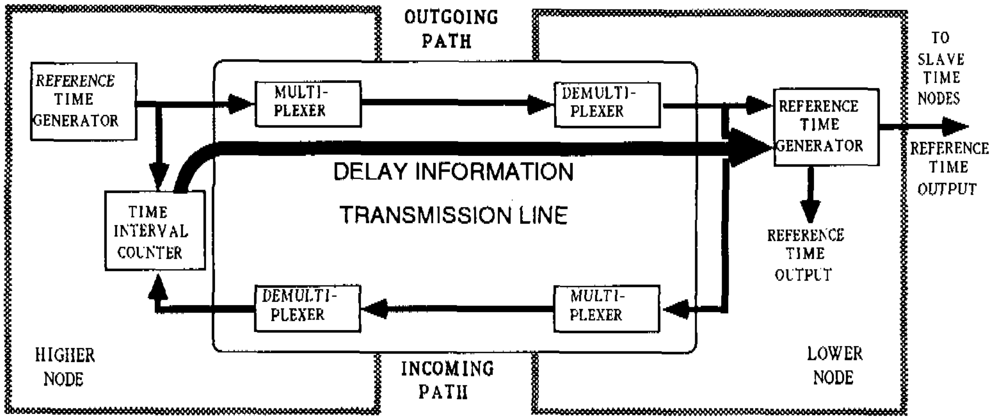

Fig. 1 Basic configuration of time distribution link

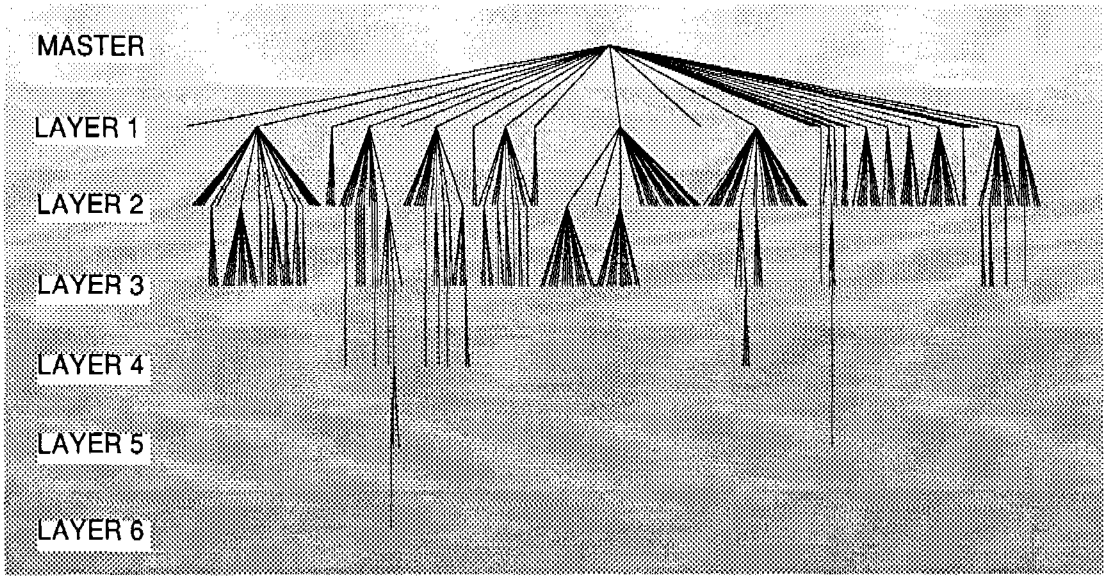

Fig. 2 Hierarchical tree for time synchronization analysis

PHASE-TIME SYNCHRONIZATION NETWORK

The performance of time synchronization can be evaluated by relative phase-time stability and absolute time concurrency. In our new synchronization system, these characteristics are simultaneously accomplished by transmission delay compensation. The measurement of the round-trip delay in digital paths allows a transmission delay correction because, for the most part, outgoing and incoming paths in digital transmission systems have the same transmission delay and are laid under the same circumstances.

Network topology for time synchronization follows the master-slave hierarchy, in which a unique time master node generates reference time signals that are distributed to other slave nodes. The basic configuration of the time distribution link is shown in Fig. 1. A higher node measures a round-trip delay and transfers the half-transmission delay as delay information to a lower node. The lower node compensates the time signal according to the received delay information.

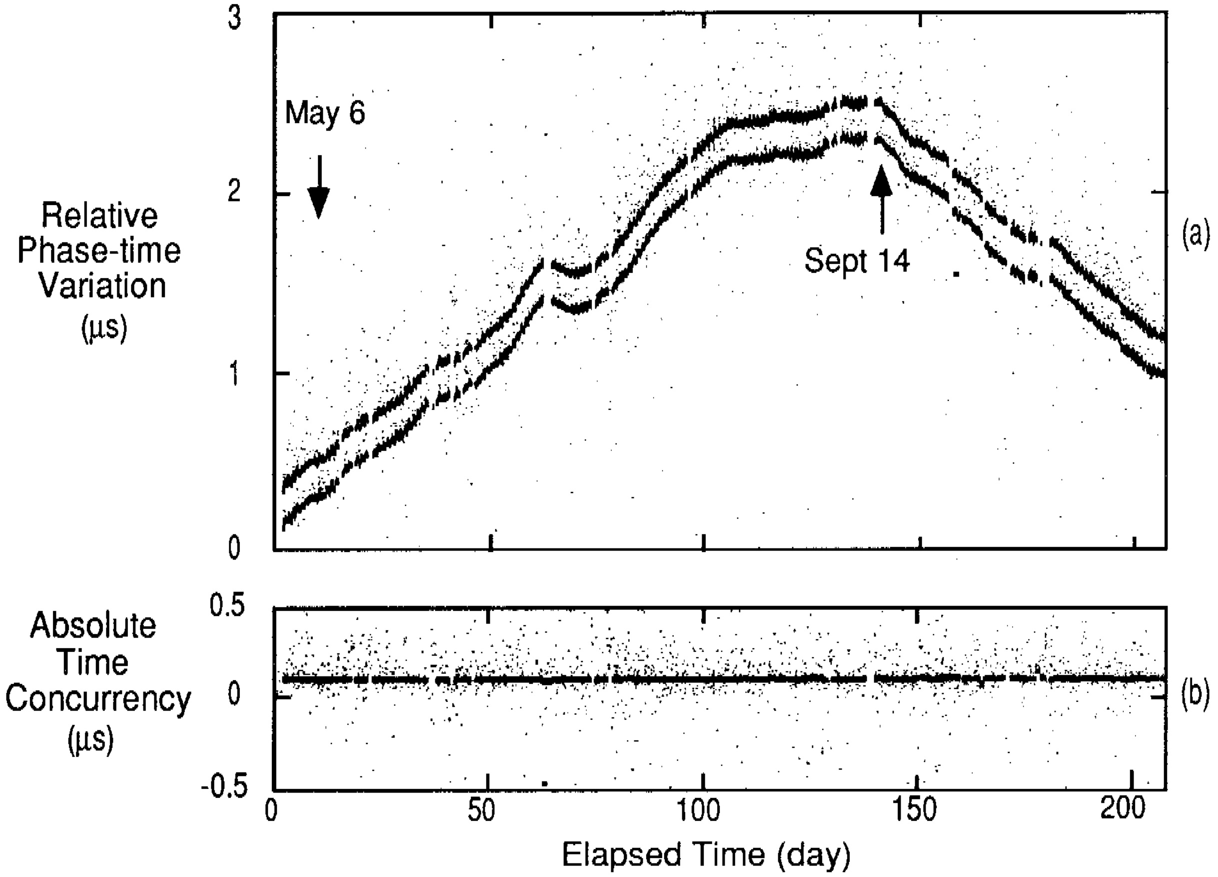

Fig. 3 (a) Measured wander and (b) compensated wander

TIME SYNCHRONIZATION CAPABILITY

Time synchronization topology

The topology of the master-slave method is mostly determined by geographical situations since node locations are settled independent of transmission systems. Therefore, characteristics of future time-synchronization networks can probably be estimated based on the analysis of the current syntonization system in an existing network. The hierarchical tree for the time synchronization network is shown in Fig. 2. For this topology we selected 400 nodes out of NTT's synchronized network. There are 7 layers. The top one is called the master layer and they are connected through 6 links.

Relative phase-time synchronization capability

Arrival time dispersion of time signals is determined by long-term delay variation in transmission lines due to temperature change in transmission cables originating from the environment. This variation, called wander, corresponds to relative phase-time synchronization stability and its influence can be reduced by measuring round-trip delay. Practical wander is on the order of micro seconds as shown in Fig. 3 (a). This is one of the results obtained through measuring an approximately 2400-km transmission path in the terrestrial NTT network for 7 months. The influence of this wander is compensated to be within 50 ns by the time distribution link, as shown in Fig. 3 (b). Furthermore, filtering, whose time constant is 100 to

1000 s, decreases timing jitter caused by multiplexers and demultiplexers, and can achieve about 2 ns relative time synchronization.

The accumulation of these measured results has yielded the experimental equation for the relation between the transmission path length,L in km, and the relative time synchronization, $\Delta T_{relative}$ in ns as follows:

$$\Delta T_{relative} = K_1 \cdot L + K_0 \qquad (1)$$

Constants, K_1 and K_0 are 5×10^{-4} ns and 0.8 ns *in the* 6.312 Mb/s digital path. K_1 is the factor of the asymmetry in round-trip delay compensation. K_0 is the factor of the delay asymmetry in digital circuits. Relative time synchronization stability is consequently proportional to transmission length.

Absolute time synchronization capability

The above time compensation method simultaneously enables absolute time concurrency; however, residual time errors, which correspond to the difference between transmission delays of the outgoing and incoming paths in the round-trip compensation, degrade it [2]. The delay difference is caused by variations in the cable length which depends on the number of fiber fusion splices, fiber connections by connecters and the delay difference in connections between multiplexers. As time concurrency, the following model can be employed in the event time errors are not correlated:

$$\Delta T_{absolute} = \sqrt{K_{fs}^2 N_{fs} + K_{rc}^2 N_{rc} + K_{ic}^2 N_{ic}} \qquad (2)$$

K_{fs}: time difference in fiber fusion splices
K_{rc}: time difference in the fiber connection of repeaters and multiplexers by connecters
K_{ic}: time difference due to multiplexer connections in an intra-office
N_{fs}: number of fiber fusion splices
N_{rc}: number of fiber connections
N_{ic}: number of multiplexer connections

In Fig. 3 (b), absolute time concurrency, $\Delta T_{absolute}$, is 100 ns. This value can be estimated on the condition that K_{fs} and K_{rc} are 2 ns rms, K_{ic} is 20 ns rms, N_{fs} is 1128, N_{rc} is 240 and N_{ic} is 64.

The time difference from UTC is not presented here. It is important not to guarantee UTC itself, which is maintained by governmental facilities, but rather to trace it. Guaranteeing UTC itself is beyond the work of telecommunication companies.

TIME CONCURRENCY PERSPECTIVES

Time synchronization performance is influenced by the transmission path configuration for transfer time signals and by timing clock systems which supplies timing clocks to digital systems in transmission paths. These constituent elements in networks classify the time concurrency. This classification also shows the transition stream of the progress in time synchronization. The different configurations shown in Figs. 4, 6 and 8 can be considered in terrestrial digital networks. The time transition is classified into 5 stages.

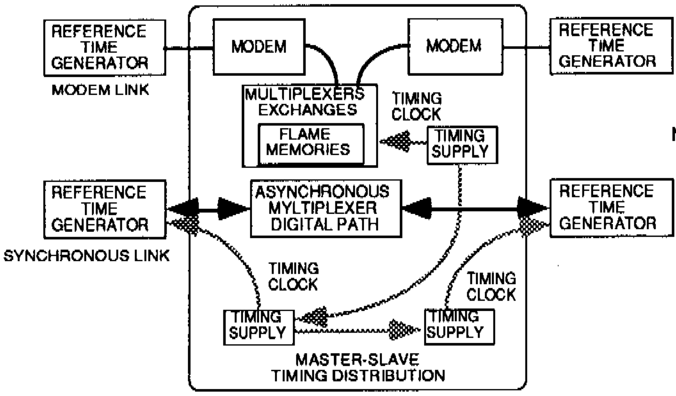

Fig. 4 Entry level time distribution configuration

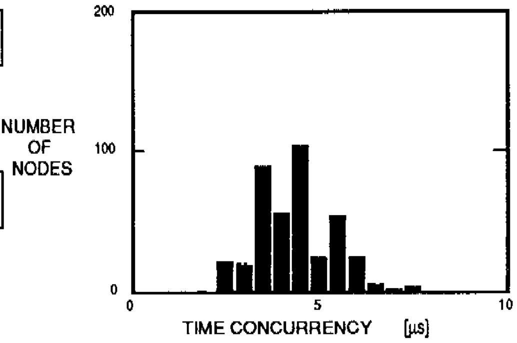

Fig. 5 Time concurrency distribution in stage 2

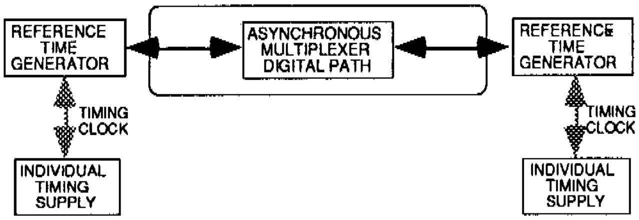

Fig. 6 Advanced level time distribution configuration

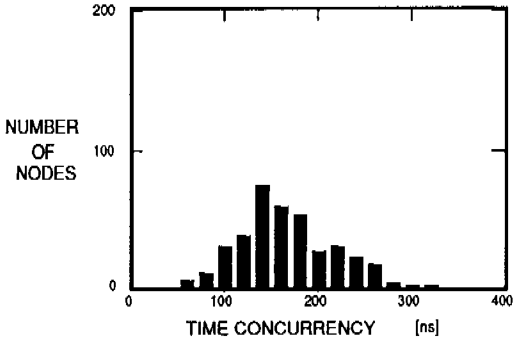

Fig. 7 Time concurrency distribution in stage 3

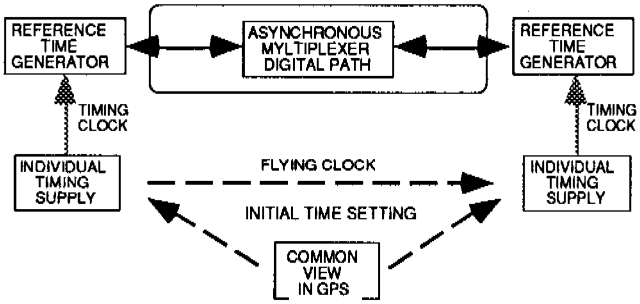

Fig. 8 Final level time distribution configuration

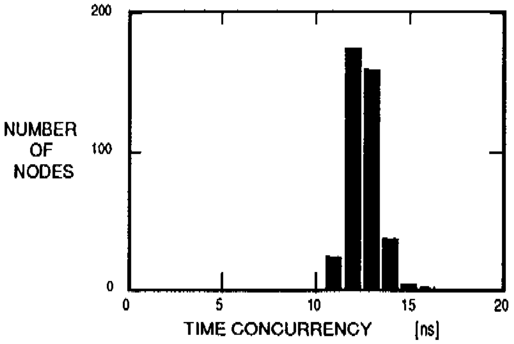

Fig. 9 Time concurrency distribution in stage 5

Entry level (Stages 1 and 2)

One of the most practical configurations is time transfer via low-speed digital paths such as the modem links and 64 kb/s ISDN shown in Fig. 4. Since these paths include synchronous digital multiplexers and exchanges, uncertainty in time concurrency is on the order of 100 μs and is equivalent to the amount of frame memories installed in those systems. Practical measurements in such systems have been shown by D. W. Allan and others [3][4]. Time concurrency in stage 1 can be estimated to be 100 to 200 μs.

It is possible to eliminate the influence of frame memories if paths are composed of asynchronous digital multiplexers using pulse justification up to the highest hierarchy. In these situations, phase-time variations of timing clocks remain in the total time uncertainty. Two timing clock configurations are possible at both ends of paths in time control systems: synchronized timing clocks supplied by the existing frequency synchronization (syntonization), and individual timing clocks generated by independent oscillators.

Wander appearing in synchronized timing clocks is gradually increasing according to digital network expansion. In stage 2, time concurrency can be estimated at this time to be within 10 μs using these clocks. If stage 2 is introduced in the existing networks, time concurrency distribution can be calculated in Fig. 5 based on the hierarchical tree shown in Fig. 2.

Advanced level (Stage 3)

Individual timing clocks can prevent the influence of network expansion in master-slave synchronization. These clocks can be indirectly synchronized in frequency by the phase-time synchronization shown in Fig. 1 (Fig. 6).

In stage 3, where there are multi-links of digital paths for the time transfer, time concurrency is determined by the number of repeaters and fusion splices in fiber connections, which varies with a transmission cable length, and by the number of connections between multiplexers in intra-offices. The factor of multiplexer connections is dominant in these situations and it can be estimated within 300 ns rms as shown Fig. 7.

Final level (Stages 4 and 5)

If the virtual container in SDH (Synchronous Digital Hierarchy) can be used for the time transfer, the single-linking of digital paths is possible (Stage 4). However, time concurrency can not be dramatically improved even if the single-link between time synchronized nodes is introduced. When the initial time setting is adopted together with the single-link configuration, time concurrency can obtain the highest performance (Fig. 8). Its distribution is shown in Fig. 9 and it is within 20 ns rms (Stage 5).

The first half of time concurrency in Fig. 9 results from uncertainty in the initial time setting. There are two ways for the initial time setting: flying clock and common view method in GPS. Uncertainty in the initial time setting here is expected to be within 10 ns in this estimation. Using conventional Cesium beam standards for flying clock method, the setting accuracy is now within 100 ns; however, it will be improved to 10 ns by applying new oscillators such as optically pumped Cesium standards. If the initial time setting can correct the residual time error, the second half of time concurrency shown in Fig. 9 is determined by relative phase-time synchronization calculated by Eq. (1). It can also be estimated to be within 10 ns rms.

Time concurrency transition

Time concurrencies in each level are shown in Fig. 10. The entry level providing time concurrency within 1 ms is an area in the application coping with 1 second. In the advanced level, time concurrency within 1 μs enables time stamping for distributed data-base and network operation systems, and provides time synchronization in comparatively lower speed digital signals. The final level is effective in future TDMA such as next-generation cellular phone systems, and can also contribute to academic applications such as geophysics and astronomy.

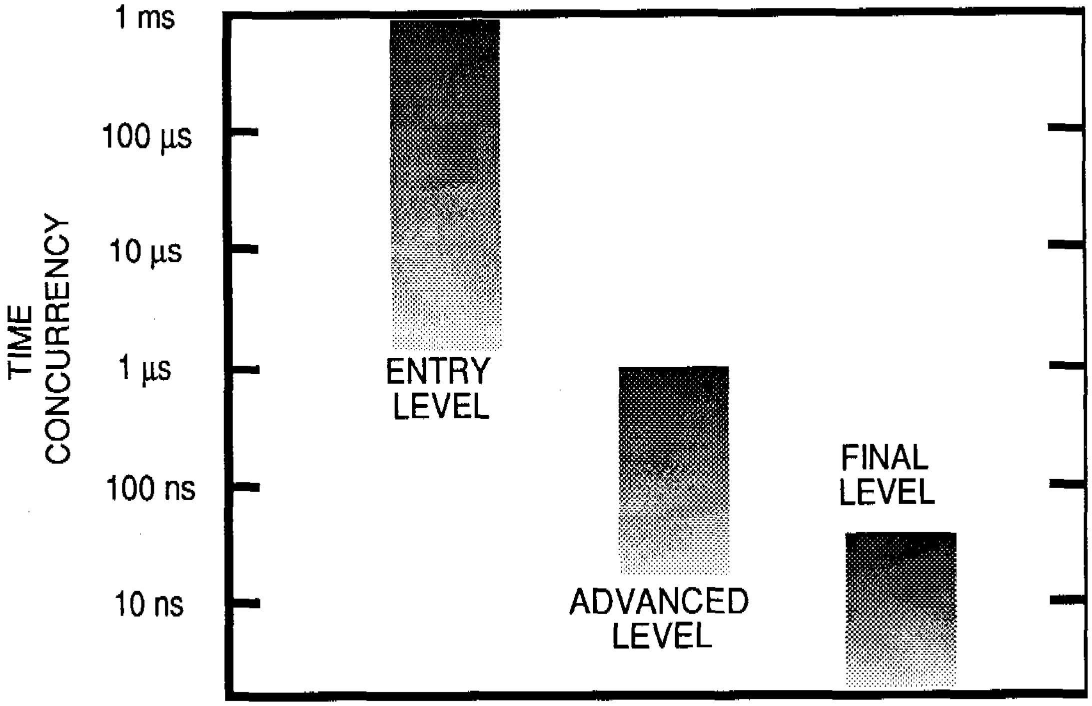

Fig. 10 Time concurrency transition stream

CONCLUSION

We presented the possibility of submicro-second time concurrency in a 400-node scale telecommunication network with a maximum transmission length of approximately 2400 km. This scale is similar to that of NTT networks in Japan; however, this estimation method can be applied to other networks in other countries.

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QUESTIONS AND ANSWERS

David Allan, NIST: Did I understand you to say that you are planning to use time division multiplexing for communication networks?

Mr. Kihara: Yes, the most important application is time division multiplexing systems.

Mr. Allan: Can you tell us how much more efficiency you expect from this new system?

Mr. Kihara: I am not sure.