Time and Frequency Transfer in an Asynchronous TCP/IP over SDH-network Utilizing Passive Listening

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Abstract—**A technique for time and frequency transfer over an asynchronous TCP/IP network is being developed by SP, Swedish National Testing and Research Institute together with STUPI. When implemented, users will be able to compare their clocks by connecting to the system. The technique is based on passive listening to existing data traffic in the network. Since the network is asynchronous, intermediate clocks are located and compared at each router. We use the frame alignment bytes of the SONET/SDH protocol as references in order to compare these clocks. As a test bed for the experiment, we will use the Swedish university Computer Network (SUNET). A preliminary assessment of the technique in a lab environment will be performed late 2005.**

I. INTRODUCTION

Accurate time transfer over existing fiber optic networks has attracted increasing interest in recent years, as awareness of dependence on GPS has become more apparent.

Experimental field trials on two-way time transfer over existing fiber have been presented, however using dedicated fibers, e.g., [1, 2, 3]. These solutions actively transmit data over the network, and hence require access to the infrastructure. Hence they may be difficult to implement in non-dedicated networks. Furthermore this technique does not allow stand-alone modules to be installed in existing networks.

As an alternative, we are developing a technique to use the data already transmitted in the network, and recover the time information from this data. This technique will be used in an asynchronous TCP/IP network based on Synchronous Digital Hierarchy (SDH). Synchronous Optical Network (SONET) and SDH, which define the standard for fiber optic transmission between routers in a network in North America and Europe, respectively, are based on synchronous transmission of 125 μs long packages. Each package begins with a well-defined sequence, followed by packet information and finally the payload. At OC-192/STM-64, corresponding to 10 Gbit/s which is the most common data rate in new long haul networks, this sequence is 384 bytes long and identical for both SONET and SDH. At every TCP/IP router, also denominated node below, small parts of the transmitted and received signals are dropped and analyzed with respect to the timing when a start sequence is detected. Advanced algorithms, and distribution of timing data between the routers, will result in a distributed, traceable, clock signal at every node of the network.

Initially, we will evaluate the technique in a lab environment, using commercial SDH equipment, prior to field trials and full scale implementation in the Swedish University computer network (SUNET). Development and experiment will be at STM-64. The fundamental technique, however, will be applicable to any data rate, utilizing synchronous packet transmission, also when the actual data is transmitted asynchronously.

II. SYNCHRONOUS DIGITAL HIERARCHY (SDH)

The Synchronous Digital Hierarchy (SDH) is based on the USA standard SONET, although with several modifications. The SDH signals are organized in frames all with the same nominal duration, i.e., 125 μs. The number of bits per frame is determined by the bit rate of the signal. This is usually referred to as the Synchronous Transport Module of Level N (STM-N). The bit rate is given by multiplying the basic rate STM-1 (155.520 Mbit/s) by N. Hence, in order to obtain, for example, a bit rate of 9.953280 Gbit/s, we use STM-N of 64. For more information on SDH, see e.g., [4].

Every frame is divided in two parts: an overhead and a payload. The overhead consists of 9xN bytes with 6xN bytes, allocated as “frame alignment bytes”. These frame alignment bytes are named A1 and A2, where A1=11110110 and A2=00101000. Using a 10 Gbit/s transfer, i.e., N=64, results in a frame alignment of 192 A1 bytes followed by 192 A2 bytes.

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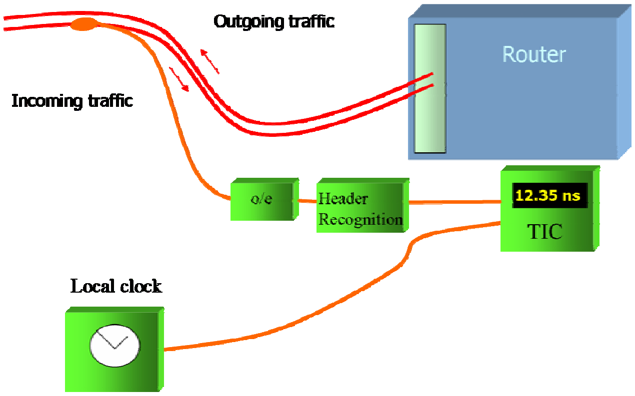

Figure 1. Schematical setup at a router in an TCP/IP network.

III. TECHNICAL ARRANGEMENT

A schematic view of the proposed setup at one router in a TCP/IP network is shown in figure 1. We couple 1% of the outgoing optical power, and 10% of the incoming power, to extract the output and input timing signals from the traffic. This is a negligible part of the transmitted power, since an operational system typically is designed with more than 50% power margin. The deflected optical signal is then converted to an electrical signal using an opto/electric converter (o/e). The converter must be 10 times more sensitive than the o/e used within the router, but nevertheless this is a commercially available device. This signal is fed into a Header Recognizer which is based on standard SONET/SDH circuit components in conjunction with a Field-Programmable Gate Array (FPGA), and has been developed together with InformAsic AB. The Header Recognizer generates a pulse of length 25 ns every time it receives a sequence of 384 bytes of the SDH frame alignment bytes A1 and A2, see Figure 2. This pulse triggers the start of a time interval measurement in the time interval counter (TIC). A similar pulse generated from the local clock indicates the end of the time interval. Such time interval measurements will be generated at a rate of 8 kHz, i.e., the rate of the incoming frames. For the clarity of the figure, the measurement of the outgoing traffic is not included. However, an equivalent setup will be installed also there, in addition to the in- and outputs of the other fiber lines connected to the router.

IV. TIME TRANSFER PRINCIPLE

Figure 3 and Figure 4 show the main principle behind the time transfer between two routers *A* and *B* equipped with clocks providing the time C_A and C_B respectively. At the outgoing fiber, the time of a start of frame, T_{Ao}, is detected in the SDH signal. Analogously the time of a start of frame, T_{Bi}, is detected in the SDH signal at the incoming signal at router *B*. The same principle is then used for the signal in the opposite direction. There will thereby be four time intervals, associated with each point-to-point transmission. By comparing the time, C_A, by the clock at router *A* with T_{Ao} (as depicted in Figure 3), we can measure the time difference ΔC_{Ao}. Hence defining ΔC_{Ao}, ΔC_{Ai}, ΔC_{Bo} and ΔC_{Bi} as:

$$\Delta C_{Ao} = T_{Ao} - C_A \tag{1}$$

$$\Delta C_{Ai} = T_{Ai} - C_A \tag{2}$$

$$\Delta C_{Bo} = T_{Bo} - C_B \tag{3}$$

$$\Delta C_{Bi} = T_{Bi} - C_B \tag{4}$$

Furthermore, the travel time in the fiber, approximately 5 µs/km, is taken into account through *F(t)* such that:

$$T_{Bi} = T_{Ao} + F(t) \tag{5}$$

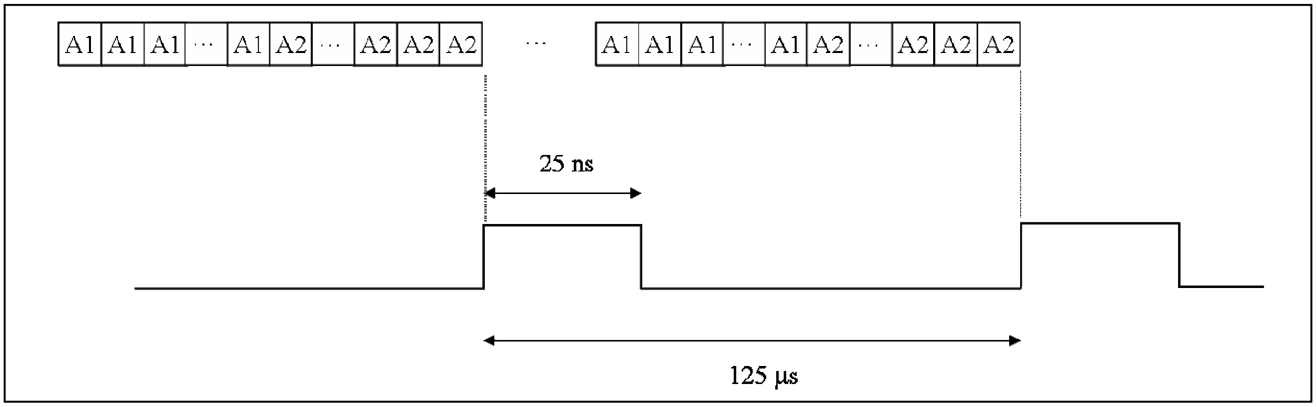

Figure 2. The header recognizer generates a pulse with the length of 25 ns every time it receives a correct sequence of A1 and A2 bytes.

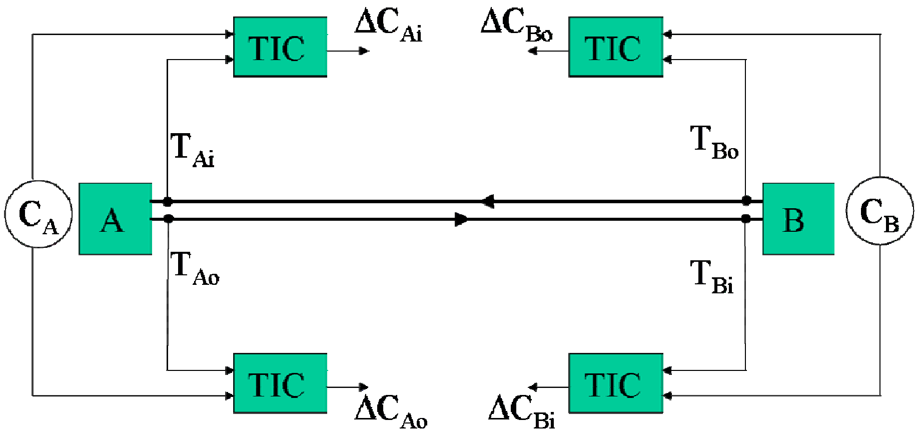

Figure 3. Main principle behind time transfer between two routers *A* and *B*.

The time dependence of *F(t)* is mainly due to variations in fiber transmission characteristics, which will change with temperature, approximately 37-80 ps/km°C [5, 6, 7, 8] and stress along the distance.

Now we can write the sought time difference between the clocks C_A and C_B as:

$$C_B - C_A = \Delta C_{Ao} - \Delta C_{Bi} + F_1(t) \tag{6}$$

and

$$C_A - C_B = \Delta C_{Bo} - \Delta C_{Ai} + F_2(t) \tag{7}$$

where $F_1(t)$ and $F_2(t)$ are travel time for the respective fiber. By assuming that the fibers carrying the traffic in the two directions between two routers are paired and thus exposed to similar environment perturbations, i.e.,

$$F(t) \approx F_1(t) \approx F_2(t) \tag{8}$$

the signal travel time in the fiber, *F(t)*, can to a large extent be estimated and compensated for. From the four time interval measurements, it can be derived that:

$$F(t) \approx \tfrac{1}{2}\left(\Delta C_{Ai} - \Delta C_{Ao} + \Delta C_{Bi} - \Delta C_{Bo}\right) \tag{9}$$

and the difference between the clocks C_A and C_B is:

$$C_B - C_A = \frac{1}{2}\left(\Delta C_{Ai} + \Delta C_{Ao} - \Delta C_{Bi} - \Delta C_{Bo} + \Delta F(t)\right) \tag{10}$$

where $\Delta F(t)$ is the difference $F_1(t)$-$F_2(t)$.

V. TIME TRANSFER IN A NETWORK

Figure 5 shows a map of the Swedish university computer network SUNET. The distance from Malmö in the south to Kiruna in the north is approximately 1400 km. SUNET is a packet oriented computer network based on TCP/IP. The protocol used between every router (displayed as circles in the figure) in the network is SDH. However, there is no synchronization of the transmission on different outputs from a router. Thus, in order to transfer time using SUNET, every router has to be equipped with dedicated hardware, see Figure 1. This equipment consists of two opto-/electrical converters, two units of Header Recognition hardware, and two time interval counters, for each fiber pair entering the router.

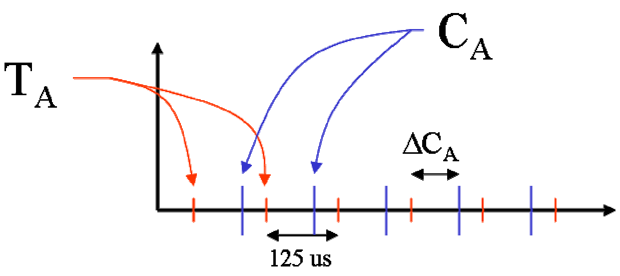

Figure 4. Time line illustrating the measurements performed at each router.

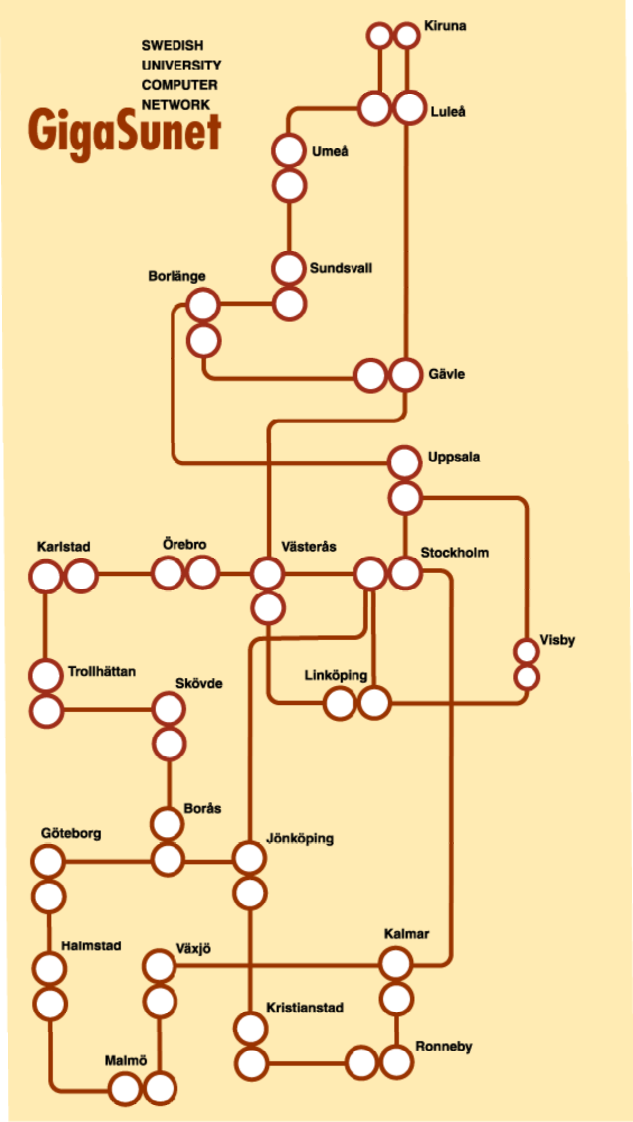

Figure 5 The Swedish university computer network, SUNET. Routers are displayed as circles.

Furthermore, every router must be equipped with a local clock. The requirements on the clock are low, however its stability will determine how often it has to be corrected or monitored over the network. Figure 6 shows the extension of time transfer between two routers *A* and *B* to a time transfer in a network consisting of three routers. In this example, comparing the clocks at router *A* and router *C* involves the intermediate clock at router *B*, which is constantly being monitored compared to the clocks at routers *A* and *C*. This concept is easily scaled to a network of arbitrary size.

At every router in a network, time differences such as $\Delta C_{Ai\&o}$ and $\Delta C_{Bi\&o}$ etc. are measured as described above. In order to estimate the difference between the clocks at every router, the measured ΔC_A and ΔC_B have to be distributed between the routers or to a central processing center. Several approaches are possible for this distribution of measurements. The most straightforward approach would be, in analogy with the time transfer between two routers, to send the measured ΔC_A and ΔC_B between every pair of routers. Other more sophisticated approaches would consist of processing the measurements at each router followed by distribution of the processed results.

At distances between routers greater than 25 km, corresponding to a signal delay of 125 µs, there will be an ambiguity in the choice of the correct time tick for the measurement of ΔC_B. This is illustrated in Figure 7 which shows an example with a fiber signal delay of 300 µs. In the example, the frame alignment bytes at router *A* that generate a tick T_A will arrive 300 µs later at router *B* to generate time tick T_B. Hence ΔC_B would not be measured as the time between T_A and C_B, but as a function of the fiber delay. In order to express the ΔC_B, we define:

- $\Delta C_{AB}{}^i$ as the clock difference $C_A - C_B$, initially determined by calibration, e.g., using GPS [9].
- $m_t{}^A$: The time interval measurement from T_A to C_A at the time *t*
- $m_t{}^B$: The time interval measurement from T_B to C_B at the time *t*
- C^Δ: Time between generated ticks, i.e., 125 µs.

Hence we can express:

$$\begin{aligned} \Delta C_A &= -m_t^A \\ \Delta C_B &= n \cdot C^\Delta - m_{t+nC^\Delta}^B \end{aligned} \qquad (11)$$

where

$$n = \left(F(t) - \Delta C_{AB}^i\right) \operatorname{mod} C^\Delta \qquad (12)$$

VI. ERROR SOURCES

The goal with the presented work is to establish a system for time and frequency transfer with a precision on the ns level and thus be competitive with other time transfer techniques such as GPS and Two-Way Satellite Time and Frequency Transfer (TWSTFT) [10]. Several different sources of error will have an effect on the attained precision of a final system. The largest anticipated error source is the deviation from the assumption that $F_1(t)$ equals $F_2(t)$, i.e., the travel time variations in the traffic between router *A* and router *B* are different in the two directions. This may be a result of hardware installations along the path or physical separation of the fibers carrying the traffic in the two directions, thus exposing the fibers to different temperature variations. Furthermore, effects that will degrade system performance to a lesser extent are: resolution of the time

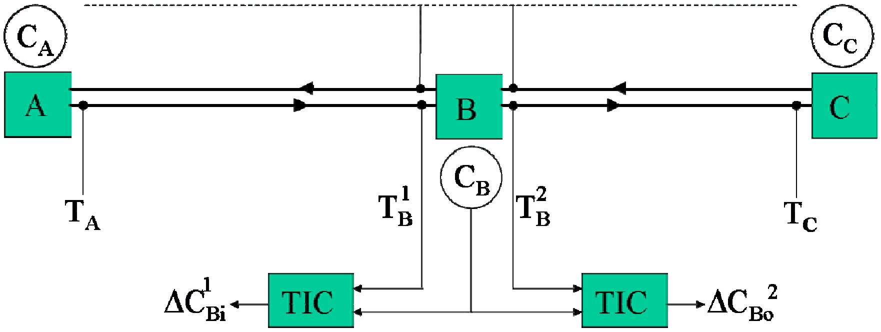

Figure 6. Time transfer between clocks at router *A* and router *C*.

interval counters, shape of the pulses generated by the Header Recognizer, and the stability of the local clocks.

VII. SYSTEM CALIBRATION

Since every packet generates a time sample, at 8 ksamples/s, there will be, without initial calibration, an ambiguity in matching the corresponding time ticks at *A* and *B*, as is indicated in Figure 7. This is solved by calibration at installation, where the fiber distance can be measured and time differences between local clocks can be estimated through alternative methods, e.g., using GPS [9]. During operation, transfer time variations can be dynamically adjusted for, provided abrupt shifts in *F(t)* never exceed 62.5 µs between two corrections. Thus the system can be programmed to continuously correct itself. However, also when the adjustment exceeds 62.5 µs or even when there has been an interruption in the connection, the system can be self adjusted. This feature will be possible at sites equipped with routers that have at least two direct connections to other routers, i.e., for the case of SUNET every site except the site Kiruna. When dropping one of those connections, the local clock at the router will still be monitored through the remaining connection. Hence, external methods for calibration of the system are expected to be applied only at installation and otherwise at a few specific sites in a network.

VIII. CONCLUSIONS AND FUTURE WORK

We are developing a new system for time distribution using the Internet. The goal is to establish a system with an precision on the ns level and thus be competitive with other time transfer techniques such as GPS and Two-Way Satellite Time and Frequency Transfer (TWSTFT) [10]. The next phase in the development is an assessment of the system in a lab environment in late 2005. This will be a simplified setup compared to an implementation in an operative network. However, positive results from lab measurements confirm that the main principles are valid. In addition, we will investigate the implications of transferring the setup to the national scale, i.e., SUNET. This will lead to a full scale implementation of the system. Furthermore, the system utilizes the packet frame header in a very dynamic way, such that it can be implemented in any packet switched network, even an asynchronous transmission, however with some minor adjustments on header recognizer and the interpretation of the result.

ACKNOWLEDGMENT

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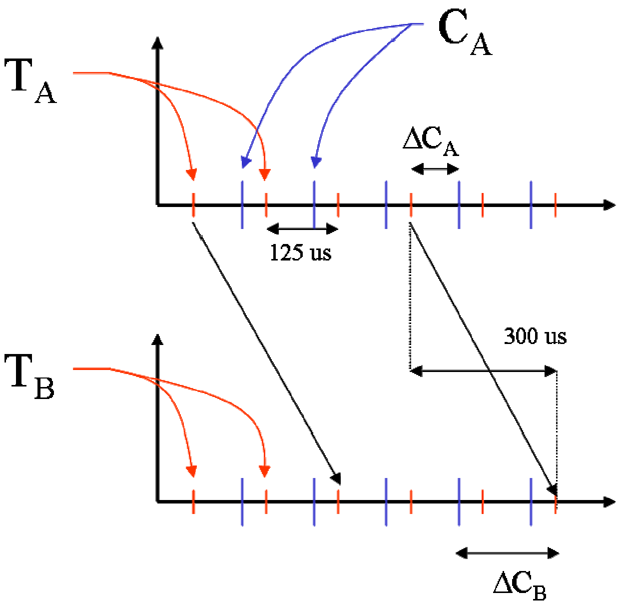

Figure 7. Ambiguity resolution illustrated by a travel time in the fiber of 300 µs.

REFERENCES

[1] S.R. Jefferts, M. Weiss, J. Levine, S. Dilla, and T. E Parker, “Two-way time transfer through SDH and Sonet systems”, European Frequency and Time Forum, 5-7 March, 1996.

[2] M. Kihara, A. Imaoka, M. Imae, K. Imamura, “Two-way time transfer through 2.4 Gb/s optical SDH systems”, IEEE Trans. Instr. Meas., 50, 2001.

[3] K. Hisadome and M. Kihara, “Time and frequency transfer across Gigabit Ethernet networks”, EFTF Besançon , France, 2005.

[4] S. Bregni, “Synchronisation of digital telecommunications networks”, John Wiley & Sons, West Sussex, England, 2002.

[5] Y. Serizawa, M. Myoujin, S. Miyzaki, and K. Kitamura, “Transmission delay variations in OPGW and overhead fibre-optic cable links”, IEEE Trans. On power delivery, 12, 1415-1421, 1997.

[6] M. Kihara, and A. Imaoka, “Accurate time/frequency transfer method using bidirectional WDM transmission”, IEEE Trans. Instr. Meas., 47, 537-542, 1998.

[7] M. Kihara, and A. Imaoka, “Long-term propagation delay characteristics of telecommunication lines”, IEEE Trans. Instr. Meas., 41, 653-656, 1992.

[8] Y. Serizawa, K. Kitamura, M. Myoujin, T. Matsushima, O. Masui, and R. Takada, “Additive time synchronous system in existing SDH netwirks”, Proc. 12 th EFTF, pp. 263-268, 1998.

[9] W. Lewandowski, C. Thomas, “GPS time transfer”, Proc. IEEE, 79, 991-1000, 1991.

[10] W. J. Klepczynski., P. J. Wheeler, W. Powell, J. Jeffries, A. Myers, R. T. Clarke, W. Hanson, J. Jespersen, D. and Howe, "Preliminary comparison between GPS and two-way satellite time transfer", 42nd Annual Frequency Control Symposium, pp.472-477, 1988.