A TIME REFERENCE DISTRIBUTION CONCEPT FOR A TIME DIVISION COMMUNICATION NETWORK

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ABSTRACT

Starting with an assumed ideal network having perfect clocks at every node and known fixed transmission delays between nodes, the effects of adding tolerances to both transmission delays and nodal clocks is described.

The advantages of controlling tolerances on time rather than frequency are discussed. Then a concept is presented for maintaining these tolerances on time throughout the network. This concept, called time reference distribution, is a systematic technique for distributing time reference to all nodes of the network. It is reliable, survivable and possesses many other desirable characteristics. Some of its features such as an excellent self monitoring capability will be pointed out.

Some preliminary estimates of the accuracy that might be expected will be developed and there will be a brief discussion of the impact upon communication system costs.

Time reference distribution is a concept that appears very attractive to the author. It has not had experimental evaluation and has not yet been endorsed for use in any communication network.

BACKGROUND

Time division multiplexing and/or switching which is often desirable in a digital communication network presents timing problems. These are problems of a type not experienced in analog networks using frequency division multiplexing and space division switching.

For time division multiplexing and switching in a digital communications system, each bit from an incoming bit stream must be available to fill its time slot when it is needed. In an ideal system, exact time would be available at every transmission node and there would be known, fixed delays between nodes. Under these conditions, the system could be designed so that each bit arrives at the time division multiplexer or switch at the desired moment.

However, in the real world this ideal situation does not exist. There are variations in transmission delay between nodes. These can be allowed for by using "elastic" storage buffers between the receivers located at each node and the associated time division multiplexing or switching equipment. Bits which arrive too soon are stored in these buffers until they are needed. The buffer storage also serves as a reservoir to supply bits when incoming bits arrive late. At any given data rate each bit of buffer storage represents an increment of time tolerance.

If, in addition to variations in transmission delay between nodes, there is a tolerance on time at each node, the buffers may be enlarged to also accommodate the nodal timing errors. Technology is presently available, MOS microcircuit first-in first-out (FIFO) serial buffers used by the computer industry, that can economically provide hundreds of microseconds of variable delay storage. A bit read into the input of these devices propagates by itself to the unfilled bit location nearest the output. When data is read out, the remaining stored data automatically shifts toward the output. The input and output clocks are independent. Unless timing is used for functions other than keeping the bits in the proper sequence, the acceptable timing tolerance for the communications system is limited only by the acceptable number of bits of buffer storage and the data rate, i.e., the acceptable variable time delay of the buffers.

A tolerance on nodal frequency (instead of on nodal time) is equivalent to a tolerance on the rate at which an error in time may accumulate. A frequency tolerance will permit a boundless time error; therefore, the interval of time over which an error is permitted to accumulate must be specified. The amount of buffer storage required by the communications system is determined by the accumulated time error rather than the rate at which it accumulates. As a result, whenever a frequency tolerance is specified, a reset interval must also be specified. For a system which is to be in continual use over a long period of time, it is preferable to control time rather than frequency.

One presently planned communications system (TRI-TAC) will employ a tolerance on frequency rather than time. In this system an atomic standard is used at each node to maintain the required frequency tolerance. Buffer storage sufficient for a 24-hour period is provided. The buffers are dumped and reset as required.

Another technique not requiring a tolerance on time is called mutual synchronization, in which each node adjusts its own frequency to reduce the timing error between itself and some average of the rest of the network[1,2,3]. Removal of any node of the network still leaves a synchronized network, but a transient disturbance in one part of the network will propagate to other parts of the network. Any one clock can perturb the system frequency.

A technique called pulse stuffing[4], which does not require synchronism, has been developed for point-to-point time division transmission. In pulse stuffing, multiple asynchronous signals are padded with dummy pulses to bring them to a common bit rate for time division multiplexing. After multiplexing at this common rate, transmission of the combined signals and demultiplexing at the receiver, the dummy pulses are moved to return each signal to its original asynchronous rate. Although this pulse stuffing technique appears economical for point-to-point applications, it does not appear economically attractive for a time division switched network. If a large number of channels are combined synchronously at the transmitting end, the pulse stuffing technique is an attractive method of multiplexing many of the resulting higher rate channels. The cost of stuffing is shared among all of the individual channels that are synchronously combined to form the higher rate input to the pulse stuffing equipment. The signals that are originally synchronous at the input of the point-to-point transmission system remain synchronous at its output. In a switched network each member of a group of synchronous channels at a single origin may have a different destination. Each might be grouped with signals originating from other points in the network so that members of the new group will not be synchronous. They no longer will be able to share the same pulse stuffing and destuffing equipment. Pulse stuffing on an individual channel basis thus becomes necessary in an unsynchronized switched digital network. This implies expense.

Perhaps the most obvious of all synchronizing methods is a master-slave technique in which all nodes of the network are slaved, either directly or through intermediate nodes, to a single master clock. The reliability of this technique and its survivability in a military environment have been questioned. However, several commercial communications systems plan to use it[5, 6].

From this background discussion it can be seen that a close time tolerance at every node of a digital communications network employing time division multiplexing and/or switching would be desirable if an economical, reliable and survivable method could be found. The Time Reference Distribution technique is offered as a possibility. After the technique has been explained some of its advantages will be listed. Some of the listed advantages result from maintaining a close time tolerance.

TIME REFERENCE DISTRIBUTION

The Time Reference Distribution technique[7] for digital communications network timing provides an accurate clock at each node. Accuracy is maintained by occasional correction of nodal clocks using time reference information transmitted over every link of the network in such a way as to be independent of transmission delays. Since a timing path is associated with every communications link, the only way for any node to be isolated from timing information is for it to have no communications with the remainder of the network.

For the Time Reference Distribution technique, all nodal clocks are rank ordered, i. e., sequentially arranged in order of priority. Time reference information is passed in both directions over every link. Time comparison signals to be used for time difference measurement can be superimposed on the data stream or its carrier by a special modulation technique. Alternatively, the frame synchronization code may be used for this purpose. In addition to these basic time comparison signals, four types of data are transferred from each node to the node at the other end of each link. These data are:

1. The time difference between the local clock and the clock at the other end of the link as observed at the local clock (this time difference includes transmission delay).

2. The rank of the node used as the master time reference for the local clock.

3. The merit of the transmission path over which the time reference information is passed from the reference clock to the local clock.

4. The rank of the local clock.

The first datum, i. e., the clock difference information, is used to make the time reference "independent" of transmission delay. Each node measures the time difference between its own clock and that at the other end of each link. This measurement is transmitted to the other end of the link so that both measurements are available at both ends of each link. To illustrate its use, let T_A be the time of the clock at node A, and let T_B be the time of the clock at node B. Let D_{AB} be the transmission delay from node A to node B, and let D_{BA} be the transmission delay from node B to node A. Then the time difference measured at node A is $K_A = T_A - (T_B - D_{BA})$ and the time difference measured at node B is $K_B = T_B - (T_A - D_{AB})$. Subtracting K_A from K_B and dividing by 2 gives

$$T_B - T_A = \frac{K_B - K_A}{2} + \frac{D_{BA} - D_{AB}}{2} \qquad (1)$$

When the transmission delays in the two directions are the same, they cancel, giving the time difference between the two nodes independent of transmission delay. Adding K_A to K_B gives

$$D_{AB} + D_{BA} = K_A + K_B . \qquad (2)$$

When D_{AB} is equal to D_{BA}, the transmission delay between nodes is also available by dividing $(K_A + K_B)$ by 2. Only a few bits of information per minute are required on each link to transfer the required timing data. Although timing difference measurements are made quite frequently, the clock time corrections may be made much less frequently because time errors will accumulate very slowly.

The other three data are used with a simple set of rules to allow each node to unambiguously select its time reference from the incoming link that should provide the best reference. Other cross checks are available to determine whether this path is reliable. If it is not reliable, an alternate choice can be made by applying the same set of rules. The basic rules are as follows:

Rule 1. The time reference for the local clock is taken from the link coming from the node which uses the highest ranking clock as its time reference. However, if the local clock outranks the others, the local clock is used as reference. If any two links come from nodes referencing the same highest ranking clock, the criterion is inconclusive. In a normally operating network, all nodes will be referencing the same master time reference so that this criterion will normally be inconclusive and rule 2 must be applied.

Rule 2. When the first test is inconclusive because the links come from nodes all referencing the same highest ranking clock, select the one that comes over the highest merit transmission path, i.e., the one with the best time transfer capability. If two or more come over transmission paths with the same highest merit rating, this test will also be inconclusive and rule 3 must be applied. In most cases this will be a conclusive test.

Rule 3. When the first and second tests are both inconclusive, select from those links with time reference coming from the same highest ranking clock over paths with the same highest merit rating the one that comes from the highest ranking, directly connected node.

Nodes carry the same ranking as the nodal clock that they are using at the moment. Multiple clocks of different rank may be provided at an individual node for reliability. Considerations in ranking the network clocks include the quality of the clock and the merit (time transfer capability) of communications paths to the higher ranking nodes. Those nodes equipped with cesium beam clocks will normally be ranked higher than those equipped with rubidium clocks which in turn will be higher than those equipped with quartz clocks. Of those nodes with cesium beam clocks those with the best time reference path to the highest ranking nodes will normally outrank those with poorer paths, e.g., those with a direct high resolution satellite path would normally outrank those with other types of long transmission paths. A node with more than one type of clock will be identified in rank by the particular clock in use at the moment.

Each transmission link will be assigned a merit (or perhaps more appropriately—demerit) value which depends upon its length and the transmission medium. Each node is informed of the accumulated transmission path merit for the time reference used at the other end of the link (one of the four pieces of information exchanged). Using the characteristics of the link over which the time reference information is received, the merit rating is further degraded before it is used at the local node. Thus, the path merit rating is increasingly degraded as the time reference information is passed through more nodes of the network.

Examination of the rules above shows that they assure that there will be no system closed loops to contribute to system instability. This is true because of the additional degradation of the path merit rating as additional links are traversed. Any return path must have a lower merit rating and therfore cannot be selected as the reference. The rules assure that every node will have a time reference signal so long as any one communications link to the node is still useful. These same rules permit the next ranking node to take over as the reference for the system if the highest ranking node becomes inoperable. They also direct that the highest ranking node in any isolated portion of the network will be selected as its reference.

The nodal clock is used for all time division multiplexing and switching functions at the node. It also clocks the bits out of the "elastic" storage buffers associated with each received link and times the data on every outgoing data link. The receivers for every incoming link derive their time from the received signal. (This is usually done by providing a phase shifted signal from the nodal clock and making it coincide with the timing of the received signal. This takes advantage of the stability of the nodal clock.) This receiver timing is used to demodulate the received signal and clock bits into the "elastic" buffers; thus bits are independently clocked into the buffers by the received timing and out of the buffers by the nodal clock.

SOME ADVANTAGES OF THE TECHNIQUE

1. By referencing one node of the network to a precise time source, such as the Naval Observatory, an accurate time reference becomes available throughout the network.

2. Since the rules for selecting the reference sources prevent the establishment of system closed loops, there is no problem with system stability.

3. It has superior self-monitoring capability. Every node receives time reference information from every directly connected node; any disagreement in these time references at any node indicates a potential problem. This indication can occur while the system is functioning quite satisfactorily. It can be used to initiate maintenance procedures so that the problem can be corrected before any degradation in system performance can be detected.

Each node can have transmission delay information available for every connected link and the status of buffer contents can also be available for the same links. Any incompatibility among them can indicate a potential problem and permit corrective action to begin early. Any sudden change in (1) the time reference information received over any link, (2) measured transmission delay of any link, or (3) the status of buffer contents can indicate a potential problem.

4. Redundant timing information can serve as a powerful trouble-shooting tool.

5. Since the effect of transmission delay on timing is mostly cancelled on every transmission link and everything is retimed at every transmission node, a high degree of nodal environmental isolation is provided; i. e., the environmental effects upon the time delay of any transmission link are removed and not permitted to propogate from node to node.

6. A fixed, accurate, time reference is a familar concept easily grasped by operating and maintenance personnel.

7. The technique places limits on the size of "elastic" storage buffers which are required at each node to absorb variations in transmission path delays and/or nodal timing errors.

8. It requires no resetting of buffers such as that required to compensate for time differences between independent clocks.

9. The availability of more accurate time will encourage innovation of future applications which will be of benefit to the overall effectiveness of the communications system and its users. There will be a growing need for accurate time among several government agencies[8]. Availability always stimulates need which in turn will generate new capabilities and operational improvements which were initially unplanned.

10. Some major navigation systems are already being coordinated in accurate time. Overall system coordination among all of these systems and a communications network should be synergistic, providing each with benefits beyond its individual contribution.

11. A by-product of the Time Reference Distribution technique is that accurate time at each node of the network can easily be made available to external users.

12. All normal decision processes and time corrections can be made automatic and do not require human intervention.

13. System operation is not dependent upon the continued operation of any node. Time reference is always available to all surviving nodes that could make use of it.

14. The system is compatible with all external references which are accurately related to universal time. Any of these external time references can be utilized and blended into the system by applying the same rules that are applied to the nodes of the network. Each external time reference can be assigned a rank and a transmission path merit. However, the method of correcting for transmission path delay would normally be different because the duplex communications path would not be available with most of these external time references. External references such as Loran-C could be used on an interim basis during development of the complete Time Reference Distribution system and could phase into participation with the Time Reference Distribution system as the complete system becomes operational.

15. Time Reference Distribution permits the convenient collection of much valuable engineering information, including statistical information about transmission time delay of the individual links and any variation in time reference as received over different paths. This information could be very valuable in the development of future systems of many different types.

16. The Time Reference Distribution technique is capable of effectively utilizing future technological improvements to provide greater precision without the major system redesign that other timing methods might necessitate. It also has the capability of making use of the greater precision thus provided.

17. The Time Reference Distribution technique provides accurate time reference information at the nodes. This information can be used to evaluate the performance of nodal clock oscillators. All information to predict future drift rates and their rate of change can be made available. This information can be used to compensate for the predicted drift of the oscillators and provde

a resulting clock of much higher accuracy than could otherwise be obtained in a similar price range. This ability to greatly enhance the effectiveness of lower cost oscillators could be significant advantage.

18. If the timing for all link receivers at a node is derived by phase shifting a signal from the very stable reference of an accurate nodal clock, the time to reacquire synchronization after a deep fade can be minimized. The technique integrates naturally with the Time Reference Distribution technique and, if desired, can be incorporated into the time difference measurement (first of the four pieces of information exchanged between nodes).

19. Time Reference Distribution appears to have a superior flexibility for handling unforeseen requirements as they arise.

20. Fall back modes of operation are provided and could be extended. Whenever the incoming link that is being used for a node's time reference fails, the node selects the next best link as its time reference. This process can continue until all incoming links have failed and there is no longer need for a time reference. The same procedure provides for failures of other nodes since they are equivalent to link failures as far as incoming signals are concerned. Assume that some failure of the timing system should occur independent of the data transmission system so that the data transmission system would continue to function but lacked time reference information. The affected node could fall back to an independent clock mode of operation (requiring periodic or automatic resetting of buffers at the other end of each link).

DIFFERENCE IN TRANSMISSION TIME DELAYS IN OPPOSITE DIRECTIONS

In the Time Reference Distribution system presented here, timing information is passed in both directions over every transmission link. This information is used to permit the time provided by the two clocks at the ends of the transmission link to be directly compared by cancelling the time delays of the transmission link. The cancellation of propagation delays depends on the assumption that the transmission delay is the same in both directions over the link. A question naturally arises as to whether this is a good assumption—particularly about over-the-horizon tropospheric scatter transmission that depends on bending and scattering of the electromagnetic waves. The multipath character of troposcatter transmission causes substantial frequency selective fading and intersymbol interference on digital links. These characteristics appear to make it somewhat questionable as a time reference distribution medium. Well known nonreciprocal delays in HF ionospheric propagation are attributed to the wave passing through an ionized medium in the presence of the earth's magnetic field. Many researchers agree that there is no comparable mechanism for tropospheric transmission whereby the propagation delays in opposite directions over the same path at the same time and frequency should not be the same[9, 10, 11].

No record of actual measurements of delays in both directions between the same pair of terminals at the same time for tropospheric scatter have been located. Because there is no known mechanism for making the tropospheric medium non-reciprocal, any differences in transmission delays that might occur in the two directions would be attributable either to the terminal equipment or to different paths being used in the two directions. The difference in paths could be attributed to different antenna positions or to the use of different frequencies. In either case, the difference in propagation delay times between two independent paths in opposite directions should be the same as the difference between two independent paths in the same direction. Measurements have been made of the difference in time delay between two independent tropospheric paths 168 miles long at 900 MHz[12]. The standard deviation of the relative delay was found to be 22 nanoseconds. Phase data observed over a 230 km path[13] indicated that random variations of a 900 MHz signal over several minutes rarely exceed about 10 radians. This corresponds to about 5 nanoseconds at the 900 MHz frequency. The 5 nanosecond observations of[12] are based on phase fluctuations of a single carrier frequency, while the 22 nanosecond deviation from[12] is based on correlation measurements on simultaneously transmitted, pseudo-random-modulated PSK signals. The 22 nanosecond standard deviation seems to be the prefereable reference point, since it was measured more nearly in the form of the desired application. Note from equation (1) that the error in time measurement is only half as great as the difference in transmission times in the two directions.

$$T_B - T_A = \frac{K_B - K_A}{2} + \frac{D_{BA} - D_{AB}}{2} \tag{1}$$

(repeated for convenience)

The random fluctuation of the differential time delay between two independent paths may be expected to contain frequency components of many cycles per minute. By averaging the measurements over several minutes the resulting average measurement should have a standard deviation which is only a small fraction of the 22 nanoseconds measured in the experiment. The interval between clock corrections for the Time Reference Distribution system may be quite long because stable clocks are used. Therefore, the time measurements may be averaged over long periods, making it possible to almost completely remove the effects of fluctuations in the propagation medium from the time reference measurement. The most significant errors could be associated with equipment rather than the propagation medium. The stability of time delays in the equipment should be given consideration and tolerance in time delays among units of the same type should be minimized.

A CONSERVATIVE PRELIMINARY ESTIMATE OF ACCURACY

As previously mentioned, a troposheric transmission link is probably one of the more difficult types of transmission link for time transfer because of its multipath characteristics. If we use the 22 nanosecond standard deviation mentioned previously as a starting point we may reach some rough estimates of the accuracy that might be obtained from a Time Reference Distribution system.

Since the delay difference may be expected to contain some higher frequency components, averaging over several minutes should provide a much lower standard deviation than 22 nanoseconds. The timing error due to differences in transmission delays in the two directions is only half the difference in transmission delays. Assuming that there is no measurement averaging, the standard deviation of the timing error is 11 nanoseconds. It should be better than this in practice where averaging would be used Allowing ±4 standard deviations for the tolerance range makes the potential accuracy ±44 nanoseconds. Allowing an additional ±156 nanoseconds (much more than that allowed for the particularly severe tropospheric scatter medium) for error contributions of the equipment employed gives a total time reference transfer tolerance of ±200 nanoseconds for a tropospheric scatter link. If the time transfer errors of all links are random and independent of all other links, the tolerance for a tandem connection should be the square root of the sum of the squares of the tolerances of the individual links. In a highly connected network, the largest number of tandem time transfers required should be a small percentage of the total number of nodes in the network. Assuming that the number of tandem time reference transfers does not exceed 100 and all tolerances in the path are the same, the overall tolerance for the tandem path will be $\sqrt{100} = 10$ times the tolerance for any individual link. If all links have a 200 nanosecond tolerance, then the time at any node in the network will be within 2 microseconds of the time at any other node.

This should be a conservative estimate. It is quite unlikely that any network would be 100 percent tropospheric scatter links, and line of sight microwave links are much better for time transfer. (Only 18 percent is troposcatter in the DCS in Europe while over 63 percent is line-of-sight microwave[14].) Even for tropo links the propagation time variation of the transmission medium would be largely eliminated by averaging over a significant period of time. The ±156 nanoseconds allowed for error contributions of the equipment on each link is very large for broadband microwave equipment. Two-microsecond accuracy between any two nodes of the network should be a desirable goal that is both readily achievable and useful.

CONCLUSIONS

The Time Reference Distribution system will not only satisfy the timing requirements of a digital time division communications system, but will provide a large number of additional advantages.

The viewpoint should not be too narrow when considering the merits of a timing technique for a digital time division communications system. In addition to keeping the bits in the proper sequence, monitoring and testing the system should be given careful consideration. Other uses for timing within the system should be considered along with timing relationships external to the network. Under this type of evaluation, Time Reference Distribution should rank very high. A large communications network that distributes accurate time for its own use should be a natural vehicle for coordinating the many other users of accurate time.

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TIME REFERENCE DISTRIBUTION FOR A TIME DIVISION COMMUNICATION NETWORK

TOLERANCE CONSIDERATIONS

1. EXACT TIME AT EACH NODE. (unrealistic)
   FIXED DELAYS BETWEEN NODES. (unrealistic)
2. EXACT TIME AT EACH NODE. (unrealistic)
   TOLERANCES ON VARIABLE DELAYS BETWEEN NODES.
3. TOLERANCES ON TIME AT EACH NODE.
   TOLERANCES ON DELAYS BETWEEN NODES.
4. TOLERANCES ON FREQUENCY AT EACH NODE.
   TOLERANCES ON DELAYS BETWEEN NODES.
5. TIME OR FREQUENCY NOT DIRECTLY CONTOLLED.
   TOLERANCES ON TIME DIFFERENCES BETWEEN CONNECTED NODES.

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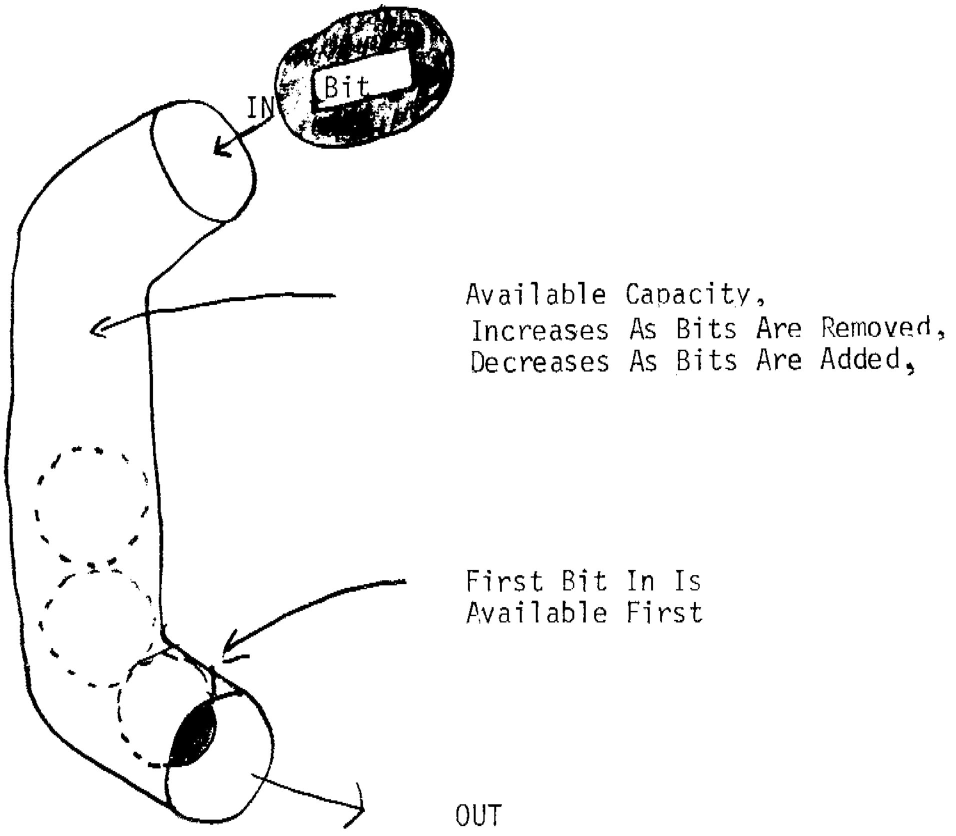

FIFO BUFFER ANALOGY

TOLERANCE CONSIDERATIONS

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   FIXED DELAYS BETWEEN NODES. (unrealistic)

2. EXACT TIME AT EACH NODE. (unrealistic)
   TOLERANCES ON VARIABLE DELAYS BETWEEN NODES.

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TIME REFERENCE DISTRIBUTION

- ALL NODES HAVE ONE OR MORE CLOCKS
- EACH COMMUNICATION PATH IS A TIME REFERENCE PATH
- ALL CLOCKS HAVE RANK ORDER
- TIMING INCLUDED IN FRAME SYNC OR SUPERIMPOSED ON DATA
- FOUR TYPES OF DATA ARE TRANSFERRED OVER EVERY LINK
  - (1) TIME DIFFERENCE BETWEEN REMOTE CLOCK AND LOCAL CLOCK AS OBSERVED AT LOCAL CLOCK
  - (2) RANK OF MASTER TIME REFERENCE USED FOR LOCAL CLOCK
  - (3) MERIT OF TRANSMISSION PATH FROM MASTER REFERENCE
  - (4) THE RANK OF THE LOCAL CLOCK.

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    2. RANK OF MASTER TIME REFERENCE USED FOR LOCAL CLOCK
    3. MERIT OF TRANSMISSION PATH FROM MASTER REFERENCE
    4. THE RANK OF THE LOCAL CLOCK.

SELECTION RULES

Rule 1: SELECT REFERENCE SOURCE FROM HIGHEST RANKING CLOCK

Rule 2: IF MORE THAN ONE PATH FROM SAME HIGHEST RANKING CLOCK, SELECT REFERENCE FROM HIGHEST MERIT PATH

Rule 3: IF MORE THAN ONE PATH OF THE SAME HIGHEST MERIT RATING, SELECT ONE FROM HIGHEST RANKING DIRECTLY CONNECTED NODE.

TIME REFERENCE DISTRIBUTION AS A MEANS OF NETWORK SYNCHRONIZATION HAS MANY ADVANTAGES RELATED TO HAVING ACCURATE TIME AT EACH NODE AND THE METHOD OF PROVIDING IT.

TIMING COMPARISON BETWEEN NODES

T_A = TIME OF CLOCK AT NODE A

T_B = TIME OF CLOCK AT NODE B

D_{AB} = TRANSMISSION DELAY FROM NODE A TO NODE B

D_{AB} = TRANSMISSION DELAY FROM NODE B TO NODE A

TIME DIFFERENCE MEASURED AT NODE A

$K_A = T_A - (T_B - D_{BA})$

TIME DIFFERENCE MEASURED AT NODE B

$K_B = T_B - (T_A - D_{AB})$

TIME DIFFERENCE BETWEEN CLOCKS

$$T_B - T_A = \frac{K_B - K_A}{2} + \boxed{\frac{D_{BA} - D_{AB}}{2}} \longleftarrow \text{Very Small} \qquad (1)$$

TRANSMISSION DELAY

$$D_{AB} + D_{BA} = K_A + K_B \qquad (2)$$

CONSERVATIVE PRELIMINARY ESTIMATE OF ACCURACY

22ns = STANDARD DEVIATION OF TRANSMISSION
BETWEEN TWO INDEPENDENT 168 MILE
TROPO LINKS

11ns = STANDARD DEVIATION OF RESULTING TIMING
TIMING ERROR IF NOT REDUCED BY
AVERAGING

4X11ns = 44ns = ALLOWED TOLERANCE FOR
PROPAGATION

156ns = VERY LAX TOLERANCE FOR EQUIPMENT

44ns+156ns = 200ns = TOLERANCE PER LINK

200nsX $\sqrt{10C}$ = 2000ns = 2μs = TOLERANCE FOR 100
TANDEM TIME
TRANSFERS

QUESTION AND ANSWER PERIOD

MR. EASTON:

We have five minutes, time for two questions.

DR. KARTASCHOFF:

I have one question about the propagation time delays.

Do you have any data about pattern dependent jitter cable systems? Because that is one problem which bothers the civilian communications when one works quite often over coaxial cable with, say, about a hundred pulse regenerative repeaters. There is not much data available, actually, about long term spectral density on the pattern dependent jitter.

Do you have any data or do you have the same problem that there is not much data available?

DR. STOVER:

I don't have the data, but I know that it is very bad, so I would jump to the conclusion initially that one of the other paths, through a satellite, will be better. Therefore it will be chosen as the reference, and the need for using the cable can be avoided in most cases.

DR. KARTASCHOFF:

Well, thank you very much, but you see, in the civilian systems we will use cable, and we will go Digital, too, in the next 20 years. So, this problem remains. It needs to be investigated.

I think it must not necessarily be traumatic, but it is worse than microwave line of sight.

DR. STOVER:

I agree with that. As far as the Trans-Atlantic cable is concerned, again I come back to my statement about this being synergistic with all these other systems. If you are talking about, say, Trans-Atlantic, for example, and we are going to use Universal Time, you have already a reference in Europe that is much better than you could get across that cable.

So, there is a good reference there, and if you tie it into the network somehow, again you always use your best reference back to the Naval Observatory or whatever we use as our link with Universal Time.

DR. COSTAIN:

I understand in some of the networks they go via satellite one way and land line or microwave the other. You would have to have a third of a second discrimination, I think, in the time differences for the two paths.

DR. STOVER:

Well, I am assuming that we will have a duplex link for all links. You are right.

MR. LIEBERMAN:

You talked strictly about time division multiplex. Wouldn't synchronous systems fit into this by regeneration?

DR. STOVER:

There are large numbers of systems that will be compatible with this. All I am suggesting is that all of the nodes in the network have accurate time, and how we get it there is—I suggested one instance there are other possibilities, of course, but I have tried to point out that using this system has some of its advantages, just from this technique of getting it there, as well as advantages of having it there. Most other systems under consideration wouldn't even have it there.

So, my first advocate is to have it there, and my second advocate is to provide a system similar to this for getting it there.

MR. LIEBERMAN:

One last question.

What is the comparative cost of this versus some of the other systems you talked about?

DR. STOVER:

I believe that the cost of all the systems is somewhere in the same ballpark, because most of the equipment required to establish the synchronization is required for any type of digital network. We always have to lock onto the frame sync, and once you have got that, you have most of what we need, and as far as the accuracy of the clock, as I pointed out, the information we have permits us to use a lower precision clock, and operate on it with the information we have available to get a higher precision than we otherwise would.

So, I believe for the same accuracy it would cost less than some of the other approaches. But among all the approaches, I don't think the cost is a significant factor.

DR. WINKLER:

My comment is not related to your paper, but to Dr. Kartaschoff's question.

At the Observatory, for purely internal reasons, we have made some tests using RG58 cable, coaxial cable. The effects which we found of course are in agreement with your comments, they are very bad. For a 10,000 foot loop above ground we found a diurnal change of about 10 to 20 nanoseconds, time delay.

Now, that is average, using a relatively long time constant in the order of 1 second. The diurnal, of course, is completely thermal.

We used these data only to assure ourselves that the clock time scale which utilizes underground cabling (less than 700') in between the clock vaults is not limited by these delays variations.

But subsequent to that, I happen to have come into possession of some commercial literature on low temperature sensitive cables. It appears that there are some dielectric cables available which minimize these variations. I don't remember where I have the information, but you may contact me on that.

DR. KARTASCHOFF:

Thank you very much, Dr. Winkler.

The cable, that is one problem. I think that the worst problems in digital communications over a long cable line are the repeaters. The repeaters which at every end regenerate the pulse, and send it out again in a nice form to the next repeaters and so on. For these repeaters, their average phase of the transition is dependent on the pulse pattern, that is on the content of the information which goes through the link and of course this is user dependent.

So, you can have any form of pattern, and there can be very large excursions in the instant of time with which the information arrives at the end.

The general suggestion we have now in our discussions internal in our telecommunications system is that we should try to absorb these delay variations by buffer memories, and use good oscillators for keeping the long term average rate constant.

DR. STOVER:

I agree that you want to absorb the variations with buffers. As far as the use of cables, again, I state, that in most cases, any of your major nodes will have other links coming in besides cable links, and they would be given a priority, and I am not suggesting that we use this distribution technique down to every TBX and everything.

I am suggesting that all local groups would be slaved to the thing. Only the ones that would have a number of links coming in from widely separated geographical locations would need to have the time reference distribution.

All the ones that communicate primarily with one point would be slaved to that point.

MR. EASTON:

Thank you very much, Dr. Stover, for the fine paper.