

TIME SYNCHRONISATION CONTROL APPARATUS AND METHOD

Field of the Invention

The present invention relates to a system for and method of providing accurate and predictable synchronised clock signals at a plurality of remote stations.

Background of the Invention

There is an increasing need in many transactions and processes to be able to obtain an accurate indication of time, for example in control situations, for commercial and financial transactions, for measuring and monitoring and so on. For this purpose, there is an established central Coordinated Universal Time (UTC) reference which is administered by the BIPM, the International Bureau of Weights and Measures, in France. This reference is used by a plurality of metrology laboratories to provide a local Coordinated Universal Time (UTC) within their region. Where two separate entities wish to synchronise their transactions or work on a common clock, the Coordinated Universal Time from one UTC supplier is used as the time reference. Synchronisation of physically separated and unconnected users is carried out using GPS, using GPS time as the single source for each user network. This is viable but is vulnerable to manmade and natural interferences such as jamming, spoofing, meaconing and solar storms. Additionally, the latencies introduced by each component of the receiver chain: antennae, cables, amplifiers, distribution systems, receivers and so on, all require careful calibration in order to understand the traceability offsets that must be implemented.

Synchronisation requirements on a global scale are becoming critical, particularly in sectors such as the financial trading sector. Audit trails and forensic analyses of events such as flash crashes are important to understand the causes of these events.

Errors in a local time clock caused by the above-mentioned latencies and vulnerabilities can result in the local time clocks of separated users being offset from one another often by as much as 1 millisecond and sometimes more. Errors

in clock synchronisation of this nature are becoming increasingly critical in many transactional environments.

Summary of the Invention

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According to an aspect of the present invention, there is provided a system for providing a synchronised clock signal at a plurality of remote stations, including: a reference clock signal at a reference station, a clock signal indicator at each remote station, a two-way direct communication connection between the
10 reference station and each remote station, a processing unit at the reference station, wherein the processing unit is operable to determine at least one latency in the clock signal indicator through each communication connection and to determine therefrom a remote station offset for each remote station, the processing unit being operable to store each remote station offset, and the
15 reference station is operable to send to each remote station an individual clock signal based upon the reference clock and the associated station offset such that the clock signal indicators of all the remote stations are synchronised.

Embodiments of the present invention provide a system and apparatus able to provide accurate and predictable synchronised clock signals at a plurality of
20 remote stations and which avoids many of the deficiencies of known systems.

The system in practice can provide a closed loop time synchronisation environment in which the time indicator at each of a plurality of separate and remote stations is set and controlled by a reference station. In this manner, the reference station is able to ensure that the local time clocks of remote stations are
25 all synchronised, irrespective of their individual component of connection latencies. The system can also be robust in terms of communication between the reference station and the remote stations, utilising in the preferred embodiment a direct cable link therebetween, thereby avoiding the vulnerabilities experienced with existing systems. It is not necessary for the remote stations to have any
30 involvement in the calculation of a synchronised time signal, itself liable to inaccuracies, as the entire control and provision of synchronised time signals is effected by the reference station. In practice, the reference station will determine

for each remote station the latencies introduced by each component of the receiver chain: antennae, cables, amplifiers, distribution systems, receivers and so on, and generate from this a timing offset specific for that remote station.

In an embodiment, the two-way direct communication connection between the reference station and each remote station is a wired connection. Preferably, this connection is an optical fibre connection.

Advantageously, the processing unit of the reference station is operable to repeat at intervals the determination of the latency of each remote station and to adjust the remote station offsets on the basis of each determination.

In the preferred embodiment, the reference station is operable to determine a master offset in the reference clock signal on the basis of a master clock signal and to provide for adjustment of the reference time signal on the basis of the determined master offset. In a practical embodiment, the master clock signal is a local UTC, for example UTC(NPL) administered by the National Physical Laboratory in Teddington, England. Thus, the reference clock can be closely synchronised with UTC.

It is envisaged that there may be a plurality of reference stations, each connected to its own set of remote stations, wherein the reference stations are operable to determine a reference time offset based on a difference between the reference times thereof, at least one of the reference stations being operable to adjust its reference time on the basis of the determined reference time offset. The system can therefore be spread to separate locations, with each location providing a network to local remote user stations, all of which can be accurately synchronised. In practice, each reference station can be synchronised with a local UTC(x), thereby ensuring precise synchronisation to Universal Time.

In embodiments, there is a plurality of reference stations, each connected to its own set of remote stations, the plurality of reference stations including a master reference station and at least one slave reference station; wherein the reference stations are operable to determine a reference time offset for each slave reference station based on a difference between a reference clock signal thereof and a reference clock signal of the master reference station, each slave reference station

being operable to adjust each remote station offset for its respective remote stations on the basis of the respective determined reference time offset.

In some embodiments, each slave reference station is operable to adjust each remote station offset for its respective remote stations on the basis of the
5 respective determined reference time offset by adjusting its reference clock signal on the basis of the respective determined reference time offset.

According to an aspect of the invention, there is provided a method as in claim 12.

According to another aspect of the present invention, there is provided a
10 method of providing a synchronised clock signal at a plurality of remote stations, including the steps of: providing a reference clock signal at a reference station, providing a clock signal indicator at each remote station, providing a two-way direct communication connection between the reference station and each remote station, wherein the reference station determines at least one latency in the clock
15 signal indicator through each communication connection and determines therefrom a remote station offset for each remote station, and the reference station sends to each remote station an individual clock signal based upon the reference clock and the associated station offset such that the clock signal indicators of all the remote stations are synchronised.

20 Preferably, the two-way direct communication connection between the reference station and each remote station is a wired connection, most preferably an optical fibre connection.

In an embodiment, the reference station repeats at intervals the determination of the latency of each remote station and adjusts the remote station
25 offsets on the basis of each determination.

In the preferred embodiment, the reference station determines a master offset in the reference clock signal on the basis of a master clock signal and provides for adjustment of the reference time signal on the basis of the determined master offset.

30 Advantageously, the method includes, for a plurality of reference stations, each connected to its own set of remote stations, the steps of determining a reference time offset based on a difference between the reference times of the

plurality of reference stations, at least one of the reference stations adjusting its reference time on the basis of the determined reference time offset.

Brief Description of the Drawings

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Embodiments of the present invention are described below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of the existing clock synchronisation arrangement for synchronising separate user clocks;

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Figure 2 is a schematic diagram of a preferred embodiment of system according to the present invention;

Figure 3 is a schematic diagram of the embodiment of system of Figure 2 for synchronising separate user clocks by means of separate Universal Time Clocks; and

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Figure 4 is a schematic diagram of a system according to an embodiment of the invention.

Description of the Preferred Embodiments

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Referring first to Figure 1, this shows in schematic form an example of the existing apparatus and arrangement for providing synchronised clock signals at separate locations.

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A first system (system 1) provides a reference clock signal to a plurality of local users, shown as the nodes in the left-hand box in Figure 1. Synchronisation of physically separated and unconnected networks, for example in a second country, is carried out using GPS. In this case, the system uses GPS time as the single source for each network and the Universal Time Clock. This is viable but is vulnerable to manmade and natural interferences such as jamming, spoofing, meaconing and solar storms. Additionally, the latencies introduced by each component of the receiver chain, namely antennas, cables, amplifiers, distribution systems and receivers, all require careful calibration in order to understand the traceability offsets that must be implemented.

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Synchronisation requirements on a global scale are becoming critical, particularly in sectors such as the financial trading sector. Audit trails and forensic analyses of events such as flash crashes are important to understand the causes of these events. As a result, the system of Figure 1 no longer provides sufficiently
 5 robust or sufficiently accurate time synchronisation of clock signals at a plurality of separate locations.

Referring to Figure 2, there is shown a preferred embodiment of system for providing accurate and predictable synchronised clock signals at a plurality of remote stations. Figure 2 shows two separated networks 10, 12, which are linked
 10 to one another by a remote communications path 14, which may be a satellite link, a wire or any other suitable path. It is to be understood that the invention could include only one such network as it could include more than two networks.

Each network 10, 12 is provided with a reference control unit 16a, 16b which includes a reference clock as well as a processing unit and a data memory.
 15 The reference clock may be synchronised to a local Coordinated Universal Time (UTC) clock 18a, 18b, which itself is synchronised in accordance with the international protocol on UTC synchronisation administered by the BIPM, the Bureau of Weights and Measures in France.

Coupled to each reference clock 16a, 16b by means of a two-way direct
 20 communication connection, preferably a cable and most preferably a fibre optic cable $20a_1-20a_n$ and $20b_1-20b_n$, are a plurality of user remote stations units $22a_1-22a_n$ and $22b_1-22b_n$. The user stations are typically clients desiring an accurate clock signal which is precisely and reliably synchronised with the local clock signal of other users within the network or interconnected networks. For
 25 instance, one set of user stations 22a may be branches of a bank and the other user stations 22b may be foreign branches of the same bank or of a different bank. The user station units $22a_1-22a_n$ and $22b_1-22b_n$ are preferably in the form of a clock indicator unit which provides a clock signal for use by the internal client systems. That local clock signal, as described below, is certified as accurately
 30 synchronised within a defined margin of error, which may in some applications be of the order of a few tens of nanoseconds and in others even more precise, by the

reference station 16 or by a master reference station 16 in the case that a plurality of networks 10, 12 are operated together.

Each network 10, 12 is a closed loop system between the associated reference station 16a, 16b and the associated remote user stations 22a, 22b.

5 Specifically, each reference station 16a, 16b has a processor associated therewith which is operable to determine the latency associated with each remote user station $22a_1$ - $22a_n$ and $22b_1$ - $22b_n$, in practice the latencies introduced by each component of the receiver chain: antennas, cables, amplifiers, distribution systems, receivers and so on. Once determined the latency for each user station, 10 the reference station 16a, 16b determines an offset appropriate for each user station $22a_1$ - $22a_n$ and $22b_1$ - $22b_n$ in order to have each user station $22a_1$ - $22a_n$ and $22b_1$ - $22b_n$ indicate a time synchronised with all the other user stations in the network 10, 12. Those offsets are continuously re-evaluated and as appropriate stored in a memory associated with the reference station 16a, 16b.

15 Each reference station 16a, 16b then generates a specific clock signal for each remote user station $22a_1$ - $22a_n$ and $22b_1$ - $22b_n$ on the basis of its reference clock signal adjusted by the appropriate user station offset. The individual user stations $22a_1$ - $22a_n$ and $22b_1$ - $22b_n$ are then supplied with their associated clock signal through the communication lines $20a_1$ - $20a_n$ and $20b_1$ - $20b_n$ such that they all 20 indicate the same time in synchronous fashion. This synchronisation can be extremely accurate given the control by the reference station 16a, 16b. Moreover, client user stations $22a_1$ - $22a_n$ and $22b_1$ - $22b_n$ can be added at any time, with each new station having its latencies and associated offset determined by the reference station 16a, 16b, thereby ensuring that the time indicator of the new client station 25 is rapidly synchronised with the other client stations $22a_1$ - $22a_n$ and $22b_1$ - $22b_n$ of the network 10, 12.

The distribution of specific clock signals for each remote user station can utilise public domain techniques of synchronisation, such as IEEE 1588.

It is to be understood that each local Coordinated Universal Time Clock 30 18a, 18b may still transmit its clock signal in conventional manner for less critical clock synchronisation, as occurs presently.

In the example shown in Figure 2, each reference station 16a, 16b performs in the manner described above. In addition, the two reference clocks 16a and 16b are synchronised between one another. In this embodiment, each reference clock 16a and 16b is calibrated to its own Coordinated Universal Time Clock 18a, 18b, with the Coordinated Universal Time Clocks 18a, 18b calibrated in accordance with the BIPM. These calibrations are typically in the form of a calculated offset from the mean UTC derived from around four hundred local Universal Time Clocks run by various metrology laboratories and similar facilities.

The UTC formulation process is a monthly process whereby each UTC lab contributes its clock data to the BIPM in Paris. This data is used to form the weighted average timescale that is UTC. The offset UTC-UTC(k) of each lab's timescale from UTC, is disseminated via a newsletter called Circular T. The process of formulation and the publication effectively offers information of offsets one month in arrears. The offsets between labs could be several nanoseconds to hundreds of nanoseconds.

In the embodiment of Figure 2, reference stations 16a and 16b repeatedly exchange time and frequency data via the communications path 14, which may be a geo-stationary satellite link. Both reference stations transfer time and frequency data each way via the communications path 14. This exchange is typically carried out at regular intervals considerably shorter than one month, such as daily or hourly. The implementation of two way satellite time and frequency transfers between reference stations, on an hourly basis, allows for rapid measurement of the offsets.

The offsets determined can be used by one of the reference stations 16a, 16b to ensure synchronisation of their respective reference clocks. In practice, one of the reference stations 18a, 18b will be designated a master reference station to which all other reference stations will calibrate. In other words, if in the example of Figure 2 the reference station 16a is designated as master, the clock signal it will send to each associated user station 22a₁-22a_n will be:

$$\text{UTC}(18a) \pm \text{Offset}(\text{client } 22a_n)$$

On the other hand the clock signal sent by each associated or slave reference station will be:

$$\text{UTC}(18n) \pm \text{Offset}(\text{UTC}(18a \text{ to } \text{UTC}18n) \pm \text{Offset}(\text{client } 22n_n))$$

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Thus, the clock signal for reference station 18b will be:

$$\text{UTC}(18b) \pm \text{Offset}(\text{UTC}(18a \text{ to } \text{UTC}18b) \pm \text{Offset}(\text{client } 22b_n))$$

10 It is not necessary for the communication link between the reference stations 16a, 16b to be robust as they are able to rely on their local Coordinated Universal Time Clock and require only occasional calibration reference.

An example of this arrangement can be seen in Figure 3.

Figure 4 shows another example of the system.

15 Figure 4 shows reference stations, designated in this figure as Lab A and Lab B. Lab A is connected to a plurality of remote user stations 22a in a similar manner as described above, and Lab B is connected to a plurality of remote user stations 22b in a similar manner as described above. Lab A and Lab B are connected via a communications path as described above, in this case including a
20 geostationary satellite 100. Lab A includes a Coordinated Universal Time Clock providing a time signal UTC(A) and Lab B includes a Coordinated Universal Time Clock providing a time signal UTC(B).

If the timescale UTC(A), from lab A, is distributed to a network of users 22a, the replication of UTC(A) at lab B, via the transfer mechanism described above,
25 allows for UTC(B), at lab B, to be distributed to a second network 22b, physically un-connected from that at lab A, via high resolution offset generators implementing the offset UTC(B)-UTC(A), thereby providing a large scale, un-connected, synchronised network.

It is to be noted that this differs from a physical point to point and bespoke
30 synchronisation methodology. Embodiments of the present invention are able to scale as per the number of UTC labs in the consortium already submitting their data to the UTC formulation process via two time and frequency transfer.

In some embodiments, it is not necessary for the reference stations 16a, 16b to have their own clock signal separate from the Coordinated Universal Time Clocks 18a, 18b. In some embodiments, the reference stations 16a, 16b can utilise time signals from the respective Coordinated Universal Time Clock, and
5 calculate specific clock signals for remote user stations directly from the time signal from the respective Coordinated Universal Time Clock using the calculated offset described above without calculating an intermediate reference clock signal.

It is to be understood that in some embodiments it is not necessary for each reference clock 16a, 16b to transmit separate clock signals to each client station
10 22a₁-22a_n and 22b₁-22b_n. In another embodiment, each reference station 16a, 16b transmits the same reference clock signal which is then adjusted by the associated client offset, which can be stored either at the reference station 16a, 16b or in the associated client station 22a₁-22a_n and 22b₁-22b_n. It is preferred, though, that all control of the client clock signals is performed exclusively by the
15 associated reference station 16a, 16b to ensure reliability. This, moreover, can allow each reference station 16a, 16b and, in the case of a plurality of interconnected networks 10, 12, the master reference station, to certify the clock signal to a given synchronisation accuracy.

All optional and preferred features and modifications of the described
20 embodiments and dependent claims are usable in all aspects of the invention taught herein. Furthermore, the individual features of the dependent claims, as well as all optional and preferred features and modifications of the described embodiments are combinable and interchangeable with one another.

The disclosures in UK patent application number GB 1310114.2, from which
25 this application claims priority, and in the abstract accompanying this application are incorporated herein by reference.

CLAIMS

1. A system for providing a synchronised clock signal at a plurality of remote stations, including:

a reference clock signal at a reference station, the reference clock signal being a signal from a Coordinated Universal Time Clock,

a clock signal indicator at each remote station,

a two-way direct communication connection between the reference station and each remote station,

a processing unit at the reference station,

in which the processing unit is operable to determine at least one latency in each clock signal indicator through each communication connection and to determine therefrom a remote station offset for each remote station, the processing unit being operable to store each remote station offset,

in which the reference station is operable to send to each remote station an individual clock signal based upon the reference clock signal and the associated station offset such that the clock signal indicators of all the remote stations are synchronised;

in which the reference station is operable to adjust each remote station offset on the basis of a determined reference time offset based on:

a difference between the reference clock signal and a reference clock signal of a second reference station wherein the reference clock signal of the second reference station is a signal from a Coordinated Universal Time Clock, or

an offset from a mean UTC.

2. A system according to Claim 1, in which the two-way direct communication connection between the reference station and each remote station is a wired connection.

3. A system according to Claim 2, in which the wired connection is an optical fibre connection.

4. A system according to any preceding claim, in which the processing unit is operable to repeat at intervals the determination of the latency of each remote station and to adjust the remote station offsets on the basis of each determination.

5. A system according to any preceding claim, in which the reference station is operable to exchange time and frequency data with the second reference station in order to determine the reference time offset.

6. A system according to any preceding claim, in which the reference stations are operable repeatedly to determine a reference time offset at intervals, preferably at regular intervals, preferably hourly.

7. A method of providing a synchronised clock signal at a plurality of remote stations, in which each remote station includes a clock signal indicator and is connected to a reference station by a two-way direct communication connection, the method including the steps of:

- 10 (a) providing a reference clock signal at the reference station, the reference clock signal being a signal from a Coordinated Universal Time Clock,
in which the reference station determines at least one latency in the clock signal indicator through each communication connection and determines therefrom a remote station offset for each remote station, and
- 15 the reference station sends to each remote station an individual clock signal based upon the reference clock signal and the associated station offset such that the clock signal indicators of all the remote stations are synchronised;
- (b) determining a reference time offset based on:
 - (i) a difference between the reference clock signal and a reference clock signal
 - 20 of a second reference station wherein the reference clock signal of the second reference station is a signal from a Coordinated Universal Time Clock, or
 - (ii) an offset from a mean UTC;
- (c) adjusting each remote station offset on the basis of the determined reference time offset.

25 8. A method according to Claim 7, in which the two-way direct communication connection between the reference station and each remote station is a wired connection.

9. A method according to Claim 8, in which the wired connection is an optical fibre connection.

10. A method according to any of Claims 7 to 9, in which the reference station repeats at intervals the determination of the latency of each remote station and adjusts the remote station offsets on the basis of each determination.

5 11. A method according to any of Claims 7 to 10, in which the reference station exchanges time and frequency data with the second reference station in order to determine the reference time offset.

12. A method according to any of Claims 7 to 11, in which the reference stations repeatedly determine a reference time offset at intervals, preferably at regular intervals, preferably hourly.