

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
7 May 2009 (07.05.2009)

(10) International Publication Number  
**WO 2009/055931 A1**

- (51) International Patent Classification:  
H04L 7/04 (2006.01) H04W 56/00 (2009.01)  
H04L 12/16 (2006.01)
- (21) International Application Number:  
PCT/CA2008/001927
- (22) International Filing Date:  
3 November 2008 (03.11.2008)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
60/985,036 2 November 2007 (02.11.2007) US
- (71) Applicant (for all designated States except US): NOVA-TEL INC. [CA/CA]; 1120 68th Avenue N.E., Calgary, Alberta T2E 8S5 (CA).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): LADD, Jonathan [CA/CA]; 212 Sutherland Mews, N.W., Calgary, Alberta

- T3R 1H1 (CA). FENTON, Patrick, C. [CA/CA]; 1504 21st Street, N.W., Calgary, Alberta T2N 2N2 (CA).
- (74) Agent: SMART & BIGGAR; P.O. Box 2999, Station D, 900 - 55 Metcalfe Street, Ottawa, Ontario K1P 5Y6 (CA).
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL,

[Continued on next page]

(54) Title: SYSTEM AND METHOD FOR DISTRIBUTING TIME AND FREQUENCY OVER A NETWORK

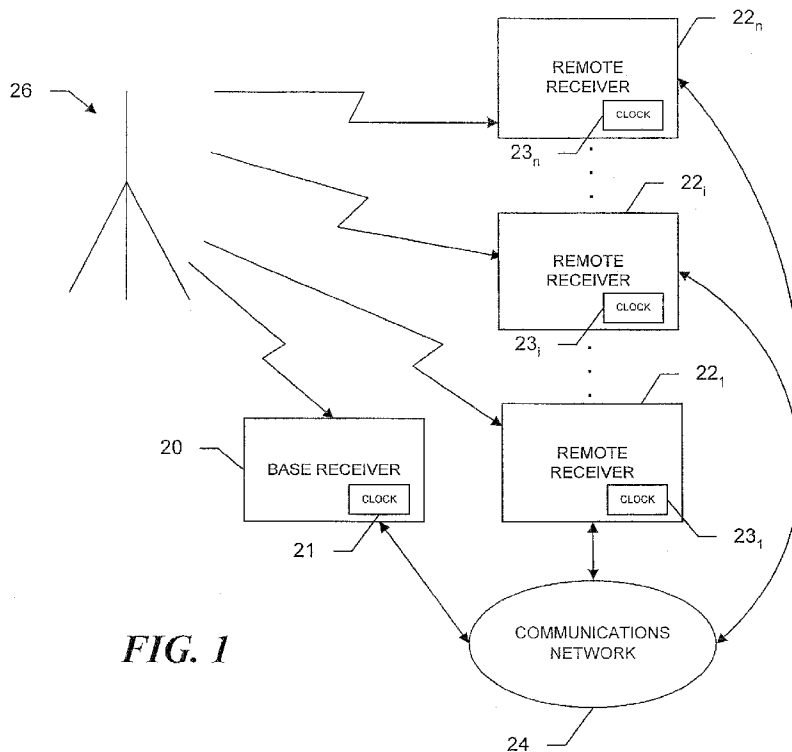


FIG. 1

(57) Abstract: A system to distribute accurate time and/or frequency over a network utilizing signals of opportunity transmitted by one or more local transmitters with known locations, the system includes a base receiver with a clock synchronized to a reference time scale such as GNSS or UTC time that saves a series of samples of the signals of opportunity and time tags the series with a calculated time of broadcast. A remote receiver saves samples of the signals of opportunity and correlates the series with the saved samples. The remote receiver calculates a time of transmission of saved samples that correspond to the series, determines a time offset as a difference in the time of broadcast calculated at the remote receiver and the time of broadcast calculated at the base receiver, and determines the time offset with respect to the base receiver. The base receiver further or instead phase locks to the signal opportunity and at predetermined intervals determines phase measurements of the integrated carrier

frequency of the signal of opportunity and provides the phase information to the remote receiver. The remote receiver, which is also phase locked to the same signal of opportunity, uses the phase measurement information to frequency lock its clock to the base receiver clock by determining a frequency error based on the rate of change of phase measurements made at the base receiver and the remote receiver.

WO 2009/055931 A1



NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG,  
CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— *before the expiration of the time limit for amending the  
claims and to be republished in the event of receipt of  
amendments*

**Published:**

— *with international search report*

# SYSTEM AND METHOD FOR DESTRIIBUTING ACCURATE TIME AND FREQUENCY OVER A NETWORK

## CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from United States Provisional Patent Appli-  
5 cation Serial No. 60/985,036 filed November 2, 2007.

## BACKGROUND OF THE INVENTION

### *Field of the Invention*

The invention relates generally to systems and methods for distributing accu-  
rate time and frequency for networked receivers and, in particular, to systems for dis-  
10 tributing time and frequency through the use of radiated "signals of opportunity,"  
such as local radio or television signals.

### *Background Information*

Timing is critical for networks, for example, in high speed wireless networks  
15 in which handoffs occur. Another example of network in which timing is critical is a  
city power distribution network in which high voltage direct current (DC) transmis-  
sion lines are used to transfer power over long distances between power generation  
facilities, such as hydroelectric dams, and consumers. The high voltage DC power  
signals must be converted to low voltage AC power signals before distribution to  
20 businesses and households. Cities generally have a number of power transformer sta-  
tions that are interconnected on power grids to do the conversion. The interconnected  
power transformer stations must be producing the low voltage AC power signals in  
exactly the same frequency and phase before the signals can be distributed across  
common low voltage transmission lines. Accordingly, the power transformer station  
25 operations must be synchronized in time and frequency. There is thus a need for ac-

curate time determination as well as accurate frequency determination at distributed, or remote, locations within the network.

GNSS receivers at the remote locations can provide timing and frequency information, as long as the antennas at the remote locations have sufficiently clear  
5 views of the sky. However, remote locations that are within cities often do not have such views of the sky, and there is thus a need for providing timing and frequency information at the remote locations.

## SUMMARY OF THE INVENTION

A method and system for providing timing information at distributed, or remote,  
10 receivers uses radiated signals of opportunity, such as, AM and FM radio signals, television signals, signals from geo-stationary communications satellites and so forth, that can be received simultaneously by the base and remote receivers, to determine time and frequency offsets from the time and frequency determined at a base station, where the source of the time and/or frequency to be distributed is located.

15 Based on the measured offsets, the remote receivers determine their relative time and frequency differences from the base station and take appropriate action such as correcting their clocks to more closely align in phase and frequency to that of the clock at the base station.

The base station and remote receivers know their respective locations and the  
20 location of the signal of opportunity transmitter (referred to herein also as the "SOP transmitter"). The base station, which has an accurate time clock that is synchronized to the reference clock to be distributed, such as GNSS or UTC time, takes a series of samples of the broadcast signal of opportunity, determines the time of transmission based on the time delay associated with transmission over the known baseline between the base station and the SOP transmitter, and time tags the samples. The base  
25 station then transmits the time tagged series of samples.

During overlapping time periods, the remote receivers store samples of the broadcast signals. The remote receivers then correlate the time tagged series of samples with the stored signal samples, and determine a time of transmission of the saved  
30 signals that correspond to the series, taking into account the delay over the known baselines between the respective remote receivers and the SOP transmitter. The remote receivers determine their phase clock errors from the time difference between times of transmission calculated at the respective remote receivers and the base re-

ceivers. The remote receivers thus maintain time within microseconds of the base receiver time, which may be tied to the reference time such as GNSS or UTC time.

For tighter timing and in particular frequency requirements, the base station monitors the frequency of the broadcast signal of opportunity and determines an associated phase error, that is, the phase differences between the registered broadcast frequency of the SOP transmitter and the actual broadcast frequency. The base station utilizes its reference frequency control, and thus the base station determines the phase differences between the actual frequency of the broadcast signal and the reference frequency. The base station transmits the phase error information to the remote receivers, which use the phase error information to phase lock to the reference frequency. The frequency synchronization precision over the network using the common signal of opportunity source, can then be accurate to within nanoseconds/second.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention description below refers to the accompanying drawings, of which:

Fig. 1 is a functional block diagram of a system constructed in accordance with the invention; and

Fig. 2 illustrates a snapshot of a signal of opportunity.

## DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

Referring to Fig. 1, a reference, or base station 20 (referred to hereinafter as "the base receiver") and remote receivers  $22_1 \dots 22_n$  are connected to a communication network 24, such as, for example, the internet, or a private network. Each of the receivers simultaneously receives a signal broadcast from one or more high power radiators 26 with known locations, i.e., AM/FM radio transmitters, Beacon or Loran transmitters, television station transmitters, geo-stationary communications satellites, and so forth, with respective service areas that cover all or part of the network. The broadcast signals, which are selected due to their quality of signal, known transmis-

sion locations, and continuous broadcast, are "signals of opportunity", that is, signals that are broadcast at various frequencies and for purposes such as the transmission of random conversation or dialog. This is in contrast to GNSS signals, for example, which are broadcast at the same frequencies by the GNSS satellites and carry particular codes. Further, in contrast to known systems, the current system does not utilize the data or content of information modulated onto the broadcast signals, that is, does not, for example, utilize transmitted time of day information contained in the broadcast signals. The terrestrial radiator is referred to hereinafter as the "SOP transmitter."

The base receiver 20 in one embodiment uses a GNSS receiver to provide the reference time and frequency for the network. Because of the use of GNSS receiver, the base receiver is located such that it has a sufficiently clear view of the sky to determine GNSS time using GNSS satellite signals. The base receiver 20, operating in a known manner, then synchronizes its clock 21 to the GNSS or UTC time based on the GNSS satellite signals. Preferably, the base receiver has a sufficiently clear view to also determine its position using the GNSS satellite signals. Otherwise, the X, Y, Z position coordinates of the base receiver must be known by, for example, GNSS satellite information obtained from a hand held GPS receiver during installation of the base receiver, through a survey, and/or through use of topological maps.

The locations of the remote receivers  $22_1 \dots 22_n$  are also known. In certain applications, the street addresses of the remote receivers are sufficient. For more precise applications, the locations must be known to within tighter tolerances by, for example, GNSS satellite information obtained from a hand held GPS receiver during installation of the remote receivers, through survey, or through the use of topological maps.

The location of the SOP transmitter 26 is usually known or can be readily determined from the information provided by a registration authority, such as, for example, the U.S. Federal Communications Commission or the FCC. The information may be available, for example, over the internet. The network 24 may provide the base and remote receivers with a list of usable local signals of opportunity, or the system may select a particular signal of opportunity, for example, for the stability of its carrier frequency, its modulated frequency content and based on the field strength of the signal at the respective receivers. In addition, for redundancy, the signals from more than one SOP transmitter may be utilized.

Notably, the broadcast signals are of sufficiently low frequency to have excellent building penetration. Thus the remote receivers need not have particularly good

views of the sky, but instead must have relatively good reception of the selected broadcast signals of opportunity. Further, the use of such low frequency signals allows the receivers to scan with configurable front end filters, such as charged capacitor filters or digital FIR filters, to find the best signal of opportunity candidates.

5           The base receiver 20, with its position known or determined using the GNSS satellite signals, can readily determine a baseline to the selected SOP transmitter 26. Similarly, the remote receivers 22, ...22<sub>n</sub>, using their known locations, can readily determine respective baselines to the selected SOP transmitter. If the SOP transmitter is far away with respect to a baseline between the base and remote receiver, the direc-  
10           tion vector may be utilized instead of the baseline between the receivers and the SOP transmitter. From the base lines, the SOP signal propagation or travel times between the broadcast antenna and the receivers can be calculated and used to further improve the time synchronization as described below.

          Referring also to Fig. 2, the base receiver 20 takes a series of samples 200 of  
15           the broadcast signal of opportunity and time tags the samples. The series may be a fraction of a second long or longer, for example, 1/4 second long. The base receiver may take the samples continuously or at predetermined times, as appropriate.

          To time tag the samples, the base receiver determines their respective times of transmission. The base receiver thus subtracts the time delay associated with the  
20           transmission of the signal from the SOP transmitter 26 to the base receiver from the time provided by the clock 21 for receipt of the samples and time tags the samples with the broadcast time. The receiver may, for example, time tag each of the samples of the series. Alternatively, the base receiver may time tag the first sample of the snapshot, or certain of the samples of the series. The base receiver 20 then transmits  
25           the time tagged series of samples to the remote receivers 22<sub>1</sub>...22<sub>n</sub> over the communication network 24. As appropriate, the base receiver may compress the information for ease of transmission over the communication network.

          The remote receivers 22<sub>1</sub>...22<sub>n</sub> are similarly saving and time tagging samples of the broadcast signals of opportunity based on their local clocks 23<sub>1</sub>...23<sub>n</sub>. To time  
30           tag the samples, the remote receiver subtracts the time delay associated with the transmission from the SOP transmitter 26 to the remote receiver from the time the corresponding signal was received at the remote receiver, to determine the broadcast time. The remote receivers may save samples of signal segments that have the same length or are slightly longer than the series of samples, as appropriate, to ensure cap-

ture of corresponding signal samples. A given remote receiver 22<sub>i</sub> correlates the series of samples received from the base receiver, with the saved time-tagged data such that the signal samples align. The time difference between the broadcast time of the series according to the remote receiver and according to the base receiver is the clock error, or time offset, at the remote receiver.

Using the time offset, the remote receiver 22<sub>i</sub> aligns its time with the base time, i.e., the time determined at the base receiver, which may have its clock synchronized to GNSS or UTC time. The base receiver continues to send time-tagged series to the remote receiver, to ensure continued time alignment to within one or a small number of microseconds.

The remote receivers 22<sub>1</sub>...22<sub>n</sub> determine the time offsets using received series of samples 200 that have diverse frequency content, such as series that correspond to a change in the broadcast signal that is distinct from the background signal and is not regularly repeated, such as, for example, a particular bit of conversation. These series represent "modulation events," and the alignment of the saved and received modulation events produce a correlation function that has an essentially triangular shape, that is, a correlation function with a single correlation peak. The series that correspond to repeating sounds, such as, for example, certain musical segments, are not utilized to determine time offsets because the associated correlation function has multiple peaks and a time offset can thus not be determined with sufficient accuracy.

The remote receiver 22<sub>i</sub> sequentially correlates the received series of samples 200, or modulation event, with the saved time-tagged signal sample data and selects the saved data that produces the highest correlation value. The remote receiver then determines the time offset as discussed above. The time offset value is verified by repeating the process with subsequent modulation events provided by the base receiver 20.

The samples taken at the base receiver 20 and a given remote receiver 22<sub>i</sub> may be taken at slightly different times, since the samples are taken with respect to the receivers' clocks. Accordingly, the accuracy of the time alignment with a correlation process that relies on the best fit, i.e., selecting the highest correlation value, is essentially limited by the sampling rate. For increased accuracy, fine adjustments may be made to the phase of the demodulation sample collection process, to drive the sampling times at the remote receiver closer to the sampling times at the base receiver.

The remote receiver 22<sub>i</sub> determines if the correlation values on either side of the correlation function peak, that is, earlier and later correlation values, are essentially symmetrical. If not, the remote receiver shifts the phase of the sample collection process, that is, a sample clock, in the direction of the larger of the earlier or later correlation values. The remote receiver may shift the phase by a predetermined amount each time it performs the analysis. Alternatively, the remote receiver may shift the phase by an amount that corresponds to the magnitude of the differences in the earlier and later correlation values. Before determining if the earlier and later correlation output values are essentially symmetrical, the remote receiver 22<sub>i</sub> may filter the correlation output values by, for example, averaging them over successive series, before making the comparisons.

The accuracy of the alignment depends on the broadcast modulated frequency content and bandwidth of the selected signal of opportunity, the broadcast signal to noise ratio and the filtering bandwidth of the early and late correlation parameters. Using, for example, a typical AM radio talk-show broadcast with 5kHz of bandwidth and average noise as the signal of opportunity, and sampling at a rate of 10KHz the remote receiver 22<sub>i</sub> can, with the fine adjustment of the phase of the sampling collection process, align the remote receiver time to within 1 microsecond of the base receiver time, that is, with the reference time such as GNSS or UTC. If a television broadcast with 100kHz of bandwidth and average noise is instead selected as the signal of opportunity, the remote receiver may align its time with absolute time to within less than 1 microsecond.

For applications with even tighter frequency synchronization requirements, the base receiver 20 may instead or in addition provide the remote receiver 22<sub>i</sub> with phase information associated with the broadcast signal of opportunity, such that the remote receiver can phase lock to the base reference frequency. To do this, the base receiver, operating in a known manner, uses its chosen reference frequency source, such as GPS satellite information, to determine a true clock frequency. The base receiver then phase locks to the broadcast signal of opportunity and continuously integrates the apparent frequency of the SOP carrier. Periodically, at for example every 1 second, the base receiver measures the value of the accumulating frequency integration, to provide an SOP phase measurement that includes integer and fractional carrier cycle components. The phase measurements are made at predetermined intervals, such as at second intervals with respect to the reference time and frequency.

The fractional cycle component can be measured accurately, however, the integer cycle component has an arbitrary start value, which must be assigned by the base receiver. The base receiver 20 has used its clock 21, which may be GNSS-tied frequency control, to determine the timing of the phase measurements, and thus, the phase measurements are based on the reference frequency to be distributed. The base receiver provides phase information, which includes the integer and fractional carrier cycle components to the remote receivers  $22_1 \dots 22_n$ , the time of the measurement, and information identifying the SOP transmitter, such as station identifier, nominal station frequency and so forth. In addition, the base receiver may send information relating to the quality of the signal and/or the base receiver tracking operation such as signal to noise ratio, number of seconds from acquisition, last lock break, or cycle slip and so forth.

A given remote receiver  $22_i$  similarly phase locks to the broadcast signal of opportunity, and similarly continuously integrates its perceived SOP carrier frequency, and similarly periodically samples the phase of the SOP frequency integration process at a sample rate derived from the reference frequency of the remote receiver. The remote receiver compares its SOP phase measurements with that of the base receiver to establish the frequency difference between the base and remote receivers. Based on a first count received from the base receiver, the remote receiver sets its integer cycle count to the count set by the base receiver and adjusts the frequency of its clock such that the phase measurements at the remote are the same as at the base. The remote receiver determines frequency error as the rate of change between the phase measurements made at the base and at the remote receiver, based on subsequent phase measurement received from the base receiver. The remote receiver then synchronizes its clock frequency to the frequency of the base receiver clock, that is, to the reference frequency, using the calculated frequency errors.

The system may operate to determine synchronous frequency over the network, with or without determining absolute time. The remote receivers may, for example, not require absolute time and use instead less accurate time determined from another source or an arbitrary time. If the remote receivers are also synchronizing to the reference time, the base and remote receivers can use carrier cycle counts to identify the modulation events from which synchronization to absolute time is determined. Providing the correlation method utilizing the series of samples 200 is able to synchronize the times between the base receiver and the remote receiver to better than 1/2

wave length of the SOP carrier, the integer ambiguity of the cycle count of the remote receiver can be resolved and set to exactly match the base. When ambiguity resolved carrier is used to make the clock and frequency adjustments, the time and frequency accuracy at the remote receivers can be maintained within nanoseconds and nanoseconds/second of the reference time and frequency, such as GNSS or UTC time.

With information from the base receiver relating to the quality of the tracking operations at the base, the remote may further improve its time synchronization by, for example, using only the highest quality pairs of measurements, that is, measurements that are of high quality at both the base and the remote receivers. Alternatively or in addition, the remote receiver may weight the measurement differences by the quality of information in a least squares solution based on redundant measurements. Further, the quality information may cause a remote receiver that is tracking a single SOP signal to switch to another SOP signal.

The system described herein has the advantage of accurate time and frequency transfer between a base receiver and remote receivers utilizing broadcast signals of opportunity. The communication network may be wired or wireless. The known location of the SOP transmitter may be a trajectory rather than a fixed location. For example, the SOP transmitter may transmit from a moving platform such as an automobile, aircraft, ship or satellite, provided that the location and the velocity vector of the transmitter can be determined by the system. For a satellite transmitter, for example, the orbital ephemeris parameters must be readily available. One or more of the remote receivers may also receive GNSS satellite signals and determine position. The GNSS remote receivers may be mobile or fixed-position receivers. The base and remote receivers may determine phase error measurements by downconverting the received signal of opportunity to base band using the nominal registered frequency for the transmitter or to some other lower frequency, determining a residual frequency offset, and integrating the down converted frequency offset to calculate the phase error measurement. The remote receivers then determine a frequency offset based on the differences in the phase measurements made at the base receiver and at the remote receiver. By downconverting to determine the phase measurements, the integer cycle count values do not grow as large and therefore are more efficient to process and require less bandwidth to communicate to the remote receivers.

What is claimed is:

## CLAIMS

- 1 1. A system for transferring time over a network utilizing signals of opportunity  
2 transmitted by one or more transmitters with known locations, the system com-  
3 prising:
  - 4 a base receiver with a clock synchronized to a reference time that  
5 samples the signals of opportunity, time tags the samples with a calculated  
6 time of broadcast, and sends a series of the time-tagged samples over a com-  
7 munications network;
  - 8 a remote receiver that receives information over the communications  
9 network, the remote receiver
    - 10 saving and time-tagging samples of the signals of opportunity,
    - 11 correlating the time-tagged series of samples received over the  
12 communications network with the saved time-tagged samples,
    - 13 calculating a time of broadcast of the saved time-tagged sam-  
14 ples that correspond to the received series of samples,
    - 15 determining a time offset as a difference in the time of broad-  
16 cast calculated at the remote receiver and the time of broadcast calcu-  
17 lated at the base receiver, and
    - 18 determining the time with respect to the reference time at base  
19 receiver based on the time offset.
- 1 2. The system of claim 1 wherein the base receiver calculates the time of broadcast  
2 based on the time of receipt of the signal that corresponds to the series of sam-  
3 ples and a time delay associated with a base line from the transmitter to the base  
4 receiver.
- 1 3. The system of claim 2 wherein the remote receiver calculates the time of broad-  
2 cast based on the time of receipt of the signal that corresponds to the series of  
3 samples at the remote receiver and a time delay associated with a baseline from  
4 the remote receiver to the transmitter.
- 1 4. The system of claim 1 further including

2                   the base receiver synchronizing clock frequency to a reference source,  
3                   determining carrier phase measurements associated with the broadcast signals  
4                   of opportunity and providing phase information to the remote receiver, and  
5                   the remote receiver having a clock and determining carrier phase meas-  
6                   urements associated with the broadcast signals of opportunity, the remote re-  
7                   ceiver determining a frequency offset of the clock from the base receiver clock  
8                   frequency by the differences between the phase measurements of the base and  
9                   remote receivers, and  
10                   the remote receiver using the frequency offset measurements to adjust  
11                   and align its clock frequency to that of the base.

1    5. The system of claim 4 wherein

2                   the base and remote receivers determine the phase measurements by phase  
3                   locking to the broadcast signals of opportunity and integrating the frequency to  
4                   produce a wave count that represents an accumulating phase of the broadcast fre-  
5                   quency associated with the transmitter and measuring the wave count at predeter-  
6                   mined times according to the reference frequencies of the respective receivers.

7    6. The system of claim 4 wherein

8                   the base and remote receivers determine the phase measurements by down-  
9                   converting the broadcast signals of opportunity using a down converting fre-  
10                   quency source generated from the respective receivers reference frequencies and  
11                   integrating the residual frequency to produce wave counts that represent the fre-  
12                   quency offset of the signal of opportunity from the down converting frequency as  
13                   measured at predetermined times according to the reference frequency.

1    7. The system of claim 1 further including additional remote receivers that deter-  
2                   mine a relative time as time offsets from the base receiver time.

1    8. The system of claim 1 wherein the base and remote receivers utilize signals of  
2                   opportunity from a plurality of the transmitters.

- 1 9. The system of claim 1 wherein one or both of the base and remote receivers in-  
2 clude configurable front end filters that scan the broadcast signals to select one  
3 or more signal of opportunity for use.
- 1 10. The system of claim 1 wherein the communication network provides a list of us-  
2 able signals of opportunity and one or both of the base and remote receivers se-  
3 lects one or more signals of opportunity from the list for use.
- 1 11. The system of claim 1 wherein the remote receivers adjust a phase of a sample  
2 clock based on non-symmetrical earlier and later correlation values determined  
3 during correlation of the series of samples to the saved signal samples.
- 1 12. The system of claim 11 wherein the remote receivers filter the earlier and later  
2 correlation values before making the adjustment.
- 1 13. A method for transferring relative time over a network utilizing signals of oppor-  
2 tunity transmitted by one or more local transmitters with known locations, with  
3 signal service areas covering all or a portion of the network, the method compris-  
4 ing the steps of  
5           synchronizing a clock to a reference time scale,  
6           saving series of samples of the signals of opportunity at the base re-  
7 ceiver, time tagging the series with a time of broadcast calculated using the  
8 base receiver clock, and providing the time tagged series of samples to a re-  
9 mote receiver;  
10           saving samples of the signals of opportunity at the remote receiver and  
11 correlating the received series of samples with the saved signal samples;  
12           calculating a time of broadcast of the signal samples that correspond to  
13 the series of samples and determining a time offset as a difference in the time  
14 of broadcast calculated at the remote receiver and the time of broadcast calcu-  
15 lated at the base receiver, and  
16           determining the relative time difference between the remote and base receivers  
17 based on the time offset to determine time at the remote receiver.

1           14. The method of claim 13 wherein the base receiver synchronizes its clock  
2 to a global reference;

1           15. The method of claim 14 wherein the base receiver synchronizes its  
2 clock to one of GNSS or UTC time.

3           16. The method of claim 13 wherein the step of calculating the broadcast time  
4 at the base receiver includes calculating the time based on the time of receipt of the  
5 signals at the base receiver and a time delay associated with a base line from the  
6 transmitter to the base receiver.

1           17. The method of claim 13 wherein the step of calculating the time of broad-  
2 cast at the remote receiver includes calculating the time based on the time of receipt  
3 of the signals that correspond to the series of samples and a time delay associated with  
4 a base line from the remote receiver to the transmitter.

1           18. The method of claim 13 further including

2  
3           determining phase measurements associated with the carrier frequency of the  
4 broadcast signals of opportunity at the base receiver and providing phase measure-  
5 ment information to the remote receiver, and

6           determining phase measurements associated with the broadcast signals of op-  
7 portunity at the remote receiver and determining a frequency offset for which the  
8 phase measurements determined at the remote receiver correspond to the phase error  
9 determined at the base receiver, and

10           aligning the frequency of the clock at the remote receiver with a clock at the  
11 base receiver based on the frequency offset.

1           19. The method of claim 18 wherein

2           the step of determining phase measurements at the base and remote receiver  
3 includes phase locking to the broadcast signal of opportunity, integrating the received  
4 carrier frequency of the signal of opportunity and periodically sampling the integrat-  
5 ing value based with a time interval derived from the reference frequency.

1           20. The method of claim 18 wherein  
2           the step of determining the phase measurements at the base and remote re-  
3           ceiver includes downconverting the broadcast signal of opportunity to a lower fre-  
4           quency using a down converting frequency signal derived from the respective receiver  
5           reference frequencies integrating the down converted frequency and periodically  
6           sampling the integrating value based on a time interval derived from the respective  
7           receiver reference frequencies.

1           21. The method of claim 13 further including additional remote receivers per-  
2           forming the steps to determining relative time synchronization from time offsets from  
3           the base receiver time.

1           22. The method of claim 13 further including utilizing signals of opportunity  
2           from a plurality of transmitters at the base receiver and the remote receiver.

1           23. The method of claim 13 further including one or both of the base and re-  
2           mote receivers scanning the broadcast signals to select a signal of opportunity for use.

1           24. The method of claim 13 further including one or both of the base and the  
2           remote receiver selecting the signals of opportunity for use from a list of usable sig-  
3           nals of opportunity.

1           25. The method of claim 13 wherein the step of sampling the signal at the re-  
2           mote receivers includes adjusting the phase of sampling based on non-symmetrical  
3           earlier and later correlation values determined during correlation of the snapshot to  
4           the saved signal samples.

1           26. The system of claim 25 wherein the step of adjusting includes filtering the  
2           earlier and later correlation values before making the adjustment.

1           27. A system for transferring frequency between two or more receivers over a  
2           network utilizing signals of opportunity transmitted by one or more transmitters at

3 known locations, with signal service areas covering all or a portion of the network, the  
4 system comprising:

5 a base receiver with a clock synchronized to a reference frequency that  
6 phase locks to the signal of opportunity, makes phase measurements at prede-  
7 termined intervals, and sends the phase measurements over a communications  
8 network;

9 a remote receiver that has a clock and receives information over the  
10 communications network, the remote receiver

11 phase locking to the signal of opportunity and making phase  
12 measurements,

13 determining a frequency offset of the remote receiver clock as  
14 a rate of change in the phase measurements made at the base receiver  
15 and at the remote receiver, and

16 adjusting the frequency of the remote receiver clock to remove  
17 the measured offset.

18

1 28. The system of claim 27 further including additional remote receivers that  
2 are synchronized in frequency based on frequency errors determined using phase  
3 measurements received from the base receiver.

1 29. The system of claim 27 wherein the base and remote receivers utilize sig-  
2 nals of opportunity from a plurality of the transmitters.

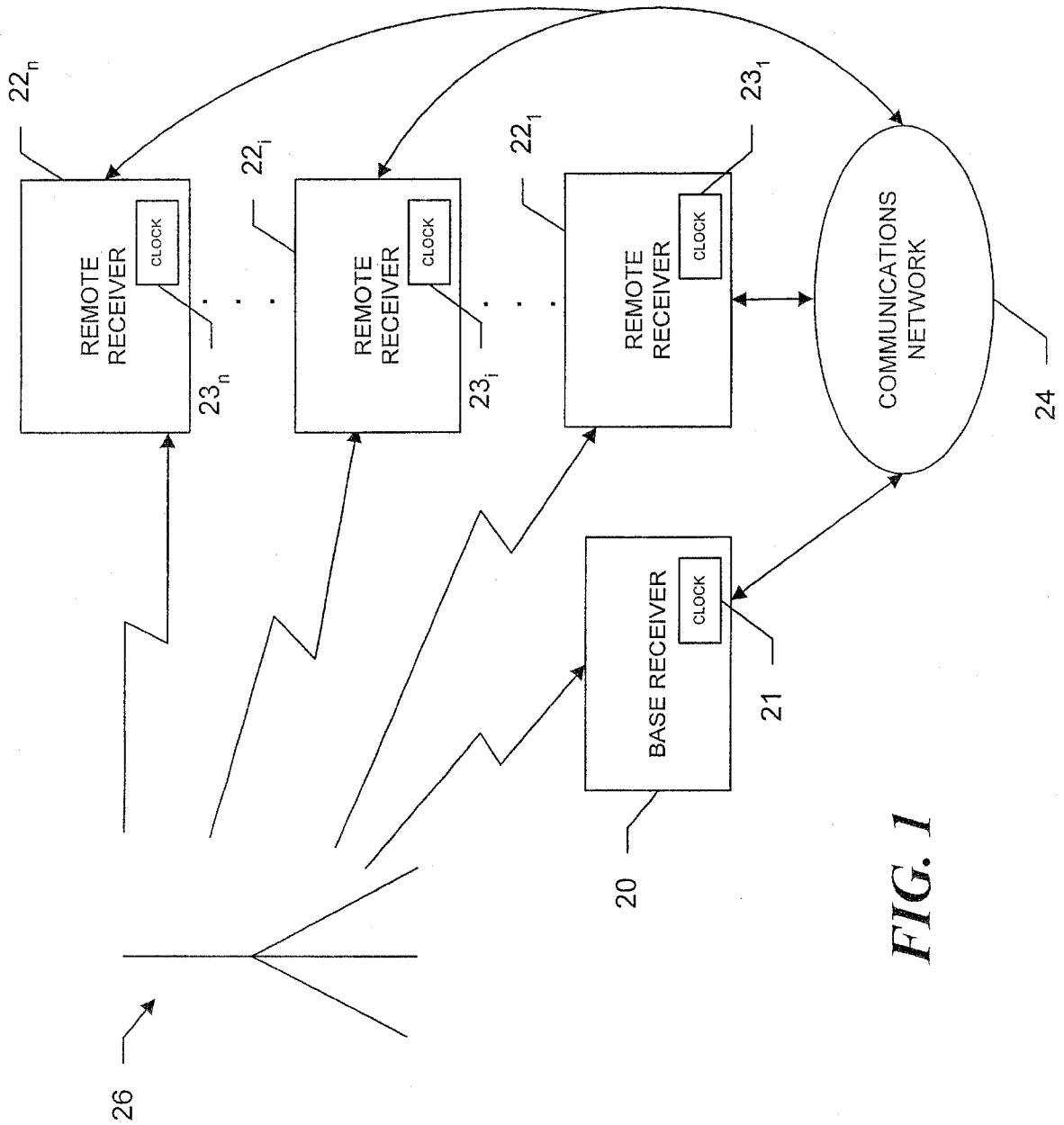
1 30. The system of claim 27 wherein one or both of the base and remote re-  
2 ceivers include configurable front end filters that scan the broadcast signals to select a  
3 signal of opportunity for use.

1 31. The system of claim 27 wherein the communication network provides a  
2 list of usable signals of opportunity and one or both of the base and remote receivers  
3 selects one or more signal of opportunity from the list for use.

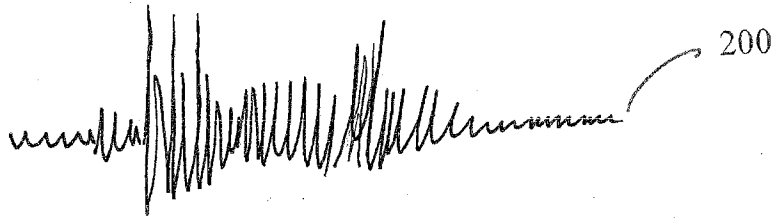
1 32. The system of claim 27 wherein

2           the base and remote receivers determine the phase measurements by phase  
3   locking to the broadcast signals of opportunity, integrating the frequency to produce a  
4   wave count that represents an accumulating phase of the broadcast frequency associ-  
5   ated with the transmitter and measuring the wave count at predetermined times ac-  
6   cording to the reference frequencies of the respective receivers.

1           33.   The system of claim 27 wherein  
2           the base and remote receivers determine the phase measurements by down-  
3   converting the broadcast signals of opportunity using a down converting frequency  
4   source generated from the respective receivers reference frequencies and integrating  
5   the residual frequency to produce wave counts that represent the frequency offset of  
6   the signal of opportunity from the down converting frequency as measured at prede-  
7   termined times according to the reference frequency.



**FIG. 1**



**FIG. 2**

**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/CA2008/001927

<p>A. CLASSIFICATION OF SUBJECT MATTER  <b>IPC: H04L 7/04 (2006.01) , H04L 12/16 (2006.01) , H04W 56/00 (2009.01)</b>                  According to International Patent Classification (IPC) or to both national classification and IPC</p>		
<p>B. FIELDS SEARCHED</p>		
<p>Minimum documentation searched (classification system followed by classification symbols)                  IPC: H04L, H04W</p>		
<p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched</p>		
<p>Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)                  Databases Searched: Delphion, US West Patent Database, Canadian Patent Database                  Keywords Searched: network, time, frequency, signals of opportunity, transmitter, receiver, offset, remote, phase lock</p>		
<p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p>		
<b>Category*</b>	<b>Citation of document, with indication, where appropriate, of the relevant passages</b>	<b>Relevant to claim No.</b>
A	US 2007/0182633 A1 (OMURA et al.) 9 August 2007 (09-08-2007) see entire document	1-33
A	US 2005/0201421 A1 (BHANDARI et al.) 15 September 2005 (15-09-2005) see entire document	1-33
A	CA 2 398 781 A1 (BEKRITSKY et al.) 23 May 2002 (23-05-2002) see entire document	1-33
A	EP 1 254 545 B1 (GAO et al.) 6 November 2002 (06-11-2002) see entire document	1-33
<p><input type="checkbox"/> Further documents are listed in the continuation of Box C.      <input checked="" type="checkbox"/> See patent family annex.</p>		
<b>*</b>	Special categories of cited documents :	<p>“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>“&amp;” document member of the same patent family</p>
“A”	document defining the general state of the art which is not considered to be of particular relevance	
“E”	earlier application or patent but published on or after the international filing date	
“L”	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
“O”	document referring to an oral disclosure, use, exhibition or other means	
“P”	document published prior to the international filing date but later than the priority date claimed	
<p>Date of the actual completion of the international search</p> <p>16 February 2009 (16-02-2009)</p>		<p>Date of mailing of the international search report</p> <p>23 February 2009 (23-02-2009)</p>
<p>Name and mailing address of the ISA/CA</p> <p>Canadian Intellectual Property Office                  Place du Portage I, C114 - 1st Floor, Box PCT                  50 Victoria Street                  Gatineau, Quebec K1A 0C9                  Facsimile No.: 001-819-953-2476</p>		<p>Authorized officer</p> <p><b>Dennis Atkinson 819- 953-0816</b></p>

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
**PCT/CA2008/001927**

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US 2007182633A1	09-08-2007	US 7471244B2	30-12-2008
US 2005201421A1	15-09-2005	CN 1667997A EP 1575200A2 EP 1575200A3 JP 2005260966A KR 20060043423A US 7483448B2	14-09-2005 14-09-2005 07-12-2005 22-09-2005 15-05-2006 27-01-2009
CA 2398781A1	23-05-2002	AU 784463B2 AU 785280B2 AU 1978502A AU 2688402A AU 2692802A AU 2002226884B2 BR 0107383A BR 0107786A BR 0115959A CA 2398779A1 CA 2398779C CA 2419796A1 CN 1311652C CN 1500323A CN 1568599A CN 1636413A EP 1334578A2 EP 1336277A2 EP 1336310A2 JP 3961951B2 JP 2004514356T JP 2004514376T JP 2004529520T JP 2007295621A TW 235615B TW 582143B US 7030811B2 US 7030812B2 US 7069025B2 US 7250906B2 US 2002059535A1 US 2002097182A1 US 2002098852A1 US 2006125690A1 US 2006160545A1 WO 0241504A2 WO 0241504A3 WO 0241545A2 WO 0241545A3 WO 0241545A9 WO 0241651A2 WO 0241651A3 ZA 200204589A ZA 200204590A ZA 200301206A	06-04-2006 21-12-2006 27-05-2002 27-05-2002 27-05-2002 01-06-2006 05-11-2002 22-10-2002 03-05-2005 23-05-2002 01-05-2007 23-05-2002 18-04-2007 26-05-2004 19-01-2005 06-07-2005 13-08-2003 20-08-2003 20-08-2003 22-08-2007 13-05-2004 13-05-2004 24-09-2004 08-11-2007 01-07-2005 01-04-2004 18-04-2006 18-04-2006 27-06-2006 31-07-2007 16-05-2002 25-07-2002 25-07-2002 15-06-2006 20-07-2006 23-05-2002 06-03-2003 23-05-2002 30-01-2003 30-05-2003 23-05-2002 06-02-2003 20-08-2003 27-01-2004 15-07-2004
EP 1254545A1	06-11-2002	AU 3145201A DE 60131142D1 EP 1254545B1 US 6603958B1 WO 0160003A1	20-08-2001 13-12-2007 31-10-2007 05-08-2003 16-08-2001