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Designing robust and reliable timestamps for remote patient monitoring

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***Abstract*—Having timestamps that are robust and reliable is essential for remote patient monitoring in order for patient data to have context and to be correlated with other data. However, unlike hospital systems for which guidelines on timestamps are currently provided by HL7 and IHE, remote patient monitoring platforms are: operated in environments where it can be difficult to synchronize with reliable time sources; include devices with simple or no clock; and may store data spanning significant periods before able to upload. Existing guidelines prove inadequate. This paper analyses the requirements and the operating scenarios of remote patient monitoring platforms and defines a framework to convey information on the conditions under which observations were made by the device and forwarded by the gateway in order for data to be managed appropriately and to include both reference to local time and an underlying continuous reference timeline. We define the timestamp formats of HL7 to denote the different conditions of operation and describe extensions to the existing definition of the HL7 timestamp to differentiate between time local to GMT (+0000) and UTC or NTP time where no geographic time zone is implied (-0000). We further describe how timestamps from devices having only simple or no clocks might be managed reliably by a gateway to provide timestamps that are referenced to local time and an underlying continuous reference timeline. We extend the HL7 message to include information to permit a subsequent receiver of the data to understand the quality of the timestamp and how it has been translated. We present evaluation from deploying a platform for 12 months.**

***Index Terms*—remote patient monitoring, telehealth, timestamps, time standards.**

I. INTRODUCTION

Remote patient monitoring platforms are typically widely deployed to patients to collect and forward observations over significant periods of time. Platforms will include a wide variety of devices to monitor physiological (e.g., blood pressure, weight, glucose, SpO_2) and environmental (e.g., motion, temperature) parameters. Typically end devices are simple, low-cost and battery operated and they connect to the gateway using low-power, short-range wireless communications. Such devices may have no internal clock, or the internal clock is not or cannot be synchronized to an external time source. Gateways typically will use wide area communication technology such as GPRS to transmit data and synchronize their internal clock to an external source, such as the time provided by the mobile (cell) phone network or Network Time Protocol (NTP) [1].

There is an expectation that the gateway will translate the timestamps from each device to the local time of the patient to provide context and ensure that observations from multiple devices can be compared and combined. This includes having the correct local time to allow interpretation of blood glucose measurements with separately recorded carbohydrate intake and exercise for the diabetic patient, or comparison of physiological data with environmental information to correlate health and behavioral changes as in [2]. It ideally should also provide a reference to an underlying continuous time base to support correlation between data from multiple sources that may have been recorded at different locations, such as Holter ECG recordings that are correlated with drug data in FDA trials. Each of these applications will have its own consideration of the accuracy of timestamps. Although remote patient monitoring applications may tolerate an error in synchronization of minutes, other applications such as hospital procedures may require a greater accuracy in synchronization. As tolerance on synchronization cannot be defined uniquely, the error will need to be specified in the message.

Platforms can be used to monitor patients for significant periods, so aspects of time zone (TZ) and daylight savings (DST) must be taken into account when translating to qualified time that includes both the local time and time zone offset relative to the underlying continuous time base. This may be further complicated if devices store observations that span time changes, and whether the device changes its time or not. For example, a simple weighing scale may have readings stored due to loss of communication with the gateway and will not change its clock due to DST, whereas a blood glucose meter will have its clock changed. Each of these scenarios needs to be considered in order for all observations to be handled correctly.

HL7 [3] and IHE [4] have produced guidelines for management of timestamps. However these were developed with the expectation that devices are typically located within the health care enterprise, where networks and devices are

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managed by professional staff, including central management of time zone and daylight savings information..

In a practical remote patient monitoring platform, the ideal conditions of the health care enterprise do not apply. The limitations must be identified and a protocol developed to support working in such environments and this must indicate the conditions under which the platform is operating. Furthermore the protocol must allow devices to continue to operate in any adverse conditions that may prevail. This will include the gateway being unable to acquire accurate time as not all mobile (cell) phone networks provide network time on registration to the network, and the NTP server may not be accessible. In some circumstances, it may be more important to send the data than have the correct timestamp. In such cases the data will be sent, but we ensure that the reliability of the timestamp is indicated in the message.

There are currently no guidelines for timestamp management in remote patient monitoring platforms that cover all conditions of working. This paper analyses the requirements and the operating scenarios of a remote patient monitoring platform and defines a framework to convey information on the conditions under which observations were made by the device and forwarded by the gateway. This will include reference to the internal time of the device and to local time and an underlying continuous reference timeline of the gateway in order for data to be managed appropriately. Furthermore, because the current definition of the HL7 timestamp does not differentiate between time local to GMT (+0000) or UTC or NTP time where no geographic time zone is implied (-0000), we propose an extension to handle these separate cases.[i]

An important requirement of the platform must be support for very simple devices that have only a simple or no clock. In these cases the timestamp of any observation must be translated by the gateway from the internal time of the device to provide a timestamp that is referenced to a single consistent and accurate time base. Universal Coordinated Time (UTC) is the preferred choice to facilitate accurate correlation and processing. Ideally the timestamps should also include the local time (as an offset from UTC) of the location where the observations were made to facilitate correlation with records maintained by the patient and caregivers. There is the further requirement that the observation should include information to convey the quality of the timestamp and how it was translated by the gateway. This was accomplished by including information on clock status and a coincident timestamp to provide the correlation between the respective clocks of the device and gateway. The proposals of this paper are being incorporated into the draft guidelines of the Personal Connected Health Alliance (formerly the Continua Health Alliance) [5]

II. GATEWAY OPERATING CONDITIONS AND TIMESTAMPS

The operating conditions that affect the clock and timestamps of the gateway are: synchronization with an external time source such as NTP; knowledge of local time (TZ); and knowledge of local Daylight Time Saving (DST) rules. Table 1 summarizes the six distinct modes of operation that arise from valid combinations of these conditions and must be supported and conveyed through the timestamp format and further information in the message.

TABLE I
GATEWAY OPERATING CONDITIONS

Mode	Gateway clock operating condition		
	UTC/NTP	**Local**	**DST**
A	Yes	Yes	Yes
B	Yes	Yes	No
C	Yes	No	No
D	No	Yes	No
E	No	Yes	Yes
F	No	No	No
*	Yes	No	Yes
*	No	No	Yes

Whenever local time and its offset to UTC is known (whether synchronized to UTC/NTP or not), then all timestamps for a gateway operating in one of these modes (A, B, D, E) will include the time offset in the form ±ZZZZ, where ±ZZZZ denotes the offset from UTC. If the gateway is only synchronized to UTC/NTP (by an external time source such as NTP) and the local time offset is unknown (mode C) then the gateway will include the time offset in the form -0000 to denote the timestamp is UTC. If the gateway is not synchronized to UTC and the local time offset is also unknown (mode F) then no time zone offset (TZ) is included. We refer to these forms of timestamp with and without the TZ as “qualified time” and “unqualified time” respectively.

We assume that if DST rules are known, local time must also be known, so that the final two modes are deemed invalid and map to the corresponding mode with local time known.

A. *Qualified Time*

A “qualified time” expresses a unique time point along the Coordinated Universal Time (UTC) timescale, which is the primary time standard by which the world regulates clocks and time.

Qualified time is expressed as an HL7 V2 “DTM” data type and must include the time zone offset, expressed either as ±ZZZZ (HHMM) if the civil time zone offset is known or -0000 if UTC time (e.g. derived from NTP) is known but the actual civil time zone offset is not. The full form of the HL7 timestamp is as follows.

YYYYMMDDHHMMSS[.S[S[S[S]]]]±ZZZZ
if civil time zone offset ±ZZZZ is known.
YYYYMMDDHHMMSS[.S[S[S[S]]]]-0000
if UTC time is known but civil time zone is not.

B. *Unqualified Local Time*

In Unqualified local time the time zone offset is omitted: the civil time zone offset and UTC time are both unknown.

YYYYMMDDHHMMSS[.S[S[S[S]]]]

The use of these timestamp formats for each operating mode is summarized in Table 2.

TABLE II
GATEWAY TIMESTAMP FOR OPERATING CONDITIONS

Mode	Gateway timestamp
	TZ
A	±ZZZZ
B	±ZZZZ
C	-0000
D	±ZZZZ
E	±ZZZZ
F	none

III. DEVICE OPERATING CONDITIONS AND TIMESTAMPS

Devices used in remote patient monitoring platforms have a variety of forms and capabilities of internal clock. This includes: time of day clock that is not synchronized; simple time of day clock (local time) that is synchronized; time of day clock (UTC and local time) that is synchronized; relative time clock (monotonic count); and no clock.

A. Clock Types

For the purposes of this paper we have adopted the definition of clock types from IEEE 11073-20601 [66]. This defines 4 types of clock:

1) Absolute Time

Conveys only local time information of the device, that is, it is the equivalent of unqualified local time and carries no information about the civil time zone offset or relationship with UTC. Although it is termed "absolute time", there is no requirement that it is synchronized with the local time of the user.

2) Base-offset Time

This is defined to have an underlying monotonic increasing count component that is the base time that may be aligned with UTC/NTP, together with an offset component that provides of an indication of the local time of the device with respect to the base time. Base-offset time is the equivalent of qualified time.

3) Relative Time

This is defined as an underlying monotonic increasing count that is of limited period and so will exhibit frequent rollover, typically in the period of days. Its count value is not relative to any external time source.

4) High Resolution Relative Time

This is defined as an underlying monotonic increasing count but has extended period and so will not normally rollover. Typical period is over 100 years. It provides greater resolution than relative time. Its count value is not relative to any external time source.

B. Store and Forward

Although primarily designed to support translation of timestamps of data transmitted in real time, the framework supports translation of timestamps of data that have been stored in a device for later transmission ("store and forward"). Generally there is no distinction; however clock changes occurring in the device and/or gateway require specific handling when data occurring before the clock change is sent.

1) Device changes Time

The IEEE 11073-20601 protocol provides for notification that the clock in a device has been changed and the effect that this has on the data stored before the clock change. This information may be used by the gateway to perform the correct translation of timestamps and to construct the appropriate coincident timestamp for each set of observations; before and after the time change.

2) Gateway changes Time

If the gateway changes time for DST but the device does not, then it is necessary for the gateway to determine and apply the correct translation that applies. This is accomplished by inspecting each timestamp to determine if before or after the DST change. This is only possible if the gateway has the rules for DST. If a gateway does not have DST rules (mode B), then the same translation will be applied to all timestamps irrespective.

Note that the coincident timestamp provides the information on the translation that has been applied to all timestamps in that OBR, and so the original device timestamp can always be reconstructed

C. Clock Status

Information on the status of the device and gateway clocks is essential to provide assurance on the reliability of the devices. We propose this may be provided through the HL7 OBX with CWE data type and can report the value of the respective time attribute for time status (synchronized or not), synchronization protocol and the NM data type for the accuracy (defined as cumulative clock drift) of the device clock. This is shown in the example of Figure 1.

```
OBX|2|CWE|68219^MDC_TIME_CAP_STATE^MDC|0.0.0.0|1^md
s-time-capab-sync-bo-time(12)~1^mds-time-state-bo-
time-synced(13)~mds-time-state-bo-time-UTC-
aligned(14)~ mds-time-dst-rules-enabled(15)|||||R
OBX|3|CWE|68220^MDC_TIME_SYNC_PROTOCOL^MDC|0.0.0.0|
532228^MDC_TIME_SYNC_SNTPV4330^MDC|||||R
OBX|4|NM|68221^MDC_TIME_SYNC_ACCURACY^MDC|0.0.0.0|1
.2|264320^MDC_DIM_SEC^MDC|||||R
```

Where

68219^MDC_TIME_CAP_STATE^MDC – denotes the time capability attribute of the gateway which is expressed as bit settings.

68220^MDC_TIME_SYNC_PROTOCOL^MDC – denotes the time synchronization protocol.

68221^MDC_TIME_SYNC_ACCURACY^MDC – denotes the cumulative clock error.

Fig. 1. Typical gateway clock status in HL7 OBX.

In the example of Figure 1 the gateway is synchronized to NTP and has acquired information so that it can implement correct DST rules. It is operating in mode A. A full list of nomenclature codes is available in [5].

D. Coincident Timestamp

In order to perform the timestamp translation, the gateway must determine the notion of internal time from the device and reference this against its own notion of time for a coincident time instant. The difference between these two time instants is applied to each observation timestamp to perform the translation of the timestamp from the device timeline to the gateway timeline. We refer to these two time instants as the coincident timestamp, and it is sent in every HL7 message when translation has been applied for reference and audit purposes. A receiver of any HL7 message is able to reconstruct the original timestamp of the device by subtraction. We propose a form of HL7 OBX that conveys this information where we use a “DTM observation” that includes the type of time format used by the device (using IEEE 11073 nomenclature [5]), placing the device notion of time as a timestamp in OBX5, and the coincident gateway notion of time in OBX14. Each is provided as a qualified time where possible, otherwise as unqualified time. Figure 2 provides an example of a coincident timestamp for a device with absolute time correct for local time (and thus unqualified) and with the gateway synchronized to GMT (and thus qualified).

```
OBX|5|DTM|67975^MDC_ATTR_TIME_ABS^MDC|1.0.0.0|20090
828123702||||||R|||20090828173702+0000
```

Where

DTM - denotes timestamp coincident observation

67973^MDC_ATTR_TIME_ABS^MDC - the type of time supported by the device given as the IEEE 11073 time attribute of the device [5].

1.0.0.0 - a reference to the device status object in the gateway.

20090828123702 - the notion of time of the device as unqualified time.

20090828173702+0000 - the coincident notion of time of the gateway in qualified time.

Fig. 2. Typical coincident timestamp in HL7 OBX.

IV. TIMESTAMP TRANSLATION

Consideration of the operating condition and form of clock of the device leads to 3 cases of timestamp translation that must be supported by the gateway.

A. Case 1: Gateway Translates Device Timestamps

1) Internal clock not synchronized

If a device has any type of internal clock that is not synchronized to an external time reference then the gateway must translate all incoming timestamps to its notion of time and provide a coincident timestamp pair and gateway time status.

2) Absolute time

Translation will be required for all timestamps that use absolute time irrespective of synchronization as, in addition to a time translation due to any difference in notions of time, an absolute timestamp will require translation to qualified time (local and UTC).

3) Relative time

If a device provides timestamps having relative or high resolution relative time; the gateway must translate incoming timestamps to its notion of time and provide a coincident timestamp pair and gateway time status.

B. Case 2: Gateway does not translate Device Timestamps

If a device has an internal clock that is synchronized to an external reference and the device provides qualified time (base-offset), then the gateway will have no need to translate the timestamp on behalf of the device. The form of the timestamp for the observation will depend on the current operating conditions of the device. No coincident timestamp is given and gateway time status is not required. Device time status is required.

C. Case 3: Gateway provides Timestamp on behalf of Device

If a device does not supply a timestamp with an observation then the gateway must provide a timestamp on behalf of the device. The form of the timestamp will depend on the current operating conditions of the gateway. No coincident timestamp is given, however gateway time status is given.

D. Coincident Timestamp Format

The coincident timestamp, with an example shown in Figure 2, is in the form of a HL7 OBX with the type of the time attribute in OBX-3 as one of IEEE 11073 nomenclature codes to denote the timestamp format as one of MDC_ATTR_TIME_{ABS,BO,REL,REL_HI_RES}[5]. The observed value in OBX-5 is the notion of time of the device and the coincident time of the gateway is in OBX-14.

The form of the coincident timestamp will depend on the translation and on the current operating conditions of the device and gateway. A summary of the form and requirement for status depending on case is given in Table 3.

TABLE III
COINCIDENT TIMESTAMP FORM AND TIME STATUS

Case	**AHD Action**	**Status**		**OBX-5**	**OBX-14**
		AHD	**Device**		
1	Translate device timestamps	**M**	**O**	*****	**T(*)**
2	Do not translate device timestamps	**O**	**M**	**X**	**X**
3	Provide timestamp on behalf of device	**M**	**O**	**X**	**X**

O – Optional
M – Mandatory
X – Not present
* — In original form of the device
T(*) – Translated form for coincident time in the gateway

In OBX-5 the * refers to the original timestamp format of the device and T(*) in OBX-14 refers to its coincident time in the gateway in qualified time format. When relative time is being used then OBX-18 may specify the unique identity of the time base being used to synchronize devices and gateway such as might be provided by BlueTooth^{TM}.

E. Device Timestamp Format

The format of device timestamps will depend on the device time type, the operating condition of the device and the operating condition of the gateway. The format of the translated timestamp is summarized in Table 4, where * refers to the original form of the device and T(*) refers to the

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translated timestamp.

TABLE IV
DEVICE TIMESTAMP FORMAT

Case	Device Timestamps		
	Absolute (no TZ)	**Base-Offset** (±TZ)	**Hi-res/ Relative**
A	T(*)±ZZZZ else *±ZZZZ	*±ZZZZ or T(*)±ZZZZ	T(*)±ZZZZ
B	T(*)±ZZZZ else *±ZZZZ	*±ZZZZ or T(*)±ZZZZ	T(*)±ZZZZ
C	T(*)-0000 else *-0000	*±ZZZZ or T(*)-0000	T(*)-0000
D	T(*)±ZZZZ else *±ZZZZ	*±ZZZZ or T(*)±ZZZZ	T(*)±ZZZZ
E	T(*)±ZZZZ else *±ZZZZ	*±ZZZZ or T(*)±ZZZZ	T(*)±ZZZZ
F	*	*±ZZZZ	T(*)

V. TIME SYNCHRONIZATION EXAMPLE

In this example (Fig 3) a blood pressure observation (systolic, diastolic, and mean arterial pressure) for a patient in Los Angeles taken at 09:10:05 on 8 Jan 2010 is sent from a PAN device which had an internal time of 18:08:26 1 Jan 1900 at 14:03:45 on 4 Jan 2010 (shown by the coincident timestamp on line 9). The gateway supports DST rules (denoted by the time capability information in line 4) and is synchronized by NTP (denoted by the synchronization protocol in line 5) and so is operating as mode A. The time of transmission from the gateway is given on line 1. The BP observation and its timestamp are given on in line 8, and the difference between the components of the coincident timestamp has been added to the original. The components of the BP are given in lines 10, 11 and 12. As the device is not synchronized to an external time reference, the gateway translates the timestamp for a device with absolute time (case 1). As the gateway is operating in mode A, a qualified timestamp is given in line 8.

```
1.  MSH|^~\&|AcmeInc^ACDE48234567ABCD^EUI-
    64||||20100108091010-
    0800||ORU^R01^ORU_R01|MSGID1234|P|2.6|||NE|AL||
    |||IHE PCD ORU-R01
    2006^HL7^2.16.840.1.113883.9.n.m^HL7
2.  PID|||789567^^^Imaginary
    Hospital^PI||Doe^John^Joseph^^^^L^A|||M
3.  OBR|1|AB12345^AcmeAHDInc^ACDE48234567ABCD^EUI-
    64|CD12345^AcmeAHDInc^ACDE48234567ABCD^EUI-
    64|182777000^monitoring of patient^SNOMED-
    CT|||20100108091005-0800
4.  OBX|2|CWE|68219^MDC_TIME_CAP_STATE^MDC|0.0.0.0|
    1^mds-time-capab-sync-bo-time(12)~1^mds-time-
    state-bo-time-synced(13)~mds-time-state-bo-
    time-UTC-aligned(14)~ mds-time-dst-rules-
    enabled(15)|||||R
5.  OBX|3|CWE|68220^MDC_TIME_SYNC_PROTOCOL^MDC|0.0.
    0.0|532228^MDC_TIME_SYNC_SNTPV4330^MDC|||||R
6.  OBX|4|NM|68221^MDC_TIME_SYNC_ACCURACY^MDC|0.0.0
    .0|1.2|264320^MDC_DIM_SEC^MDC|||||R
7.  OBX|5||528391^MDC_DEV_SPEC_PROFILE_BP^MDC|1||||
    |||X|||||||0123456789ABCDEF^EUI-64
8.  OBX|6||150020^MDC_PRESS_BLD_NONINV^MDC|1.0.1|||
    ||||X|||20100108091005-0800
9.  OBX|7|DTM|67975^MDC_ATTR_TIME_ABS^MDC|1.0.0.1|1
    9000101140345||||||R|||20100104140345-0800
10. OBX|8|NM|150021^MDC_PRESS_BLD_NONINV_SYS^MDC|1.
    0.1.1|120|266016^MDC_DIM_MMHG^MDC|||||R
11. OBX|9|NM|150022^MDC_PRESS_BLD_NONINV_DIA^MDC|1.
    0.1.2|80|266016^MDC_DIM_MMHG^MDC|||||R
12. OBX|10|NM|150023^MDC_PRESS_BLD_NONINV_MEAN^MDC|
    1.0.1.3|100|266016^MDC_DIM_MMHG^MDC|||||R
```

Fig. 3. Example time synchronization

VI. RESULTS

The framework has been developed, deployed and evaluated in two remote patient monitoring projects (inCasa and Reaction) over a period of two years. Purpose designed gateways based on the ZigBee Health Care Profile [6] for in home communication and embedded GPRS modules for WAN communication have been developed to implement all the features discussed in this paper. All devices implement the IEEE 11073-20601 protocol [5] and the gateway uses IHE-PCD01 [3] for the WAN interface and follows the Continua Alliance Design Guidelines.

In the early deployment we observed that the UK GSM networks provided network time update on every registration to the network and this was sufficient to provide reliable time to the gateway. GSM network time (NITZ) provides full information on local time, UTC and whether DST is in effect. It also provided regular updates so that the gateway would change in a timely manner with DST. However we then noticed that gateways were not sending correct timestamps for significant periods after initial power on and it was traced to UK GSM networks no longer providing network time update on registration. Investigation shows that this is also the case for European GSM networks. In response we implemented NTP on our gateways and use the mobile country code to determine the time zone and DST rules that must be applied. This approach works well for all countries that have a single time zone and has become our preferred method of setting the operating conditions as this allows us to operate as mode A.

In countries with more than one time zone, we have to rely on GSM network time updates, unless information is made

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available for correct time zone and DST to be set. This can include position information such as GPS or GSM cell location, but mapping this to time zone and DST rules is complex in countries such as USA. Alternatively the gateway may be pre-registered with the information, but this precludes relocation and simple deployment. However GSM network time updates do not provide information on DST rules, and the gateway must operate as mode B.

We have tested our gateway throughout the world to evaluate the approach. Our evaluation from testing in six European countries (UK, Germany, Slovenia, Sweden, Denmark and Belgium) confirms that European GSM networks do not provide GSM network time updates on registration and is an unreliable approach for time synchronization. Using NTP and the country code has proven reliable. However our evaluation of operating with GSM networks in the US and in Asia (Taiwan and Hong Kong) network time updates are provided on every registration.

Gateways using forms of communication other than GSM will need other sources of information to determine time zone and DST rules. This might include IP address, position information from GPS, local radio or pre-registration.

We encountered frequent problems when there were DST changes for devices having absolute time and that did not change their clock. Initially this was as a result of GSM not providing timely network time updates and there would be a limited period when we would observe incorrectly translated timestamps. We therefore implemented DST rules on the gateway to change its clock at the appropriate time and correct all incoming timestamps. However this left us with a problem with devices that could store observations and later send them if observations spanned a DST change. In our simplistic implementation, the current DST setting was applied to all incoming timestamps, including those before the DST change. These were then incorrect. In response, we added inspection of all incoming timestamps to determine their DST period and apply the appropriate translation.

We remain left with the problem of devices on which the user can set the time and has stored data. Although we can determine the current notion of time of the device and translate for incorrect setting of the time of the device, we cannot determine if the user should have changed the time for some measurements, such as when they have travelled to other time zones.

VII. CONCLUSION

We have developed a framework to provide robust and reliable management of timestamps in remote patient monitoring platforms. The framework provides high reliability of accurate timestamps when operating conditions allow, but supports ability to report the confidence of timestamps under other operating conditions. The platform supports the typical devices with simple clocks used in such monitoring platforms and can provide accurate qualified timestamps to the electronic patient record.

Evaluation of the platform has demonstrated validity of the framework under the many non-ideal operating conditions when deployed with real patients.

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[7] http://zigbee.org/Standards/ZigBeeHealthCare/Overview.aspx.

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[i] Coordinated Universal Time (UTC) is the primary time standard by which the world regulates clocks and time. It is one of several closely related successors to Greenwich Mean Time (GMT). The Network Time Protocol (NTP) is used on the public Internet and local area networks to synchronize participating computers to within a few milliseconds of Coordinated Universal Time (UTC) after an adjustment for leap seconds is made.