Research and Application of Multipath Network Time Service System

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Abstract. The time source of this paper is based on Shanghai Laboratory of National Time-Frequency Measurement Center. The target of this paper is to build a multipath network timing system within the wide area network which could make sure the accuracy, reliability and safety of network time service. This Multipath Network Time Service System also playing an influential role in providing dedicated network time services for seconds-level time-demanding industries. The pharmacological analysis of the medical industry is used as a service demonstration case to verify and promote the application of the multi-path network timing system.

1. Introduction

With the prosperity of the electronic engineering and Internet, high-precision time services, such as electronic commerce and electronic government, have become more and more strict on the time synchronization of the entire society.

In the pharmaceutical industry, time is a key parameter for hospitals during the process of medical consultations and pharmacological analysis. Inaccurate time will directly affect life safety and cause medical dispute. For example, the time between EEG and ECG is not synchronized, which leads to medical dispute that cause the death time of patients to be unidentified, which is getting more and more attention[1].

In the field of traffic and public security law enforcement, timing-related equipment such as highway speed measurement, traffic intersection monitoring and timing equipment, and public security department illegal evidence collection equipment need to control the accuracy of time synchronization within seconds. Taking Shanghai’s vehicle restrictions as an example, the Shanghai Transportation Commission stipulates that foreign-branded vehicles cannot enter the restricted area from 7 am to 10 am on working days. If the time of the surveillance cameras at the intersection is inaccurate or unreliable, legal disputes will result.

At present, there are four main methods for time synchronization in various industries:

(1) The first type is synchronized to the GPS system time, because the GPS system time cannot be traced to the source and has no national legal status.

(2) The second type is synchronized with the network time server. Since the time source of the network time server is selected from the Internet, the source of time cannot be determined, which leads to the possibility of unstable and unreliable time sources and no guarantee.

(3) The third type is synchronized to the CDMA clock. The CDMA clock is susceptible to electromagnetic interference, there are signal interruptions, and the time source may be unstable and unreliable.

(4) The fourth type is the internal crystal holding time of the clocks. The oscillators of these clocks
work in a free-running state without proofreading. Because the four time synchronization methods are different, the time source is unreliable and has no legal status, and the synchronization accuracy also varies widely, resulting in inconsistent time in various industries. Realizing high-precision time synchronization in network systems of various industries is a very important issue.

Based on NTP protocol, this paper designed network time transfer technology and security scheme, which could remotely transmit standard time signals to industries that need time service through the WAN. Considering the impact of network fluctuating and network attacking on network timing services and deeply analyzing the factors affecting the uncertainty of synchronization accuracy in a network environment, this paper design data filtering and clock correction models to optimize transmission delay and time deviation in the network.

In this paper, a multi-path network timing system is established within the WAN. Based on the current traditional on-site metrology and calibration, modern communication technology and big data calculations are used as auxiliary tools to achieve remote source tracing. Under the influence, pass standard time to industries that need high-precision time synchronization.

2. Analysis of the status of similar research at home and abroad

2.1 Research Status of Network Time Protocol

Network Time Protocol, or NTP for short, is a widely used time synchronization protocol in the Internet[2]. It was first proposed by Professor D.L. Mills of the University of Delaware in 1985, and was designed and implemented. The purpose is to synchronize the clock between the local computer and the clock source to improve the accuracy of the local time so that different machines on the Internet can maintain a uniform, standard time[3]. The system assigns accurate and reliable time information[4].

2.2 Application Status of Network Time Synchronization Technology

At present, countries around the world use atomic clocks to generate and maintain standard time and provide time services to various industries. For example, the US Navy Observatory not only provides time service for the US Navy, but also cooperates with other agencies to provide time service for the United States and the international community[5]. The National Time and Frequency Measurement Center (NIM, Chinese Academy of Metrology) and the National Time Service Center (NTSC) of the Chinese Academy of Sciences serve as time laboratories for China's participation in the International Atomic Time Cooperation. They provide time services to society by providing IP addresses of time servers. Table 1 lists the IP addresses of mainstream NTP time servers at home and abroad[6].

| Unit name                              | NTP time server IP address |
|----------------------------------------|---------------------------|
| NIST                                   | 132.163.4.101             |
| Microsoft Corporation                  | 131.107.1.10              |
| Fukuoka University                     | 133.100.11.8              |
| National Time and Frequency Measurement Center | 220.231.55.106          |
| National Time Service Center, Chinese Academy of Sciences | 210.72.145.44          |

3. Network Time Protocol Research

3.1 Implementation model

The implementation model of the network time protocol is composed of four processes: sending, receiving, updating, and local clock, and a network for message passing, as shown in Figure 1[7].
Figure 1. basic implementation model

The sending process is triggered periodically by a timer. After triggering, the sending process first collects information about the sending destination server and sends the NTP packets to the destination server. The NTP message sent includes the timestamp when the message was sent, the server's timestamp on the day of the last reception, and other necessary information about the hierarchy and connection[8].

The receiving process is responsible for receiving incoming NTP messages and can directly connect to other precise time sources through the interface. After the NTP message arrives, the receiving process calculates the time offset between the local clock and the reference time source and other information used to calculate the error and select a time server[9].

The update process then processes the time offset of the clock and selects the best quality time reference source from all the time reference sources.

The local clock process uses the time offset obtained by the update process to adjust the frequency and phase of the local clock, that is, by gradually adjusting the phase, the offset of the local clock is gradually reduced to zero. In this way, the local clock can also be used as a stable time reference source for other clocks.

3.2 system structure

It can be seen from Figure 1 that the basic architecture of the network time protocol is divided into the following parts (as shown in Figure 2):

1. Time server
2. Server interface module
3. System processing module
4. Clock correction module

Figure 2. NTP System structure
In the network time protocol, a time server is required as a reference source. After receiving the NTP message sent by the server interface module of the client, the time server fills in the local time in the NTP message and returns it to the server interface module of the client. The server interface module is responsible for interacting with the time server and processing the received NTP messages to obtain information about the quality of the time server and provide this information to the system processing module.

Based on the information provided by the server interface module, the system processing module selects the best time server or set of time servers as the actual synchronization information source, and obtains the most accurate time information based on the information provided by these servers, and then this information is passed to the clock correction module. The clock correction module corrects the clock according to the time offset calculated by the system processing module.

3.3 Message format and its significance

The NTP protocol is an application layer protocol based on the IP and UDP protocols. In fact, NTP messages are transmitted as data of UDP messages. Table 2 shows the message format of the NTP protocol[26-28].

| Table 2. NTP message format. |
|-----------------------------|
| 2 5 8 12 24 32bit            |
| LI VN Mode Stratum Poll Precision |
| Root Delay                  |
| Root Dispersion             |
| Reference Identifier        |
| Reference Timestamp(64)     |
| Originate Timestamp(64)     |
| Receive Timestamp(64)       |
| Transmit Timestamp(64)      |
| Key Identifier(optional)(32)|
| Message digest(optional)(128)|

LI: Jump indicator, warning of approaching second (last second) inserted at the last moment of the last day of the month.
VN: version number.
Mode: Mode. This field includes the following values: 0-reserved; 1-symmetric behavior; 3-client; 4-server; 5-broadcast; 6-NTP control information.
Stratum: Overall identification of the local clock level.
Poll: A signed integer indicates the maximum interval between consecutive messages.
Precision: A signed integer indicates the accuracy of the local clock.
Root Delay: Signed fixed point sequence number indicates the total delay of the main reference source, a segmentation point between 15 and 16 in a short time.
Root Dispersion: The unsigned fixed point sequence number indicates the segmentation point between bits 15 and 16 within a short time relative to the normal error of the main reference source.
Reference Identifier: Identifies a particular reference source.
Originate Timestamp: This is the time to request the server to detach the client, in 64-bit Timestamp format.
Receive Timestamp: This is the time it takes for the server to reach the client in 64-bit Timestamp format.
Transmit Timestamp: This is the time to reply to the client to detach the server, in 64-bit Timestamp format.
Authenticator (Optional): When the NTP authentication mode is implemented, the primary identifier and message number fields include the defined message authentication code (MAC) information.
Message meaning:
Leap Indicator (LI)
A 2-digit code used to indicate whether a leap second should be inserted or deleted during the last minute of the day, as shown in Table 3.

| Code | significance                      |
|------|-----------------------------------|
| 00   | Normal                            |
| 01   | 61 seconds in the last minute     |
| 10   | 59 seconds in the last minute     |
| 11   | Warning (clock is not synchronized) |

Version Number (VN)
A three-digit number representing the NTP / SNTP version number: a value of 3 indicates version 3.

Mode
A three-digit number representing the mode, as shown in Table 4.

| Code | significance                      |
|------|-----------------------------------|
| 0    | Unspecified mode                  |
| 1    | Active symmetric mode             |
| 2    | Passive symmetry mode             |
| 3    | Client mode                       |
| 4    | Server mode                       |
| 5    | Broadcast mode                    |
| 6    | Reserved for NTP control messages|
| 7    | Reserved for private use          |

Stratum
The eight-digit level of the local clock, as shown in Table 5.

| Code meaning | Code meaning                          |
|--------------|---------------------------------------|
| 0 not specified | 0 not specified                       |
| 1 1 primary reference source (such as an atomic clock) | 1 1 primary reference source (such as an atomic clock) |
| 2-255 times reference source (via NTP) | 2-255 times reference source (via NTP) |

Poll Interval
An eight-bit signed number representing the maximum interval between two adjacent messages. If the value is n, the specified interval is 2 times. For example, if the value is 6, the minimum interval is 64 seconds. The value of this field can be an integer between 4 (16 seconds) and 14 (16284 seconds). However, most applications use integers between 6 (64 seconds) and 10 (1024 seconds).

Precision
An eight-bit signed number representing the precision of the local clock. A value of n means that the precision is about n times. The value of this field is a number from -6 to -20.

Root Delay
A 32-bit signed fixed-point number representing the total round-trip delay to the primary reference source. The decimal point is between 15 and 16 digits. Note that both positive and negative values are possible. This value may be negative, depending on the accuracy and drift of the clock.

Root Dispersion
A 32-bit unsigned fixed-point number representing the address error relative to the reference source. The decimal point is between 15 and 16. This value is generally a value greater than 0.

Reference Identifier
A 32-bit string identifying a specific reference source. When Stratum is 0 (unspecified) or 1 (main reference source), this is a left-justified 4-character ASCII string. When Stratum is 2 or greater, this is the 32-bit IPv4 address of the reference source.
4. Establishment of multi-path timing system

4.1 Timing plan and system composition

The network timing system consists of hardware and software (as shown in Figure 3), where the software part includes server software and client software.

![Figure 3. Frame diagram of network timing system](image)

The key to a hardware system is stability, and the key to a software system is real-time, immediacy, accuracy, and security.

The server software includes five parts: serial data processing, local clock update, time data processing, request reception and response sending. The serial data processing part is used to communicate with the external time source through the serial port and the network time server to obtain the external time source. The local clock update part updates the local clock of the network time server according to the standard time data from an external time source. The time data processing part processes the time data based on the network time protocol. The request receiving part is used to receive the user equipment. The time-of-day request for response is used to send standard time information to the user equipment.

Compared with the server, the software design of the client is more complicated. The client's main responsibility is to send NTP messages to the server, request time, and calculate the returned NTP messages. Each returned message contains four time stamps, and the time deviation and network delay are calculated based on the four time stamps. Each synchronization process requires multiple NTP message exchanges. Each time a group of network delays and clock deviations can be obtained. The client uses a filtering algorithm to select the most accurate one from multiple groups of network delays and clock deviations. Synchronize the local clock.

5. Major software design algorithms

5.1 Calculation of network delay and time deviation

The synchronization device in the network synchronizes the synchronization device clock with the standard clock by sending and receiving time-stamped data packets.

The time synchronization process of the NTP protocol is divided into an offset measurement phase and a delay measurement phase. The NTP protocol is based on UDP and defines four types of clock messages: synchronization message Sync, delay request message Delay_Req, follow-up message Follow_Up, and delay request response message Delay_Resp. The algorithm analyzes the clock message data of the NTP protocol to obtain the network delay and time deviation data.
5.2 Network latency threshold analysis

After the network timing system is set up, repeat experiments are performed to statistically analyze the round-trip network delays of at least 10,000 time correction requests. For occasional large network delays, the network delay threshold should be set in the program, that is, when the network delay exceeds the threshold, the time packet is discarded, and the time correction request is resent, so as to ensure the accuracy of the time correction.

5.3 Data filtering and clock correction algorithm design

The data filtering algorithm is mainly responsible for filtering the calculated network delay and time deviation, and then selecting the best set of data from multiple sets of data to correct the clock of the client based on mathematical statistics. The function of this algorithm is to confirm the validity of the data packet and select the best sample from the time samples of a given time reference source. It can be divided into two parts: sanity check and filtering. Soundness mainly refers to whether the data is unique and whether the relevant communication parameters are reasonable. Filtering mainly refers to calculating the current network delay and time deviation according to the current four timestamps, and updating the register array.

The clock correction algorithm is mainly responsible for correcting the system clock, which greatly affects the accuracy of the local clock adjustment. This algorithm uses two methods, linear phase adjustment and nonlinear phase adjustment, to adjust the clock. Linear adjustment refers to gradually adjusting the clock to achieve the effect of "fine adjustment", which makes the system clock monotonically increase. The non-linear adjustment is to directly compensate the time offset calculated by various algorithms to the system clock. This method is more suitable for the situation where the clock offset is large.

6. Application of Time Service in Medical Industry

Based on the second-level time synchronization requirements of a hospital, this project conducts a network time service experiment within the WAN range, passing standard network time to a time card in the hospital. The test time is synchronized every ten minutes, and the test is 24 hours. The network delay and time deviation test results are shown in Figure.4 and Figure.5.

![Figure 4](image1.png)

**Fig.4**

![Figure 5](image2.png)

**Fig.5**
After calculation, the average network delay of the client is 42.4ms, the experimental standard deviation of the network delay is 8.4ms, the average time deviation is 43.1ms, the experimental standard deviation of the time deviation is 8.6ms, and the synchronization accuracy is 63.6ms. Experimental data shows that there is no large jitter in the time deviation, and the network timing system has good accuracy and stability, which meets the design requirements.

7. Summary
The network time service in this paper is an important research direction in the field of high-precision time applications, and major industries have time synchronization requirements. The financial industry needs unified real-time timing services to further ensure the security of financial data; the power industry urgently needs to achieve time uniformity across the entire network, and the current power system requires time synchronization requirements to reach the microsecond level; the next-generation telecommunications network requires time synchronization Hundreds of nanoseconds; the time synchronization requirements of deformation monitoring, precision agriculture, and urban safety management have reached nanoseconds or even higher; transportation service centers, oil and gas pipeline control centers, and air traffic management systems In online monitoring, it is more necessary to achieve safe, reliable and highly accurate time synchronization. The research in this paper will accumulate experience for subsequent research on time synchronization technology, so as to further provide accurate time service for the above industries and achieve time unification.

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