A Timing Accuracy Assessment System Prototype for Multiple NTP Servers

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Abstract – **Time synchronization is a critical aspect of modern IT systems. The Network Time Protocol (NTP) plays a crucial role in maintaining consistent and accurate time across digital infrastructure worldwide. NTP is aligned with digital metrology vision, enabling precise timekeeping through the remote correction of clocks. National Metrology Institutes (NMIs) around the world, the custodians of national time standards, play a pivotal role in disseminating accurate time information through NTP services. Multiple NTP servers are generally considered for redundancy and load distribution. To maintain this ecosystem, it is crucial to ensure the timing accuracy and reliability of all the NTP servers. This work presents a system prototype for ensuring timing accuracy of multiple NTP severs. The prototype has been developed considering self-developed Python program for collecting and processing NTP data along with a Grafana based visualization dashboard for timing accuracy assessment. The system may be useful in detecting and isolating faulty NTP servers. The system may be enhanced with Machine Learning based early anomaly detection and alerting mechanisms. The work may be useful for developing application specific customized dashboards for different metrological systems.**

I. INTRODUCTION

With the rise of time-sensitive and innovative applications, precise timing has become more critical than ever before. Clocks are perhaps among the early instruments to corrected remotely with the exchange of timing messages rather than physical artifacts. Remote correction allows a clock to stay on-site and in operation while its performance is monitored in parallel and any deviations from nominal behavior are detected and corrected. In coordination with the International Bureau of Weights and Measures (BIPM), National Metrology Institutes (NMIs) across the globe plays a pivotal role in global timekeeping and time synchronization [1]. Various modern domains such as IT systems, Cyber-Physical Systems (including the Internet of Things), and Industry 4.0 require timing accuracy ranging from milliseconds to microseconds [1-3]. Multiple methods exist to achieve time synchronization and ensure traceability to a recognized time reference, e.g., Network Time Protocol (NTP) [4]; Precision Time Protocol (PTP); White rabbit; All in view global navigational satellite system (AVGNSS); Common view global navigational satellite system (CVGNSS) and two-way satellite time and frequency transfer (TWSTFT) [1-3].

Network Time Protocol (NTP) is one of the most widely used technologies for global time synchronization, which maintains system clocks on various devices on network/Internet with an accuracy within 100 milliseconds [1]. NTP servers help in coordinating/maintaining the system time of networked computers/devices in agreement with UTC. NTP service providers, like NMIs across the globe, consider multiple NTP servers for redundancy and NTP load distribution. The behavior of the internal clocks on NTP servers can be dynamic in comparison to the highly stable clocks preferred in metrology. Monitoring is a crucial aspect of IT systems for maintaining the reliability, performance, and security. It leads to improved efficiency and reduces downtime/costs. Monitoring timing accuracy is a highly specialized area to ensure all time providing systems within a network maintain precise and synchronized time, often to the level of milliseconds or microseconds. Unlike general IT monitoring, which focuses on performance indicators like CPU usage, memory consumption, etc., the timing accuracy monitoring targets specific metrics such as time offset and delay.

This paper presents an open source technologies based timing accuracy assessment system prototype for multiple NTP servers. It may be very useful for NMIs and other entities hosting multiple NTP servers. The system considers open-source, platform-independent technologies, which makes it easy to replicate and customize for an application specific environment. The concept may be helpful for developing similar systems for other metrological domains.

The paper is organized as follows. Section II introduces timing accuracy assessment aspects of Network Time Protocol. This section also covers relevant literature. Section III presents the methodology and architecture of the system. The functional system prototype and future
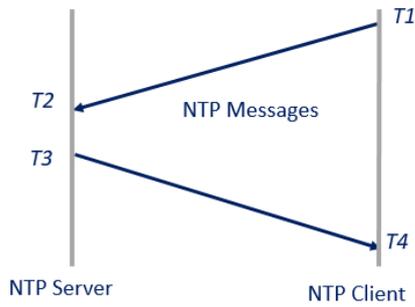
Fig. 1. NTP message exchange.

plans are discussed in Section IV. Section V concludes the paper.

II. TIMING ACCURACY ASSESSMENT FOR NETWORK TIME SYNCHRONIZATION

The time synchronization in NTP is based on four timestamps (*Fig.1*). At time *T1* (Originate Time) a client sends an NTP request to an NTP server, which is received by the NTP server at *T2* (Receive Time). The server sends a reply at *T3* (Transmit Time), which is received by the client at time *T4*. The time offset (*θ*) and round trip delay (*Δ*) are calculated as

$$\theta = 1/2 * [(T2-T1) + (T3-T4)] \qquad (1)$$

$$\Delta = (T4-T1) - (T3-T2) \qquad (2)$$

A client device can correct its clock based on the offset value (*θ*) with respect to the reference NTP server. NTP operates through a hierarchical structure, with Stratum-1 servers at the top. These servers obtain their time from highly accurate time sources, such as atomic clocks or Global Navigation Satellite Systems (GNSS) like Global Positioning System (GPS) receivers, which are typically traceable to Coordinated Universal Time (UTC). This traceability enables consistent synchronization of system clocks across networked devices. Lower-level NTP servers (with higher stratum values) receive accurate time from upper-level NTP servers (with lower stratum values). The stratum-1 NTP servers, which are hosted at NMIs, like NPL India (NPLI), take time references (generally 1 pulse per second signal) directly from their atomic time scale and hence provide the UTC traceable time over the network/Internet within 100 milliseconds accuracy.

NMIs across the globe are working on timing accuracy assessment for NTP services for end customers. National Research Council (NRC), Canada monitors NTP servers and document their traceability for traceability related client requests [5]. The Real Instituto y Observatorio de la Armada (ROA) considers NTP service calibration assessment over a Local Area Network based on data acquired from NTP server files [6]. A study considers python based program for offline performance analysis of six public NTP services based on manually collected NTP data from two distant locations [7]. Lombardi et al. [8] presented a system under SIM Time and Frequency Metrology Working Group for comparisons of NTP servers located in different regions. The system considers
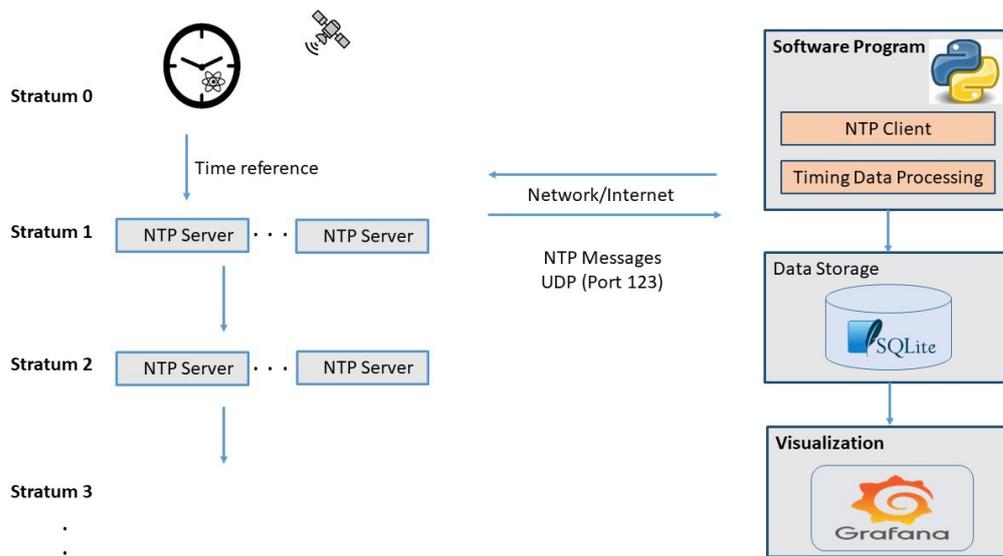

Fig. 2. System Architecture.

a 100 ns resolution clock board, synchronized to time reference via a 1 PPS signal with compensated delay. It compares NTP timestamps using both direct and common-view methods, and publishes the accuracy results of NTP servers on a website. Although proprietary tools are also available for NTP monitoring and other time and frequency metrology applications, open-source solutions offer greater transparency and customization flexibility, making them well-suited for NMIs. For instance, the Open Traceable Time Platform is an open-source timing system based on GNSS time transfer [9].The timing accuracy assessment of NTP servers is an important requirement and open source technologies based solution may be explored in this area.

III. METHODOLOGY

The system architecture of presented system prototype is shown in Fig.2. The developed system considers a python based program, which uses ntplib library for NTP messages exchange with multiple NTP servers. The key information is extracted from the NTP packets, processed and stored in a database. The NTP message exchange process is repeated periodically in rounds after few minutes interval to get the latest information. The NTP messages received from all the NTP servers under observation in a particular round are processed. The mean value of time offset values of all the servers for a particular round is calculated and relative offset values for each server is calculated with respect to the calculated mean value for the round. Median value may also be considered

instead of mean value for each round. It is assumed that the client device clock remains stable and does not deviate/drift significantly within a round due to its internal clock variation. The data is currently stored in SQLite database and the functionality has been tested with PostgreSQL database also.

Grafana Open Source Software [10] is considered for data visualization. Grafana Open Source Software is a versatile visualization and monitoring platform with multi-platform compatibility and support for variety of data sources like SQL, NoSQL and time series databases like Prometheus and CloudWatch. It helps in creating real-time dashboards to showcase data through insightful graphs and visualizations helpful in monitoring, alerting and system behavior analysis. Grafana Enterprise is a commercial edition with additional features and support. Multiple dashboards are created based on customized SQL queries on database connectivity.

IV. RESULTS AND DISCUSSION

The system prototype including the python program, the database and the Grafana dashboard (Fig. 2) are deployed on a computer on Local Area Network. The NTP client requests are generated from this computer to the NTP servers hosted in a secured zone. The NTP information is processed and stored in the database, where the Grafana software can fetch the latest information from the database. Grafana dashboards can be accessed using any web browser from any computer on the network with the IP address of the hosting computer.
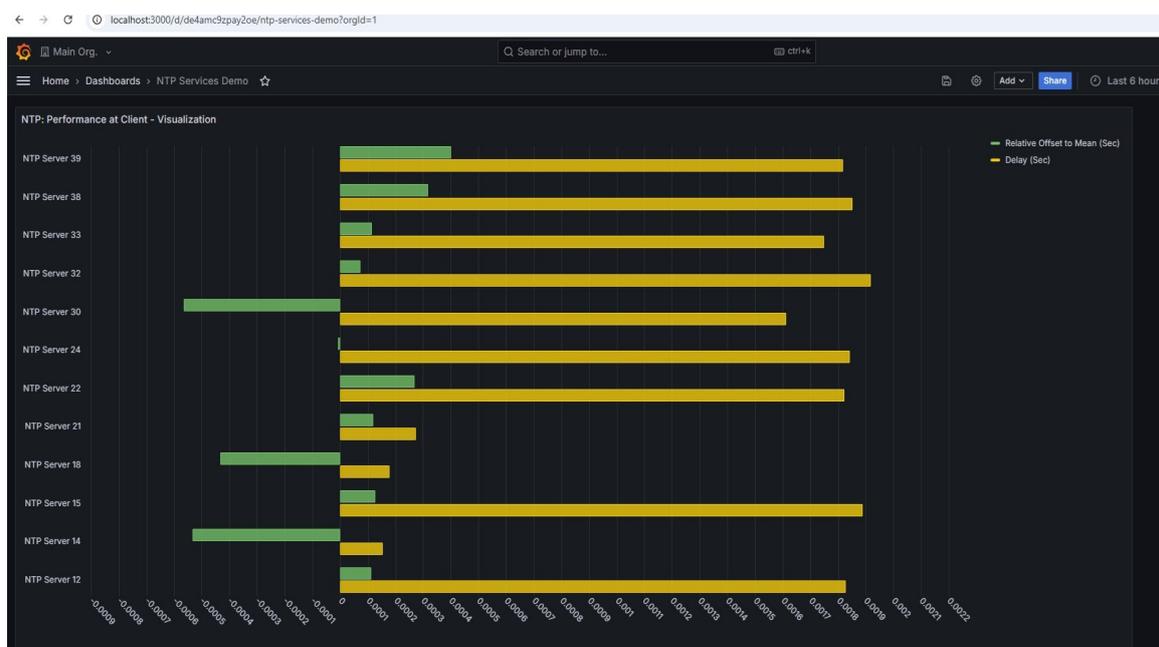

Fig. 3. Latest relative Offset and Delay values based on NTP message exchange

Fig. 4. Offset and Delay values based on NTP message exchange.

The dashboard shown in Fig.3 visualizes the latest values of relative offset of each NTP server with respect to the mean offset value of all the servers as observed by the NTP client based on NTP message exchange. The NTP message exchange round trip delay for each server is also shown, as a higher round trip delay may lead to higher measurement uncertainty. The image shows that the relative offsets values for all the servers are within 1 millisecond and the round trip delay values are within 2 millisecond. It shows that all the servers are available for NTP packet exchange and providing correct time to the end client. The dashboard shown in Fig. 4 visualizes server specific timestamped relative offset to mean and the delay values based on NTP message exchange in a tabular form. This allows behavior analysis and finding anomalies considering the information for longer time duration. The delay variation gives insights about the network performance also.

The work is planned to be enhanced with customized dashboards, alerting mechanisms and machine learning based insights.

V. CONCLUSION

Network Time Protocol is one of the most widely used technologies for time synchronization over networks/Internet. NMIs and other entities generally consider multiples NTP servers for redundancy and handling larger number of NTP requests. Monitoring of such systems requires specialized tools for ensuring timing accuracy integrity and early detection and removal of any malfunctioning NTP server. An open-source customizable solution is presented based on a python software and Grafana based dashboards. The python based software generates NTP requests to the multiple NTP servers, collects the responses, processes the data and stores in a database. Grafana dashboards are created, which fetch the data based on queries for requirement-specific visualization. The performance of system prototype is found satisfactory. The system may be further enhanced with additional customized dashboards and alert generation. Machine Learning techniques can be considered for finding anomalies and discovering hidden patterns and trends in the collected data. The system may be customized for verity of other metrological applications.

REFERENCES

[1] D. K. Aswal, "Metrology for inclusive growth of India" Springer Nature, 2020, doi: 10.1007/978-981-15-8872-3.

[2] Sharma, D., Yadav, D., Vattikonda, B., Agarwal, A. (2024). Timing Accuracy for Internet of Things and Industry 4.0 Applications: Technologies and Research Trends. In: Yadav, S., Garg, N., Aggarwal, S.G., Jaiswal, S.K., Kumar, H., Achanta, V.G. (eds) Recent Advances in Metrology. AdMet 2022. Lecture Notes in Mechanical Engineering. Springer, Singapore.

[3] M. Lévesque and D. Tipper, "A survey of clock synchronization over packet-switched networks,"

IEEE Communications Surveys & Tutorials, vol. 18, pp. 2926-2947, 2016.

[4] D. Mills, J. Martin, J. Burbank, and W. Kasch. 2010. RFC 5905: Network Time Protocol Version 4: Protocol and Algorithms Specification. RFC Editor, USA.

[5] Douglas, Rob, André Charbonneau, and Marina Gertsvolf. "Remote calibration of time from NTP servers." Metrologia 55, no. 6 (2018): 855.

[6] Vélez, Carmen, Javier Díaz, Alfonso Osuna, Héctor Álvarez-Martínez, and Héctor Esteban. "Assessment of an NTP service calibration over a Local Area Network." Measurement Science and Technology 35, no. 6 (2024): 065013.

[7] F. F. A, A. Agarwal, D. Sharma, D. S. Yadav and S. M. R, "Time Synchronization Performance Analysis based on NTP Data Captured from Two Distant Locations," 2025 International Conference on Innovation in Computing and Engineering (ICE), Greater Noida, India, 2025, pp. 1-6, doi: 10.1109/ICE63309.2025.10984309.

[8] Lombardi, Michael A., Judah Levine, J. Mauricio Lopez, Francisco Jimenez, John Bernard, Marina Gertsvolf, Harold Sanchez et al. "International comparisons of network time protocol servers." In Proceedings of the 46th annual precise time and time interval systems and applications meeting, pp. 57-66. 2014.

[9] M. J. Wouters, E. L. Marais, A. S. Gupta, A. S. bin Omar and P. Phoonthong, "The Open Traceable Time Platform : Open Source Software and Hardware for Dissemination of Traceable Time and Frequency," 2019 Joint Conference of the IEEE International Frequency Control Symposium and European Frequency and Time Forum (EFTF/IFC), Orlando, FL, USA, 2019, pp. 1-2, doi: 10.1109/FCS.2019.8856026.

[10] Grafana OSS and Enterprise, Available: https://grafana.com/docs/grafana/latest/?pg=oss-graf&plcmt=hero-btn-2#grafana-oss-and-enterprise