Demo Abstract: Natural Timestamping Using Electrical Power Grid

Sreejaya Viswanathan
Advanced Digital Sciences Center
Illinois at Singapore
1 Fusionopolis Way
#08-10 Connexis North Tower
Singapore 138632
sreejaya.v@adsc.com.sg

Yang Li
Advanced Digital Sciences Center
Illinois at Singapore
1 Fusionopolis Way
#08-10 Connexis North Tower
Singapore 138632
yang.li@adsc.com.sg

Rui Tan
Computer Science and Engineering
Nanyang Technological University
N4-02C-85
50 Nanyang Avenue
Singapore 639798
tanrui@ntu.edu.sg

ABSTRACT

The continuous fluctuation of electric network frequency (ENF) presents a fingerprint indicative of time, which we call *natural timestamp*. This live demo demonstrates the accuracy of the natural timestamps obtained by four wired voltage sensors and four wireless electromagnetic radiation (EMR) sensors that are geographically distributed in Singapore. The voltage sensors and the EMR sensors capture the minute fluctuations of the length of each voltage cycle and the average ENF over every 50 voltage cycles, respectively. The evaluation in our prior studies [1, 3] has shown that the natural timestamps recorded by the voltage sensors and the EMR sensors give sub-millisecond and sub-second average time errors, respectively. This demo will also show their time errors.

CCS CONCEPTS

•Computer systems organization →Sensor networks; *Dependable and fault-tolerant systems and networks;*

KEYWORDS

Timestamping, sensor networks, power grid

ACM Reference format:
Sreejaya Viswanathan, Yang Li, and Rui Tan. 2016. Demo Abstract: Natural Timestamping Using Electrical Power Grid. In *Proceedings of The 16th ACM/IEEE International Conference on Information Processing in Sensor Networks, Pittsburgh, PA USA, April 2017 (IPSN 2017),* 2 pages.
DOI: http://dx.doi.org/10.1145/3055031.3055039

1 INTRODUCTION

In the era of Internet of Things (IoT), we have witnessed the proliferation of networked sensors and smart devices embedded in civil and industrial infrastructures. For all these systems, having a *common notion of time* (CNoT) among nodes is a fundamental and critical requirement. Accurate timestamps are crucial for interpreting data and associating data from different sensors; synchronized clocks enable punctual and well coordinated operations among the nodes. On the other hand, wrong timestamps and clock desynchronization may lead to system chaos and failures. Thus, resilient CNoT against underperformance of clock synchronization protocols and even system failures (e.g., hardware faults and network outages) is important for diverse IoT systems. To this end, we study a novel *natural timestamping* approach. In general, a natural timestamp is a finite-length signal sampled from the environment that yields a unique form during any given sampling time. In other words, the signal form "encodes" when it is sampled. In the case of system failures where the nodes cannot synchronize their clocks to the Coordinated Universal Time (UTC), the natural timestamps can be used to recover the UTC time information of sensor data and system logs in an offline analysis.

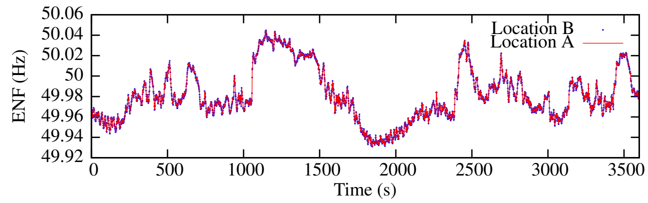

Figure 1: Per-second ENF measured at two locations 12 km **apart in Singapore [1].**

In our prior studies [1, 3], we have extensively studied the existence of natural timestamps in the electric network frequency (ENF) of an alternating current (ac) power grid. Two properties of ENF make it indicative of time. First, at any given time instant, the ENF is almost identical across all locations within a geographical region. Second, the load of a power grid is a random process and as a result, the ENF, although regulated by a centralized control system, is also a random process. These two properties can be illustrated by our ENF traces collected at two locations 12 km apart in Singapore [1], as shown in Fig. 1. The random ENF fluctuations around the nominal value (50 or 60 Hz) over time contain natural timestamps. Specifically, it is possible to match a short segment of ENF trace collected at a location against a long ENF trace collected at the other location. The best match point indicates a common time instant for the two nodes. As a power grid pervades almost all civil infrastructures in an urban geographic area, ENF natural timestamping is promising for establishing reliable time for IoT systems in these environments.

In this live demo, we will demonstrate the time accuracy of the real-time natural timestamps obtained by four wired voltage sensors and four wireless electromagnetic radiation (EMR) sensors

IPSN 2017, Pittsburgh, PA USA

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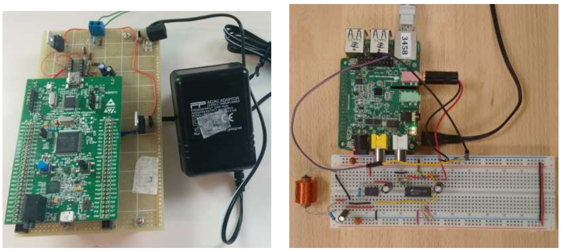

(a) Voltage sensor. (b) EMR sensor.

Figure 2: Natural timestamping sensors.

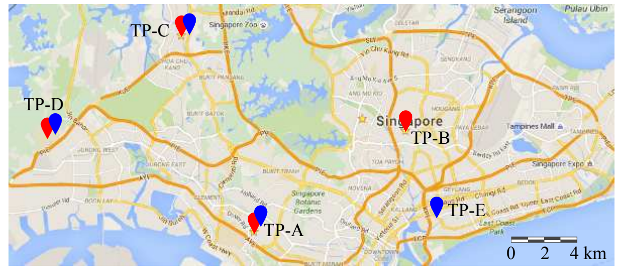

Figure 3: Sensor deployment. Red and blue markers represent voltage and EMR sensors.

that are geographically distributed in Singapore. The voltage sensor and the EMR sensor capture the minute fluctuations of the length of each voltage cycle and the average ENF over every 50 voltage cycles, respectively. Each sensor streams its natural timestamps through Internet to a central master node that uses a wired voltage sensor to continuously record the length of each voltage cycle. The master node "decodes" each received natural timestamp into UTC time [1, 3] and presents via a graphical user interface the error of the decoded time with respect to the ground-truth time recorded by the natural timestamping sensor. The extensive evaluation in our prior studies [1, 3] has shown that the voltage sensors and the EMR sensors give sub-millisecond and sub-second average time errors, respectively.

2 THE SYSTEM AND DEMO

Fig. 2(a) shows the voltage sensor prototype. It consists of an ac/ac voltage adapter, a signal processing circuit that converts the sine ac voltage to a square wave with its edges corresponding to the zero crossings of the sine wave. The voltage sensor's MCU uses its hardware timer to measure the time duration between any two consecutive rising edges of the square wave (i.e., the length of a voltage cycle) with a resolution of $0.12\,\mu s$. A natural timestamp consists of the lengths of multiple voltage cycles. Fig. 2(b) shows the EMR sensor prototype. It consists of an LC antenna and a two-stage signal amplification circuit. A Raspberry Pi single-board computer samples the amplified EMR signal using an audio card, filters the signal using a software IIR band-pass filter, and measures the average ENF over every 50 voltage cycles. A natural timestamp consists of multiple ENF readings. The clocks of the voltage and EMR sensors are synchronized to UTC via on-board GPS receivers or NTP, and used to add ground-truth time information to the natural timestamps for evaluation purpose. Fig. 3 shows the deployment of four voltage sensors and four EMR sensors in Singapore. These sensors send the natural timestamps to a central master node through Internet. Note that the central master node is located at testpoint TP-A, which is not shown in the figure.

The central master node uses three voltage sensors to continuously record the voltage cycle lengths of the three power grid phases (R, G, and B) and adds UTC timestamps using its clock that is synchronized to UTC using a GPS receiver. Upon receiving a natural timestamp, the master node identifies the power grid phase that the source voltage/EMR sensor sensed and decodes the natural timestamp (i.e., estimates its sample time) by matching the natural timestamp against the historical trace of the voltage cycle lengths in the same power grid phase captured by the master node. More details of the power grid phase identification and natural timestamp decoding algorithms can be found in [1, 3].

The demo will present a web interface [2] to show the real-time natural timestamps captured by the deployed voltage and EMR sensors shown in Figure 3, and the errors of the decoded times with respect to the ground-truth times recorded by the source sensors.

The ENF natural timestamps can be used to develop various applications with unprecedented features. The performance of existing message-passing-based clock synchronization protocols (e.g., NTP) is susceptible to packet transmission delays. Using ENF natural timestamps, in [3], we developed a new clock synchronization protocol that is immune to packet transmission delays. In [1], we presented the use of natural timestamps for the offline recovery of the global time of critical sensor data and system logs during system outages, as well as run-time integrity verification of IoT nodes' clocks.

3 CONCLUSION

This demo demonstrates a novel natural timestamping approach based on the electric power grid that was studied in our prior research [1, 3]. We believe this approach is promising for enhancing the resilience of CNoT among the IoT nodes distributed in the civil infrastructures in a geographical region that is served by the same power grid.

4 ACKNOWLEDGMENTS

This research was funded in part by the Energy Innovation Research Programme (EIRP, Award No. NRF2014EWTEIRP002-026), administered by the Energy Market Authority (EMA), in part by a Start-up grant at Nanyang Technological University. The EIRP is a competitive grant call initiative driven by the Energy Innovation Programme Office, and funded by the National Research Foundation (NRF).

REFERENCES

[1] Yang Li, Rui Tan, and David Yau. 2017. Natural Timestamps in Powerline Electromagnetic Radiation: Validation and Applications. In *IPSN*.
[2] Sreejaya Viswanathan, Yang Li, and Rui Tan. 2017. Grid frequency based time synchronization. (2017). http://popseco.org/sync/live.
[3] Sreejaya Viswanathan, Rui Tan, and David Yau. 2016. Exploiting Power Grid for Accurate and Secure Clock Synchronization in Industrial IoT. In *RTSS*.