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Precision Time Synchronization Using NB-IoT for Locating Pipe Bursts in Freshwater Networks

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Summary:
Much effort has been put into developing algorithms for locating pipe bursts in freshwater networks. Such algorithms typically require a precision time-synchronization of all participating sensor nodes. The performance and efficiency of tight clock synchronization using Narrowband IoT (NB-IoT) has thereby rarely been characterized. The present work addresses this research gap by evaluating time-synchronization using NB-IoT enabled sensors. Multiple experiments showed that a relative time precision of 10 ms across the network compared to GNSS can be expected using a custom approach.

Keywords: Time-synchronization protocols, TSP, Internet of Things (IoT), NB-IoT, Burst detection

Background Motivation

Freshwater is vital for the survival of life on Earth, and water scarcity continues to be a major issue in various parts of the world. Apart from a proper water management in areas with high water stress, as proposed by Margolis et al. [1], it is also important to use advanced technological solutions to detect and locate pipe bursts. Much effort has been put into developing algorithms for accurately locating pipe bursts [2] [3]. These algorithms, however, require a precision time-synchronization to operate properly. It is generally accepted that relative timestamping is crucial in detecting the precise location of a burst. As the propagation speed of pressure waves in a pipe network is often greater than 1000 m/s, a timing difference of 1 ms between two sensor-nodes can already result in localization inaccuracy of 1 m. Due to reduced bandwidth and power availability, low power wide area networks (LPWANs) pose new challenges to synchronizing clocks. The present paper evaluates how time-synchronization can be performed using cellular NB-IoT radio technologies within a constrained industrial environment.

Problem Statement

Aside from naturally drifting clocks, synchronization of time via distributed networks is complicated by the fact that the propagation time of messages sent to synchronize them depends on several factors, such as down- and uplink as well as network buffering. This implies that IoT devices must be re-synchronized on a frequent basis to adapt time quickly and maintain a constant small offset. Both goals, however, contradict the desire to save energy as each synchronization is expensive in terms of power and data consumption. The question of how well state-of-the-art time synchronization protocols perform within constrained low-power NB-IoT networks arises.

Literature

In recent years, numerous protocols for time synchronization have been developed for a wide range of different transport media and application purposes. Tab 1 gives an overview of some of the most widely used protocols today. These protocols can be categorized in two signaling schemes: two-way message exchange and one-way message exchange [4]. The two-way message exchange approach is widespread and used on various transmission media. However, no information regarding time-synchronization over NB-IoT is found in literature.

Tab. 1: Overview of State-of-the-art time-synchronization protocols. PTP and SPoT need special hardware. Accuracy over internet as stated in [4] [5.]

Protocol	Accuracy	Example of use
NTP	~ 50 ms	Computer
SNTP	< NTP	Smartphones
PTP	sub-ms	Industry
SPoT	~ 10 ms	LoRaWAN IoT
Time	seconds	Computer

Schema:	One-Way	Two-Way

Other signaling schemas, such as Receiver-only and Receiver-receiver are not covered in this paper as they rely on a node-to-node communication which is not feasible in a cellular network structure.

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Methodology

The presented results have undergone empirical analysis using quantitative techniques. The experiments were conducted with four SODAQ SFF N310 sensor-nodes in two distinct locations over multiple days. The SODAQ SFF N310 uses a SAMD21 µController and a u-blox SARA N310 communication module. A Raspberry Pi 3 is used as a ground-truth timeserver at another distinct place. The timeserver uses a GNSS satellite module to discipline its internal real-time clock with the Coordinated Universal Time (UTC) within ns precision. A custom application is installed on the Raspberry Pi 3 to discipline the time of each sensor-node with UTC accordingly. Because state-of-the-art protocols such as PTP and SPoT require special hardware, they are ineligible for the use with the available hardware. Furthermore, the high precision accuracy and low-power demand required by the burst detection algorithm would not be met by using NTP or SNTP; thus, a custom time-synchronization protocol (TSP) was developed. The accuracy of synchronization was measured using the time set by the built-in GNSS module and the PPS signal of each sensor-node.

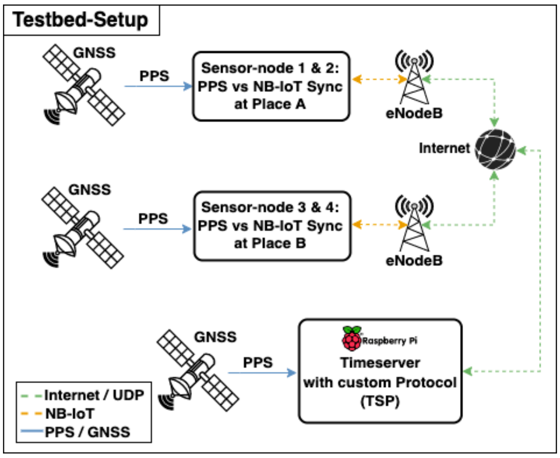

Fig. 1. The testbed consists of four exemplary sensor-nodes and a timeserver. Each node uses its own GNSS reference as ground-truth.

Solution

TSP is based on a two-way message exchange using unsolicited result codes of the u-blox communication module which enables the sensor-node to send a follow-up message with a corrected time, reflecting the real time upon transmission and reception. Using this approach, the synchronization accuracy can be increased towards ms precision. TSP yields optimal results when the delays between the sensor-node and timeserver are symmetric. TSP therefore tries to find those messages where the highest symmetry is available. This is accomplished using a custom bias-criteria algorithm that employs an estimation of the signal roundtrip time (RTT) in the NB-IoT cellular network infrastructure. Additionally, checking the NB-IoT signal quality has proven crucial in our tests. Reference Signal Received Power (RSRP) values better than -90 dBm turned out to be well suited.

Measurements and Conclusion

While excellent signal quality and bias-criteria are considered, a relative synchronization performance of 10 ms between all four sensor-nodes was found to be feasible in our test, as can be seen in Fig. 2. However, the origin of the roughly 50 ms systematic error remains unknown, and additional testing is advised. It was found out that RSRP values below -90 dBm result in significant asymmetries between the up- and downlink, to the point where reasonable ms-timing is no longer possible. This leads to the conclusion that under ideal conditions, burst detection algorithms employing NB-IoT and TSP are at least capable of detecting bursts within a radius of approximately 10 m. One advantage over existing GNSS-based time-synchronization is the fact that no additional GPS device with line-of-sight to satellites is required, allowing for easier installations in indoor and underground settings.

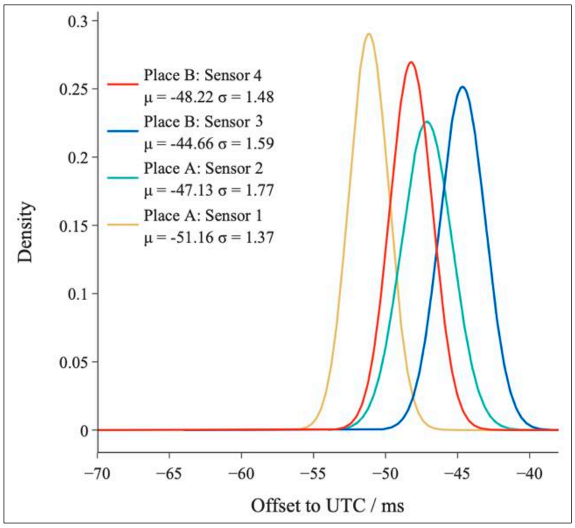

Fig. 2. Test-Result (Indoor) Relative synchronization accuracy using TSP in a NB-IoT cellular network structure.

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