On the Evaluation of Clock Synchronization Methods for Networked Control Systems

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***Abstract*—A distribute control requires to maintain time synchronization to the degree of precision depending on a particular application domain. Many large distributed systems employ Ethernet or even full TCP/IP stack for communication. Two prevalent protocols are used for clock synchronization in these networks, in particular, Network Time Protocol (NTP) and Precise Time Protocol (PTP).**

In this short paper, we present a method for practical performance evaluation of clock synchronization within a distributed environment consisting of nodes running a commodity real-time operating system. The results of measurement provide us a hint on the degree of synchronization that can be practically achieved among the set of distributed devices. The main contribution of this paper is to provide a simple method for practical evaluation of synchronization methods for a distributed control system and presenting some preliminary data from the measurement. A complete result set may be used, e.g., for defining a performance estimation functions in a platform-based design approach to networked control systems.

Keywords-Networked control system (NCS); time synchronization; real-time operating environment; NTP; PTP

I. Introduction

Embedded systems or networked control systems must obey strict real-time constraints. Depending on the application domain, these constraints are hardened by requiring fast response time and high degree of real-time synchronization. For smaller systems the message-based approach [1] is sufficient as the propagation delay is small and can be tolerated. In systems consisting of hundreds or thousands of components the communication latency become an issue. Decoupling synchronization from data communication offers a possibility to scale real-time control systems. A required degree of synchronization is achieved by introducing a clock synchronization protocol in the control network, which maintains accuracy of real-time clocks of individual components.

In this paper, we provide a description of preliminary results of work-in-progress that aims at experimental evaluation of the accuracy of real-time information in a networked control environment consisting of nodes running QNX real-time operating system. We consider network communication latency, synchronization, and jitter of scheduled and executed time to develop a simulation model usable for analysis of various system configurations. For the experiments, we based the clock adjustment method on the use of Precision Time Protocol [2], which represents a standardized method of time synchronization in industrial networks.

II. A Method and Preliminary Results

A measuring environment consists of a single master node providing a source of the precise time signal. All other nodes are clients that are synchronized to this master node. Depending on a scenario, there are other devices on paths among these devices. These intermediate devices represent network components, e.g., switches and routers, that may have a significant impact on clock synchronization. An example of the measuring environment is shown in Figure 1.

The organization of the environment reflects the goal of intended experiments, which means to observe the impact of different network topologies, devices and traffic patterns on the precision of clock synchronization and hence on the accuracy of a common time base [3]. This not only needs to consider a precision of clock synchronization protocols but also RTOS characteristics and limitations.

Both master and slave stations run QNX real-time operating system which is extended with the PTPD implementation[1]. The precision with which the real-time clock information can be accessed in software running RTOS depends on the time granularity (tick) provided by its kernel. For instance, the standard tick in QNX system occurs every

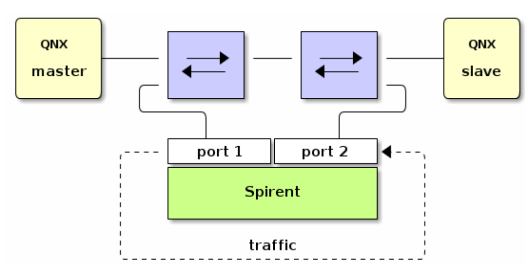
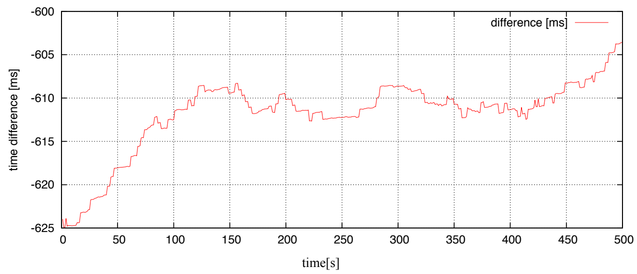
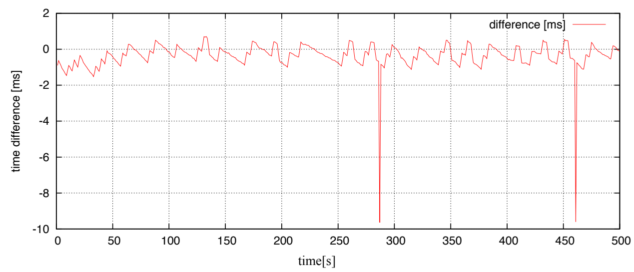


Figure 1. An example of the measuring topology.
The impact of load of network devices and end-systems was considered during measurement. The traffic generator (Spirent) was used to create different load in the network. In this topology, there are two L2 switches on the path between master and slave stations.

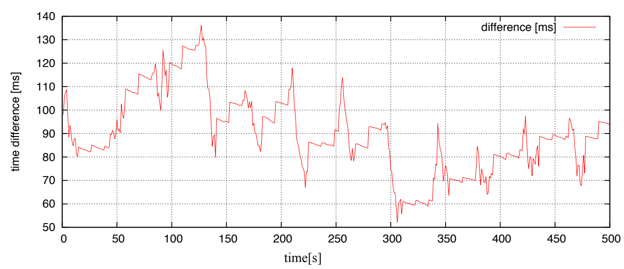
[1] The QNX port of PTPd is based on PTPD implementation available from http://ptpd.sourceforge.net.



a. without clock synchronization



b. with PTP enabled



c. with PTP and high network and CPU load (near 100%)

Figure 2. A jitter of simultaneously generated events.
Without clock synchronization the clocks diverge as shown in 2a. If PTP is employed, it is possible to reach precision as shown in 2b. In 2c, there is shown how high network and CPU load could harm clock synchronization.

1ms. Depending on the tick resolution and if considering system-wide clock synchronization it may be possible to synchronize various events and actions across the boundaries of the system up to the resolution of the common base time. To simplify the measuring we consider that events are represented by digital signals sent out through serial links to the dedicated measuring device. This device records their differences with a high degree of accuracy. We can then read the jitter of these synchronized events. This jitter consists of several contributing components:

- **clock offset** - an offset between master and slave clocks, which reflects the imprecision of synchronization protocol,
- **interrupt latency** - the latency related to kernel time needed to process interrupt internally and call the users's interrupt routine code,
- **scheduling latency** - the delay that stands for the blocking time during which the event processing thread waits for CPU allocation,
- **processing latency** - the delay that represents time required for software and hardware to generate the output signal.

Generally, it is considered that accuracy of NTP synchronization protocol is in the order of milliseconds, while PTP protocol can reach sub-microsecond accuracy. However, we need to count for the time resolution of operating system which limits accuracy in the order of tens of microseconds. This fact is also supported by information from the documentation [4], which reads that a usual interrupt latency is in the order of microseconds and thus it is difficult to reach better precision using standard approach based on OS timers in a multitasking environment.

To gain a hint on reachable performance we conducted a number of experiments with two QNX nodes running on industrial computers. These experiments gave as the first estimation of bounds for time deviation of synchronized events. The results for scenarios without clock synchronization and with PTP clock synchronization considering different CPU and network loads are provided in Figure 2. As can be seen from these preliminary results, using a commodity HW and RTOS the reachable time base precision is in the order of milliseconds considering that we can avoid excessive network and CPU load.

IV. Conclusions

In this paper we presented preliminary results of work-in-progress aimed at quantification of time accuracy in networked control systems employing time synchronization protocols. We have presented a measuring method and demonstrated the issue from the practical perspective considering QNX real-time operating system. Currently, we are working toward exhaustive experimental evaluation of environment for various parameters in order to provide a reliable data source for performance estimation. The aim is to create a comprehensive set of models to support rigorous design methods for networked control systems.

Acknowledgment

The present work was supported by projects CEZ MČMT MSM0021630528 “Security-Oriented Research in IT”, TAČR TA01010632 “SCADA system for control and monitoring RT processes”, and FIT-S-11-1 “Advanced secured, reliable and adaptive IT”.

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