Synchronous Task Scheduling for Cyber-Physical Systems

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***Abstract*—Time synchronization plays a critical role in determining the reliability and predictability of distributed cyber-physical systems. In this work, we demonstrate a distributed synchronous scheduling technique for time-coordinated distributed systems. The demonstrated technique provides user-level applications the ability to synchronously schedule tasks that can coordinate based on a shared notion of time without any explicit inter-process communication.**

I. Introduction

Accurate and reliable knowledge of time is fundamental to Cyber-Physical Systems (CPS) for sensing, control, performance, and energy-efficient integration of computing and communications [1]. System designers often over-provision resources due to timing uncertainties which leads to systems that are complex, inefficient, and fragile [1]. At the core of our approach is a holistic measure called "Quality of Time" (QoT) that captures metrics including resolution, accuracy, and stability.

Cyber-physical systems depend on precise knowledge of time to infer location, control communication and accurately coordinate activities [1]. Given the diversity of semantics used to describe time, the quality of time varies as we move up and down the system stack. Hence, maintaining a common notion of time presents a particular fundamental challenge in emerging applications of cyber-physical systems. In this demonstration, we lay the basis for a Quality of Time framework for cyber-physical systems.

The time synchronization domain is currently dominated by two principal techniques: (1) Networked Time Protocol (NTP) [2] and (2) Precision Time Protocol (PTP) [3]. NTP synchronizes even on a planetary scale, where all computers connected to a network can be theoretically synchronized to within a few milliseconds. On the other hand, PTP is used to synchronize computers on a local network, and achieves accuracy on the order of microseconds to nanoseconds. This level of accuracy is achieved through hardware timestamping at the network interfaces.

In this work, we demonstrate a prototype software architecture for a distributed cyber-physical system, which enables tasks executing on different machines to be scheduled based on a global notion of time. We demonstrate our technique on a testbench consisting of multiple Beaglebone Black (BBB) [4] nodes connected over Ethernet.

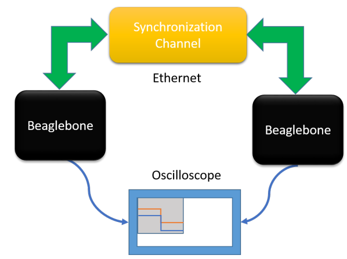

Fig. 1. Experimental Setup

II. Distributed Scheduling

In this section, we describe a distributed scheduling scheme built on top of a Linux-based system. Tasks can attach themselves to a global timeline that is shared across a network and are then able to execute synchronously by using `wait_until()` and `wait_until_next_period()` system calls. Our scheme eliminates the need for complex user-initiated synchronization among different components of a distributed cyber-physical system. Each timeline captures the notion of "Quality of Time" required by all of its tasks which can be used to optimize how and when the nodes synchronize.

III. Demonstration Overview

Our system consists of the following components:

- Multiple Beaglebone Black nodes connected over Ethernet,
- A PTP router, and
- A digital oscilloscope to visualize the accuracy of the synchronization.

In the demonstration, we will show an application running on each of the synchronized Beaglebone nodes, that toggles a local I/O pin. Using a basic layer of our QoT API, we show that all the applications are able to seamlessly subscribe to a common notion of time. The proposed experimental setup is shown in Figure 1.

References

[1] *Revolutionizing how we keep track of time in cyber-physical systems*, NSF Press Release, June 2014
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[4] G. Coley, *Beaglebone Black System Reference Manual*, April 2013