CPS Week 2013 Tutorial

Atacama: An Open Research Platform for Mixed-Criticality Real-time Switched Ethernet

Gonzalo Carvajal, Sebastian Fischmeister
University of Waterloo, Canada

Abstract: Switched Ethernet is an attractive technology to replace legacy fieldbuses in real-time distributed embedded applications. However, since Ethernet uses competitive media access to maximize throughput, even high-end Ethernet solutions have high jitter and are thus unfit for hard real-time applications without special adaptations. Although a few solutions for Real-Time Ethernet (RTE) present real implementations, they provide limited support for multi-switch topologies and are closed to the research community.

This tutorial introduces Atacama, the first fully-implemented, hardware-accelerated, open-source RTE solution with seamless support for mixed-criticality traffic on multi-segmented topologies. Atacama is fully open source and available for researchers to modify and build upon. Detailed descriptions of the hardware modules and configuration tools are available. The tutorial will provide hands-on experience with actual prototypes based on FPGA technology and investigate future networking configurations for real-time applications on top of the open framework.

Overview: As the size and complexity of real-time distributed systems grows to incorporate many processing elements and even whole Local Area Networks (LANs), Ethernet raises as an attractive technology to overcome the limitations of legacy fieldbuses. However, standard Ethernet is intrinsically unable to provide hard latency guarantees required for safety-critical tasks. A lot of different approaches for RTE solutions have appeared during the last years, mainly focused on the investigation of real-time properties of Ethernet and proposals for possible enhancements to the standard and components. In general, the literature shows that communication of hard real-time traffic over Ethernet is only possible by enhancing the network components with hardware support for coordinated communication. Despite the amount of related literature, only a few solutions report implemented prototypes and experimental validation, and they present limitations such as being closed for the research community, or limited support for multi-segmented networking with mixed-critical traffic.

This tutorial will introduce Atacama, an open hardware-based research platform for real-time communication in multi-segmented Ethernet networks. A typical network setup contains a mix of real-time and best-effort stations connected through multiple switches. Real-time stations use enhanced network interfaces executing pre-programmed TDMA schedules to coordinate the exchange of safety-critical data. Best-effort stations communicate transparently using COTS interfaces without modifications. The switches separate real-time from best-effort traffic, and use independent forwarding paths for each class. Real-time traffic receives strict priority access to the switch ports, and its delivery is guaranteed to happen within a bounded delay. The switches also perform on-the-fly frame processing tasks to implement logical real-time segments, and automatic discovery and reconfiguration of the paths between real-time stations.

The amount of related literature, the proliferation of some commercial solutions, and the ongoing efforts in the area provide clear evidence that real-time communication over Ethernet is an important and unsolved problem. This tutorial will allow the attendees to CPS week to take a close look to the available technology, know their advantages and limitations from direct experimentation with implemented prototypes, and get the necessary background to spark discussions, expand, and build networking solutions for next-generation distributed systems on top of the open source framework.

Preliminary Outline

- Overview of the Ethernet protocol, its limitations for real-time communication, and existing RTE approaches.
- Introduction to Network Code and state-based communication
- Technology aspects of the framework
    - The Network Code ASIP that coordinates communication at the end-stations
    - The dedicated real-time path inside the switches
    - Implementation, prototyping platform, and configuration tools
- Experimental characterization of communication latency and jitter between real-time stations
- Evaluation of a practical case study and experiments with hardware
- Open Discussion

Profile of the intended audience: The tutorial is intended to academic researchers, students, industry participants, and in general anyone interested on understanding and having first-hand experience on the ongoing efforts and open problems on next-generation networking technologies for modern distributed systems. The attendees are expected to have a basic understanding of real-time and safety-critical systems, and networking technologies. Some basic understanding of FPGA technology would also be useful.

Organizers

Gonzalo Carvajal received the Electronics Engineering and the M.Sc. degrees from the University of Concepción, Chile, in 2006 and 2009, respectively. He is currently a Ph.D. candidate in Electrical Engineering at the same institution, in collaboration with the ESG at the University of Waterloo, working on the evaluation and implementation of prototypes for next-generation real-time communication networks.

Sebastian Fischmeister is an Assistant Professor in the Department of Electrical and Computer Engineering at the University of Waterloo, Canada. He received his MASc in Computer Science at the Vienna University of Technology, Austria, and his Ph.D. degree at the University of Salzburg, Austria. He worked as a research associate at the University of Pennsylvania, USA, until 2008, and is currently the head of the Embedded Software Group (ESG) at the University of Waterloo. His preferred application areas are distributed embedded real-time systems in the automotive systems and medical devices domains.

References

The experimental Atacama framework is part of the research on real-time communication over Ethernet networks performed at the Embedded Software Group at University of Waterloo. Further documentation and application examples are available at https://uwaterloo.ca/embedded-software-group/projects/distributed-real-time-systems-ethernet .

Contact Information

Embedded Software Group
Department of Electrical and Computer Engineering
University of Waterloo
Waterloo, Ontario N2L 3G1, Canada
Tel: +1-519-888-4567 x 33694
Email: sfischme@uwaterloo.ca, gcarvaja@udec.cl