Achievement #2: End-to-End Guarantees

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The ability to coordinate distributed sensors and actuators in a timely fashion is key to meeting the dependability requirements of mission-critical cyber-physical systems, including industrial automation and control. However, fundamental end-to-end guarantees, such as the delivery of messages in a well-defined order or within hard real-time deadlines, were thought to be "extremely difficult" or "impossible"[1] across embedded wireless networks due to their scale, unpredictable dynamics, and resource constraints.

[1] John Stankovic, Tarek Abdelzaher, Chenyang Lu, Lui Sha, and Jennifer Hou. Real-time communication and coordination in embedded sensor networks. *Proceedings of the IEEE*, 2003

We solved these long-standing research problems by leveraging the abstraction of a wireless bus (see Achievement #1) to provide real-time and virtual-synchrony guarantees, as shown in Figure 1. On top of these fundamental end-to-end guarantees, we also demonstrated for the first time closed-loop stability guarantees across wireless mesh networks for fast physical systems, such as mechanical systems with dynamics of tens of milliseconds found in industrial settings. In addition to formal proofs, we validated our designs on real experimental cyber-physical systems (see Figure 2).

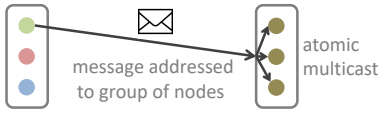

Figure 1: Virtual synchrony guarantees that all nodes in a group (*i*) see nodes joining or leaving and (*ii*) receive the same messages in identical order.

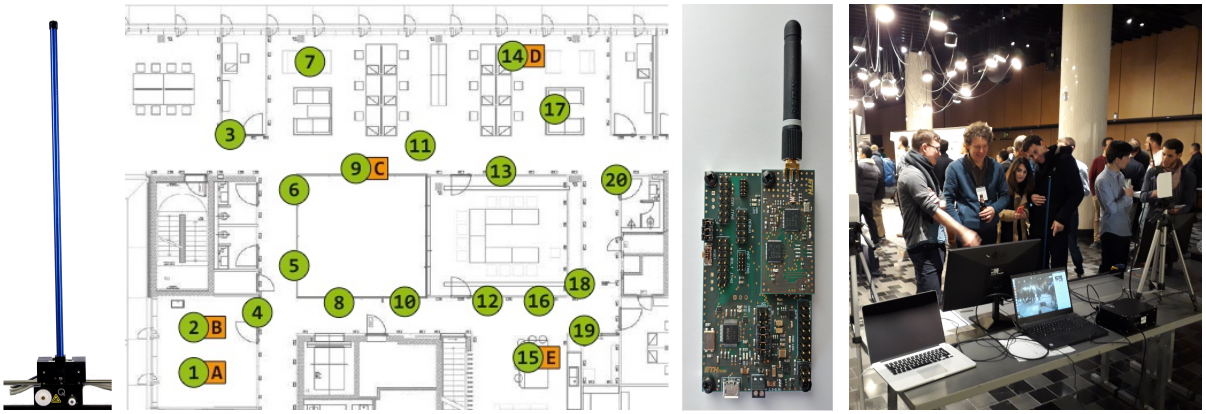

Figure 2: Experiments included the remote stabilization of multiple inverted pendulums (A–E), see also this video.

Academic and Real-World Impact

Our contributions on pushing the dependability of embedded wireless systems have appeared at top-tier conferences and journals of multiple communities (distributed, real-time, and cyber-physical systems). They were recognized with the ICCPS Best Paper Award, the IPSN Best Demo Award (video), and several prizes for my PhD thesis including the ACM SIGBED Paul Caspi Memorial Dissertation Award. Our research on closed-loop stability guarantees also won the Future Prize of the Ewald Marquardt Foundation recognizing "its potential for innovation and industrial applications."

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PIEEE'21
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