On Performance Metrics for Guaranteed QoS in Industrial Networked Embedded Sensing & Control Systems: Systems issues, Challenges and Needs

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Modern control systems play a critical role in the nation's critical energy infrastructure. For example, the economically efficient delivery of highly reliable electric power is increasingly dependent on networked SCADA (Supervisory Control and Data Acquisition System) and distributed control systems operating over commercially available, and frequently IP based, communication technologies. It is not uncommon to see control loops closed over a link comprised of more than one communication medium, such as a mix of fiber optic, twisted pair Ethernet, and RS-232 serial busses. The increasing attractiveness of wireless sensor networks, which can significantly reduce wiring costs in large networks, for these large systems poses an even more challenging control problem than that exists in systems today. The presidential committee of advisors on science and technology stated that "industrial wireless sensors can improve efficiency by 10% and cut emissions by more than 25%". However, the savings are achieved if they are deployed in large quantities. The inherent unpredictability of wireless networks coupled with their integration into legacy systems makes the networked-control problem particularly challenging. For example, 4% jitter in the process control loop can cause the PID controller to become unstable. This tolerance is about 1% for model-based, multi-variable and feed forward control loops, but the ability of a wireless network to support this type of quality of service cannot always be guaranteed. Over the past decade "networked-sensing" has been adopted fairly widely onto the industrial plant floor with standardized automation protocols like field bus, can bus etc. Increasingly "networked-control" is being adapted on the plant floor due to advances in communication and network technology.

New control schemes, modeling frameworks, design methodologies and communication protocols, are needed for the newly emerging class of systems commonly called "Networked Embedded Control Systems (NECS)". In many occasions the NECS are integrated as an upgrade to legacy systems which makes it a "systems of systems" problem with varying technological timeline for sub-systems. The dynamics of such systems are determined by the interaction of discrete-control and continuous-physical subsystems. Working examples of such hybrid systems can be found in such diverse applications as oil & natural gas, automotive control, manufacturing processes, and nation's critical infrastructure like the electric power grid. Among the current challenges the primary one is the limited ability to be able to measure the performance of the NECS in real-time. The networks in the internet context are purely data-oriented and they are different from the NECS in the industrial context that they are tied to physical systems (oil, natural gas, generators etc). This interconnection with physical systems brings a whole new dimension of network reliability, QoS, and fault-tolerance requirements. Also identified in the US DOE report on the "Roadmap to Secure Control Systems in the Energy Sector" is the cyber-security vulnerability of these increasingly interconnected systems.

The design of stabilizing controllers operating over networks with predictable behavior, including time delays and jitter, is a problem that has been studied for the past 30 years. The new problem is in characterizing communication systems, modeling current generation hybrid systems, and applying the results to design tightly-coupled adaptive networked control systems that increase reliability and fault-tolerance. Communication channels may be described by their impulse or frequency response, and therefore may be viewed as dynamical systems in their own right. The assumption that the communication mechanism can be characterized independently of the controller is fundamentally flawed.

As the industry is adapting these new-generation NECS there is an inherent need to develop:

- Performance metrics – Latency, Throughput, Reliability, Security, Adaptability, and Fragility
- Online network health monitoring
- Hybrid systems-of-systems modeling and simulation tools,
- Communication network characterization

We intend to present the problems of the NECS from the industrial end-user and OEM perspectives. A non-orthogonal set of performance metrics will be discussed to assist in easy adaptation of these new systems with guaranteed QoS in an industrial setting. As always standards drive economics, adaptation, and innovation. We will present the ISA SP100, Wireless for Industrial Automation*, efforts in addressing the fundamental issues in hybrid physical systems.

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* ISA SP100 – Wireless for Industrial Automation is a standard involving 190 companies around the world including major oil, gas, power, instrumentation, and manufacturing companies. Wayne Manges is the co-chair for the standards effort.