Engineering Research Center for

Reconfigurable Manufacturing Systems

Towards Factory-wide Time Synchronization for Diagnostics, Control and Safety

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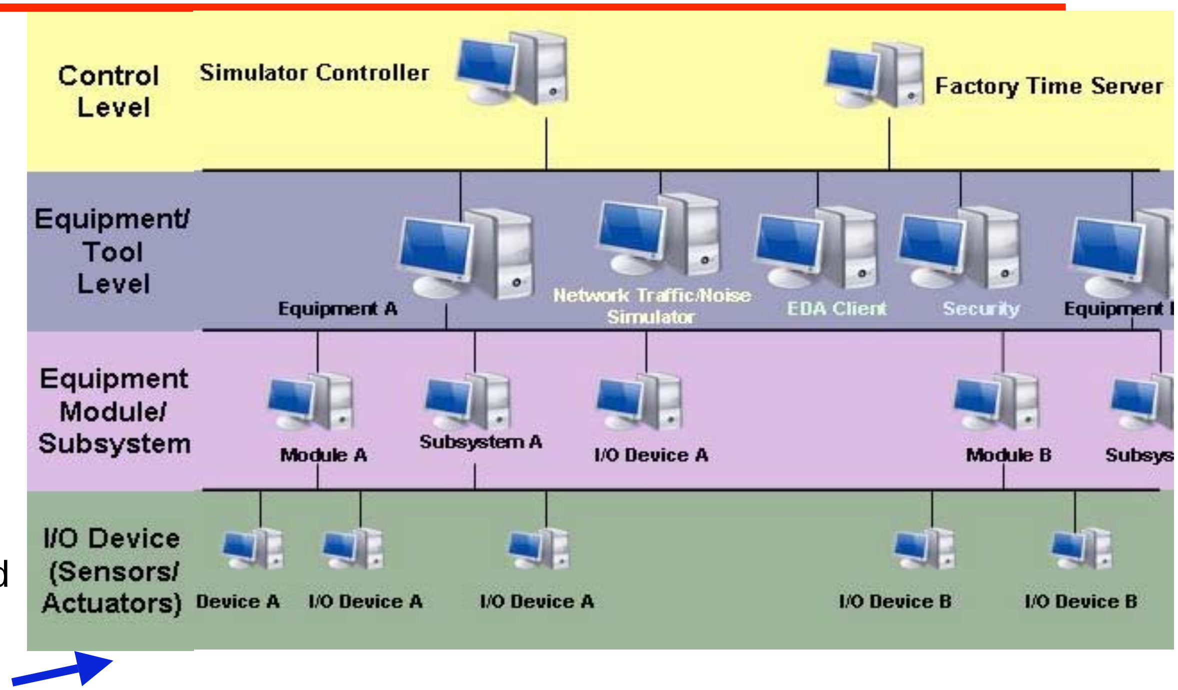
Executive Summary

- **Objectives**
  - Guide the industry in the move to enterprise wide timing, timestamping and time synchronization



- **Key Deliverables**
  - √ Node performance analysis in networked control systems
    - » Impact of VPN (security), UDP (Ethernet layers), and OPC (std. data collection)
  - √ Networked factory diagnostics simulation (client, server & noise gen.)
  - √ Best practices for deploying and utilizing timing and time synchronization
  - Standards for time synchronization in manufacturing

- **Benefits**
  - Time synchronization best practices badly needed
  - Address real-time issues down to the microsecond
  - Coordinate and sync data collection, e.g., for fault diagnostics
  - Reduce cost and increase reliability of networked systems

Motivation

- **Proliferation of networked systems**
  - **Diagnostics, Control and Safety**
- **Necessity for factory-wide and enterprise-wide coordination of data**
  - **E.g., diagnostics**
- **Need for time-stamping of data to support precision analysis and control system**
  - **"Out-of-order" data can lead to false positives in diagnostics systems**
  - **Next generation control requires accurate timestamping of sensory and actuation data**
  - **Coordination in networked safety systems**

- **What do we need?**
  - **Understand the time synchronization environment**
  - **Understand the capabilities available for time synchronization / stamping**
  - **Determine best practices ➔ standards for time synchronization / stamping**
  - **Improve technologies (control, diagnostics, etc.) to leverage these new capabilities**

Results To-Date (2006 – July-2008)

- Determined **impact of overhead on Ethernet performance**
  - **VPN (security), OPC (diagnostics), etc.**
  - J. T. Parrott, J. R. Moyne, D. M. Tilbury, "**Experimental Determination of Network Quality of Service in Ethernet: UDP, OPC, and VPN**," *Proceedings of the American Control Conference,* Minneapolis, MN, June 2006.

- Developed **factory-wide configurable networked diagnostics simulator** and Developed **detailed analysis of software time-synchronization capabilities over Ethernet** utilizing common methods (NTP)
  - **Used semiconductor industry as protocol prototype**
  - Ya-Shian Li-Baboud, et. al., “**Semiconductor Manufacturing Equipment Data Acquisition Simulation for Timing Performance Analysis**” 2008 International IEEE Symposium on Precision Clock Synchronization for Measurement, Control and Communication (ISPCS) 2008, Ann Arbor, Michigan, September 2008.

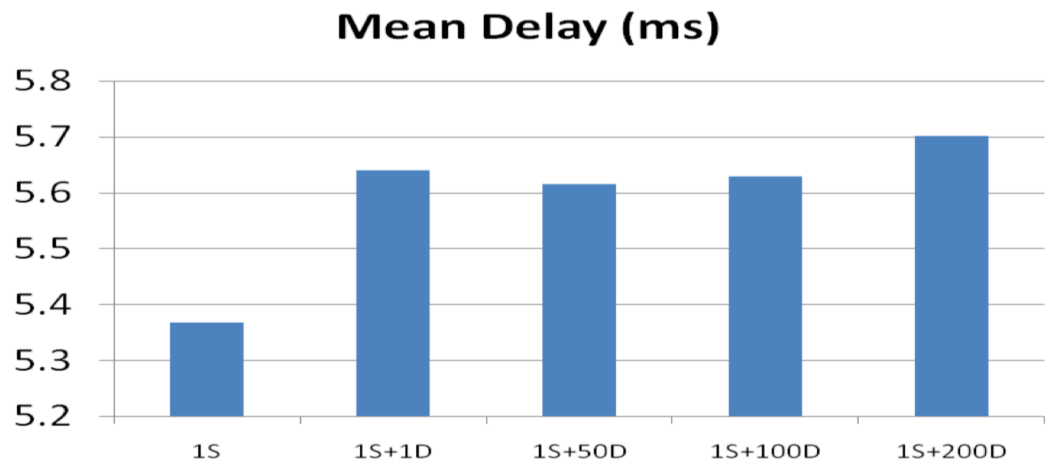
Sample Result: Impact of Network Traffic on End-to-End Diagnostic Data Delay

Setup (100 Mbps switched network)

- 1 smart EDA transmitting node
- Up to 200 “other” EDA transmitting nodes on network (typical of a fab environment)
- Measure end to end delay of smart EDA node

Delay(ms)	1 S*	1S + 1D*	1S + 50D	1S + 100D	1S + 200D
Mean Delay	**5.3679**	**5.6408**	**5.6155**	**5.6297**	**5.7018**
Max Delay	**6.1820**	**6.3470**	**6.3800**	**6.4080**	**6.2990**
Std Deviation	**0.3979**	**0.2821**	**2.4699**	**2.4071**	**3.1581**

*S: smart node. 1S means one smart node. *D: dummy node.



Sample Result: Impact of Network Traffic on End-to-End Diagnostic Data Delay

Observations

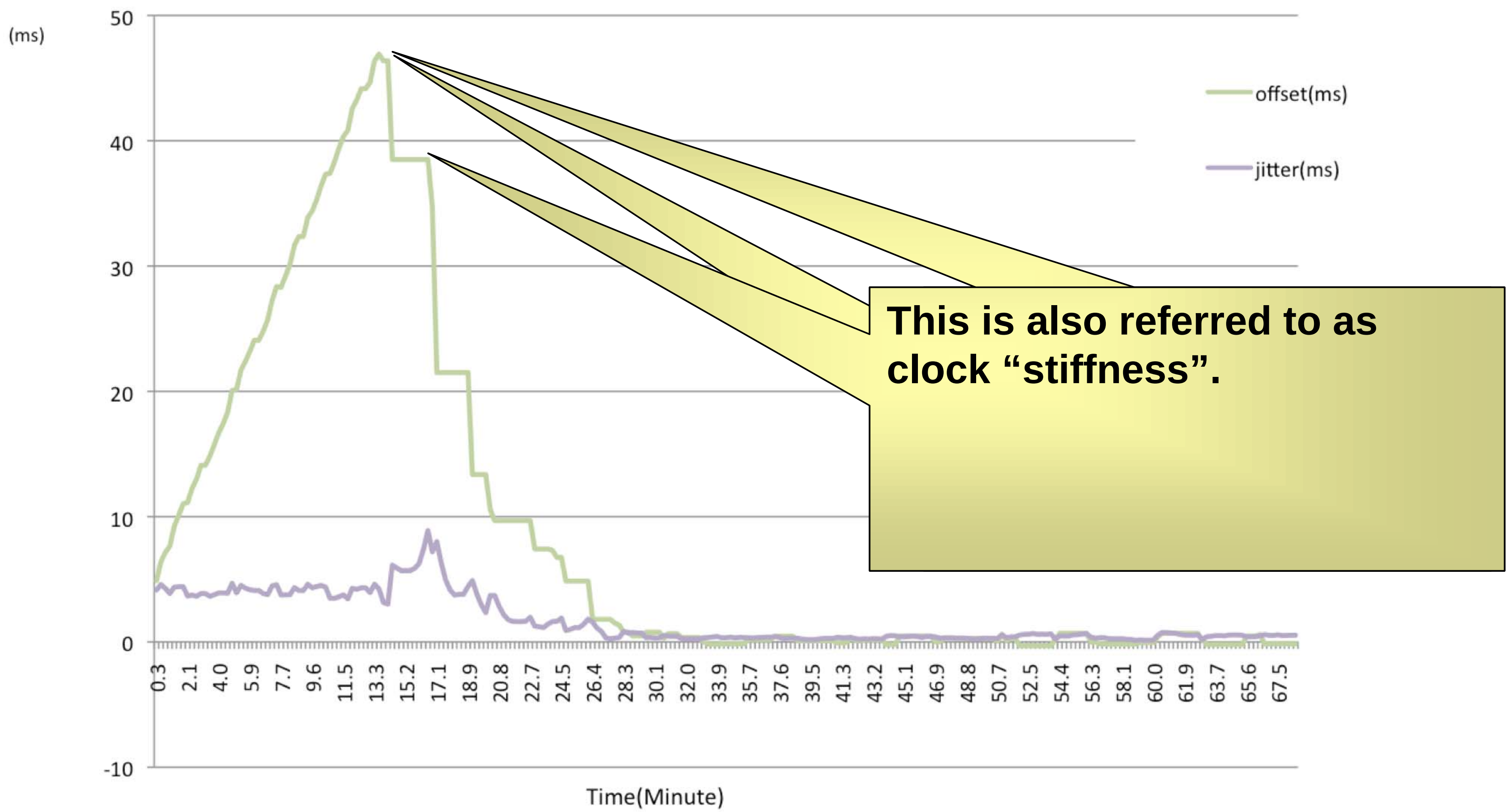
- Network delay does not increase significantly increase with number of dummy nodes
- Network congestion is *not* an issue in simulated factory-wide data collection

Issues

Since multiple "dummy" equipment transmitters were simulated at one IP node, the measured delay does not reflect switch delay in an actual system

➔ Actual delay in practice will have to include additional switch delay

Sample Result: Clock Offset and Jitter with NTP (software) Synchronization - Transient Analysis

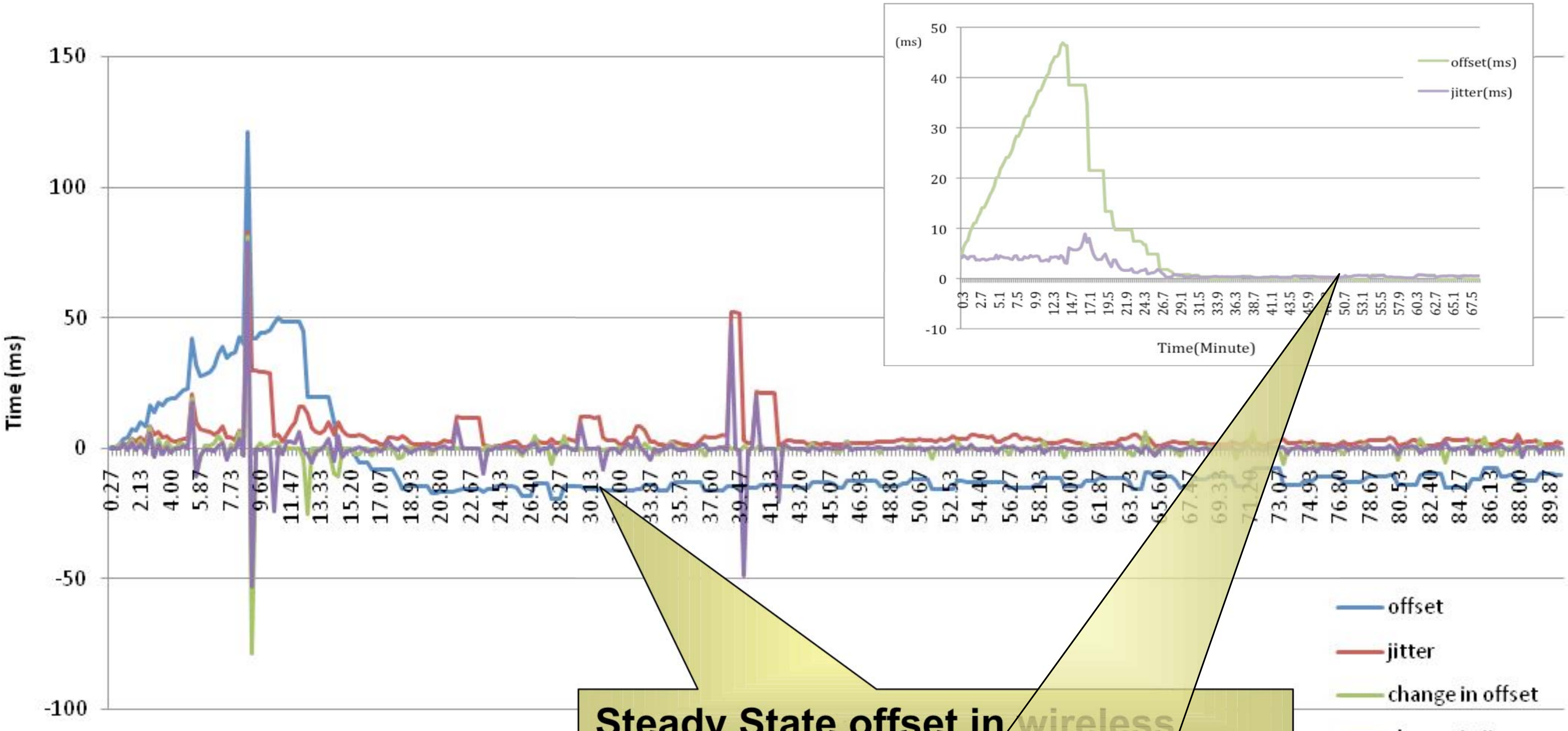


Current Efforts

- **Detailed analysis of capabilities for time synchronization over wireless networks**
  - **Bluetooth and 802.11**
- **Investigation of hardware solutions for time synchronization**
  - **Believed to be the "ultimate" solution**
  - **Low impact on existing software performance; standardized solution**
- **Long-term goals**
  - **Standards for hardware time synchronization in manufacturing**
    - » Sensor level up through enterprise
  - **Test environment for determination and verification of time synchronization capabilities**
  - **Input into advancement of control and safety system design, diagnostics systems, etc. that would take advantage of time synchronization / stamping**

<u>Sample Result</u>: Offset, jitter, Δ offset and Δ jitter Vs Time in a *Wireless Network*

Offset and jitter in wired network



Steady State offset in wireless

That doesn't exist in wired systems

Milestones and Future Plans

- 2006 — Time sync requirements of systems; analysis of Ethernet performance with factory protocol overhead
- 2007 — Configurable factory networked diagnostics simulator design and development
- Sept 2008 — Analysis of time synchronization capabilities of and best practices for wired networked factory systems
- Mar 2009 — Analysis of time synchronization capabilities of and best practices for wireless networked factory systems
- June. 2009 — Development of hardware time synchronization testbed
- Sept. 2009 — Best practices / proposed stds for time sync.
- 2009/10 — Recommendations for impacting science (e.g., next generation control, safety, …)