Fab-wide Network Time Synchronization – Simulation and Analysis

Naveen Kalappa,
Vinod Anandarajah, Julien Baboud, Ya-Shian Li and James Moyne

September 2007

AEC advanced equipment control
APC advanced process control
SYMPOSIUM XIX
September 15-20, 2007 • Indian Wells, CA

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

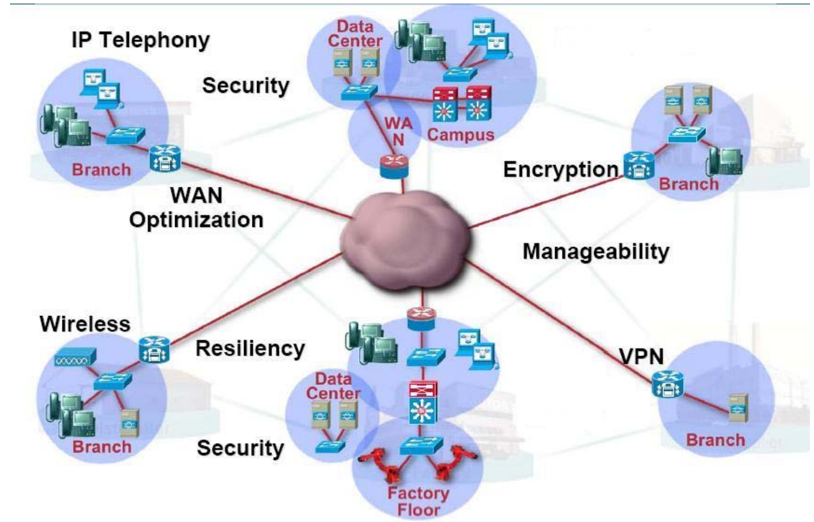
Outline

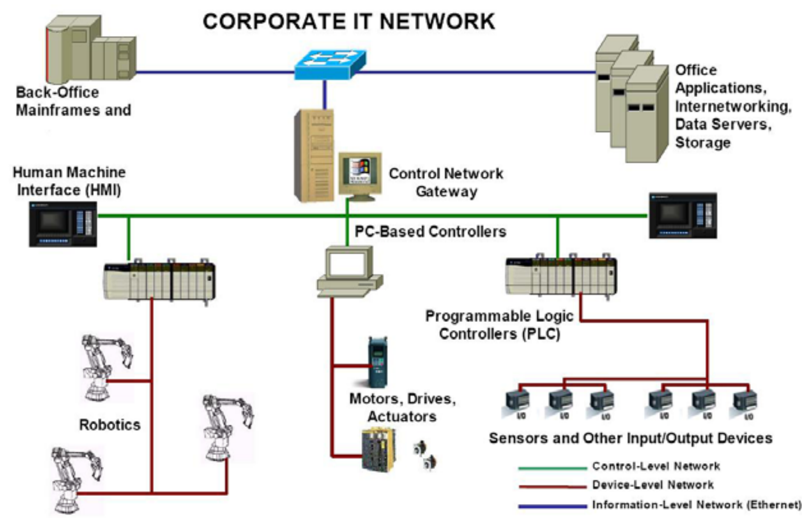
- Importance of time synchronization in semiconductor manufacturing
  - Ethernet, XML
  - Need for time synchronization
  - Time synchronization protocols
- Semiconductor factory simulator
  - NIST and University of Michigan
  - Equipment Data Acquisition Standard
  - Simulator design and implementation
- Tests conducted and project status
  - Experimental set-up
  - Interpretation of results
  - Current project status
- Future efforts and expected outcome

Ethernet to the factory floor

- **Distributed Systems**
  - Allow reconfigurability
  - Network performance critical
- **Ethernet everywhere**
  - MES to I/O Level
  - XML on Ethernet becoming uniform

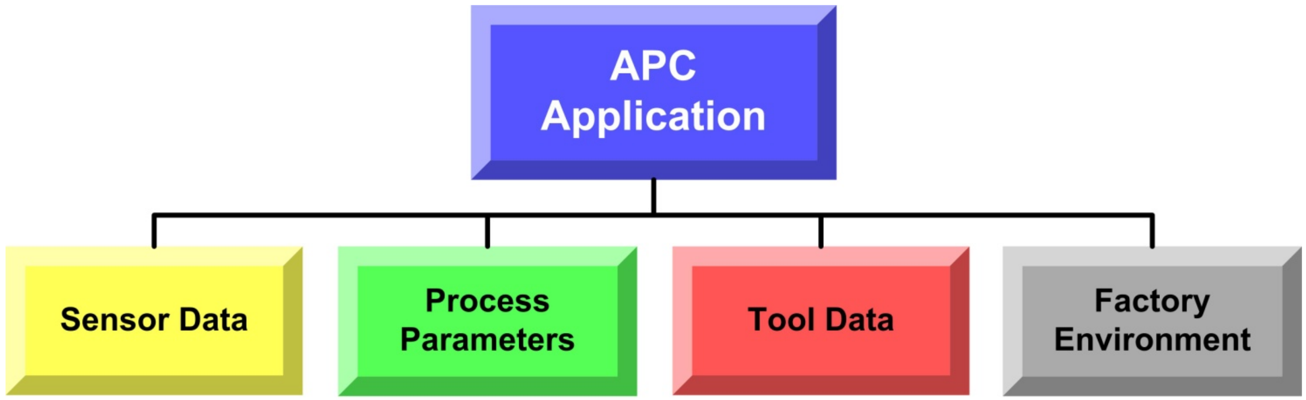
    data exchange format





National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Motivation in chip manufacturing



Precision Time Stamping to Merge Various Data Streams

- **Advanced Process Control**
  - Fault Detection Classification
  - e-diagnostics
  - Process Optimization
  - Virtual Metrology

Need for time synchronization (cont)

- **TCP/IP on Ethernet designed for data handling**
  - Non-deterministic delays
  - Overhead due to protocols such as XML, OPC, VPN
  - Impact on data quality

	UDP	VPN (UDP)	OPC (TCP)	DeviceNet
Delay Average (ms)	0.33	1.21	1.48	0.3-1.2
Delay Variation (3σ) (ms)	0.09	0.49	2.43	0.005-0.2
Min. Network Delay Contribution (ms)	0.035	0.035	0.035	0.188
% of Delay Due to Network	11%	3%	2%	63%

J.T. Parrott, J. R. Moyne and D. M. Tilbury. Experimental Determination of Network Quality of Service in Ethernet: UDP, OPC, and VPN. In *Proceedings of the American Control Conference*, June 2006

Need for time synchronization (cont)

- **What needs to be done?**
  - Minimize time synchronization delay variability by eliminating application processing time
  - Precise time-stamping close to the hardware layer
  - Application of time synchronization protocols such as NTP, PTP
  - Improve accuracy of time-based information of distributed systems

Sample time requirements

Application	Description/Needs	Absolute Accuracy	Relative Accuracy	Minimum Data Sampling Interval	Precision Required
Real-Time Data Base (Data Repository, Historian)	Provide high-speed storage and retrieval of detailed equipment and process data to support wide range of application needs.	5 sec	10 ms	20 ms	1 ms
Control / Fault Model Development	Analyze equipment, process, metrology, and yield information to development control models used for APC applications.	10 sec	10 ms	1 min	1 ms
Statistical Process Control (SPC)	Track equipment / process parameters and flag SPC rule violations; not a real-time control technique.	5 sec	100 ms	1 sec	1 ms
Run-to-Run Control (R2R)	Adjust recipe parameters between individual production runs (wafer, lot, batch) based on results of previous runs; uses combination of metrology and equipment data to calculate adjustments.	5 sec	50 ms	100 ms	1 ms
Fault Detection and Classification (FDC)	Analyze equipment and process parameters to ensure tool is in its acceptable operating envelope; identify and classify (or prevent) equipment faults and interrupt processing accordingly.	5 sec	10 ms	50 ms (in process) 20 sec (post-process)	1 ms
Event / Alarm Management	Capture, analyze, communicate, and support user response to events and alarms across the production environment.	5 sec	1 sec	1 sec	1 ms
Scheduling/ Dispatching (RTD)	Provides ability to accurately estimate time of completion, arrival of wafers, and to prepare a tool for wafer processing.	5 sec	2 sec	2 sec	1 ms
Factory Time Synchronization	Maintain and provide reference time for all systems in the fab.	5 sec	1 ms	10 sec	1 ms

Source: SEMI Time Synchronization Working Group

Time synchronization solutions

- **Available solutions**
  - **Network time protocol (NTP)**
    - Mainly for internet
    - Software implementation
    - Millisecond-level synchronization
  - **Precision time protocol (PTP)**
    - For real-time control
    - Hardware assisted time-stamping
    - Nanosecond synchronization

- **Investigation required for application of these protocols on the factory floor based on the desired timing accuracy**

Outline

- Importance of time synchronization in semiconductor manufacturing
  - Ethernet, XML
  - Need for time synchronization
  - Time synchronization protocols
- Semiconductor factory simulator
  - NIST and University of Michigan
  - Equipment Data Acquisition Standard
  - Simulator design and implementation
- Tests conducted and project status
  - Experimental set-up
  - Interpretation of results
  - Current project status
- Future efforts and expected outcome

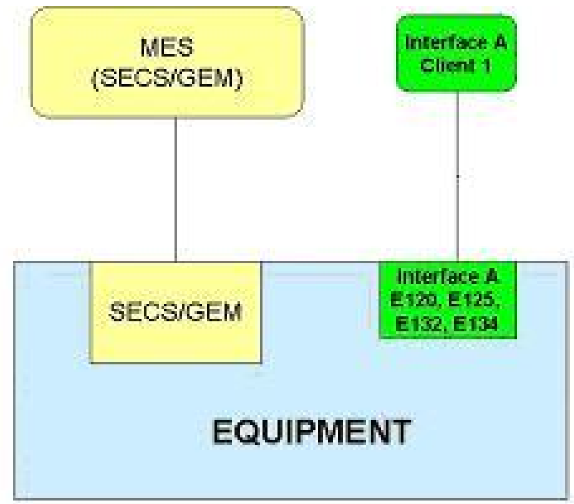
NIST – UofM Simulator Goals

- **Determine best practices for networked time synchronization in semiconductor manufacturing**
  - Investigate time-stamping accuracy
  - Data collection performance characteristics
  - Advanced process control simulations
    - Simulate predictive analysis capabilities
    - Experiment with new process control models to analyze impact on yield/cost

- **Compare cost and accuracy benefits of**
  - Deploying time synchronization protocols such as PTP, NTP
  - Different time-stamping methods
  - Using different operating systems

Equipment data acquisition (EDA)

- **Equipment Data Acquisition – Interface A Standard**
  - Second communication port in addition to SECS/GEM port
  - Data exchanged, collected, and analyzed for better process control
  - Data obtained from different systems and sub-systems
  - Correlate data obtained from the various sources



National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Equipment data acquisition (cont)

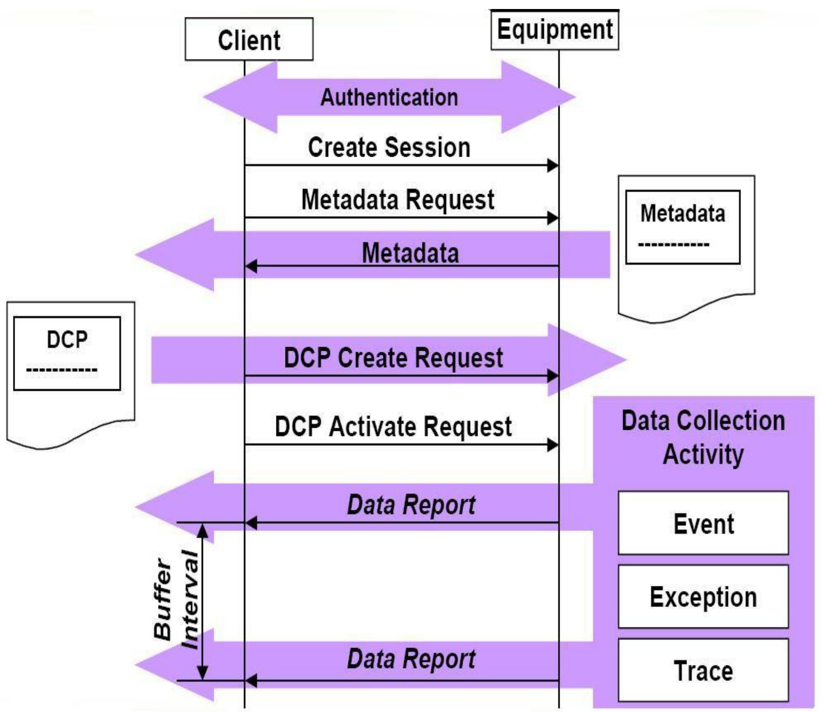
- **Lack of time synchronization and accurate time-stamping for EDA related data leads to**
  – Events and data being out-of-order
  – Inaccurate correlation of event occurrence from data recorded
  – “Out-of-control” situations for R2R controllers
  – Problems in fault detection and classification may lead to “false positives” and contribute to equipment downtime and lack of confidence in FDC solutions

SEMI standards in EDA

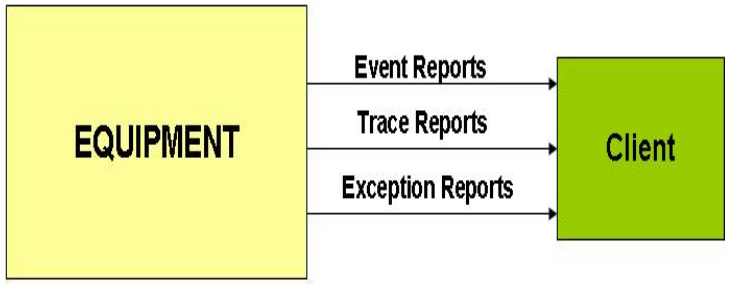
- **Interface A or the EDA standard is a collection of SEMI standards to facilitate communication between EDA clients and a server. It uses SOAP/XML messaging over a HTTP connection. The standards used to describe are**
  - E120: Common Equipment Model. Represents a general object model that represents an external view of the equipment.
  - E125: Equipment Self Description. Provides a parametrical description of the E120 model allowing clients to request particular parameters.
  - E132: Client Authentication and Authorization. Security related features for Interface A messaging.
  - E134: Specification for Data Collection Management. Create a flexible and manageable data collection environment through definition of data collection plans.

EDA message exchange session

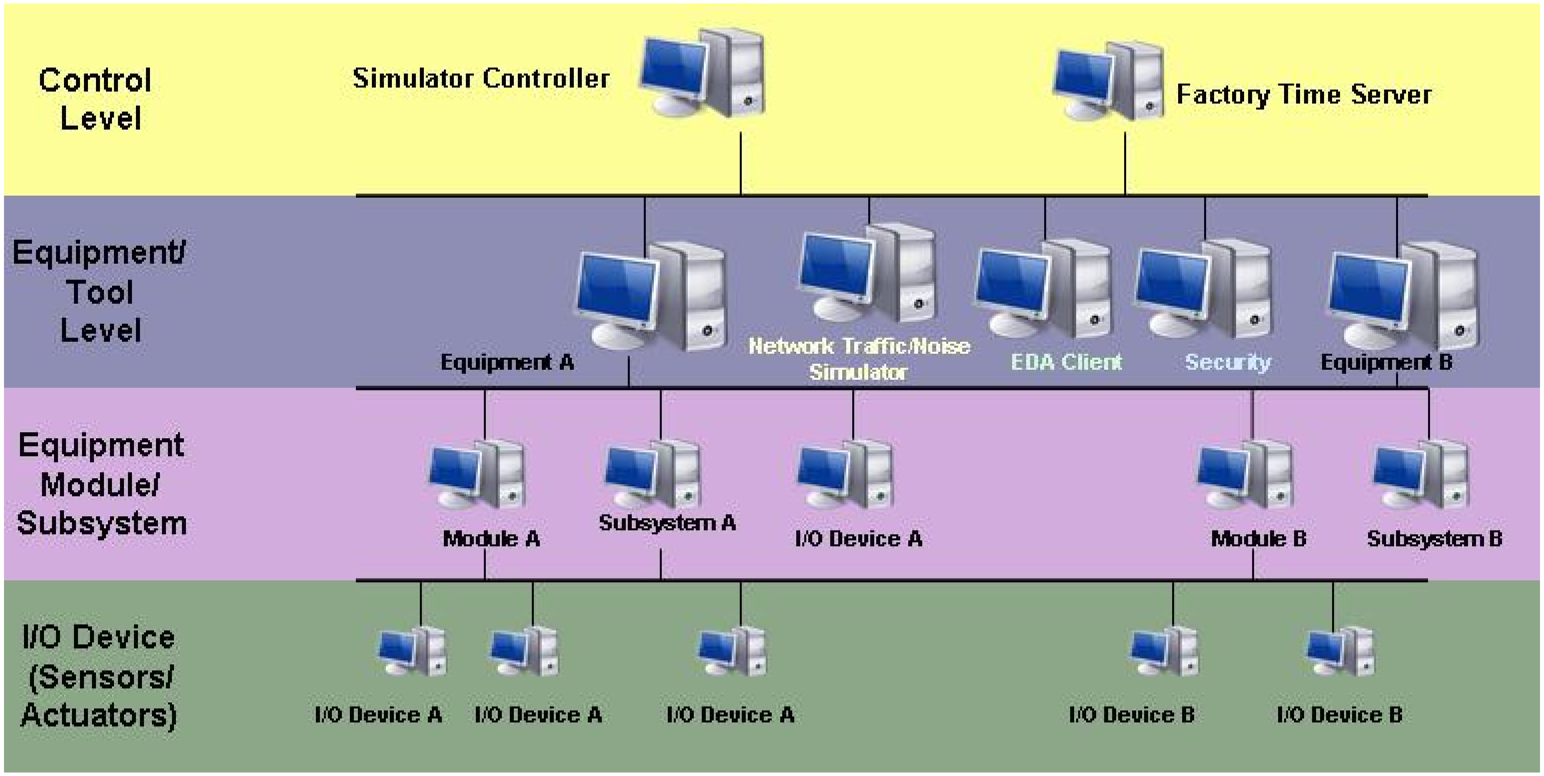
- An EDA Server and Client session



- Data reports exchanged
  - Event
  - Trace
  - Exception



Simulator architecture



Simulation of entire semiconductor factory to study benefits of time synchronization

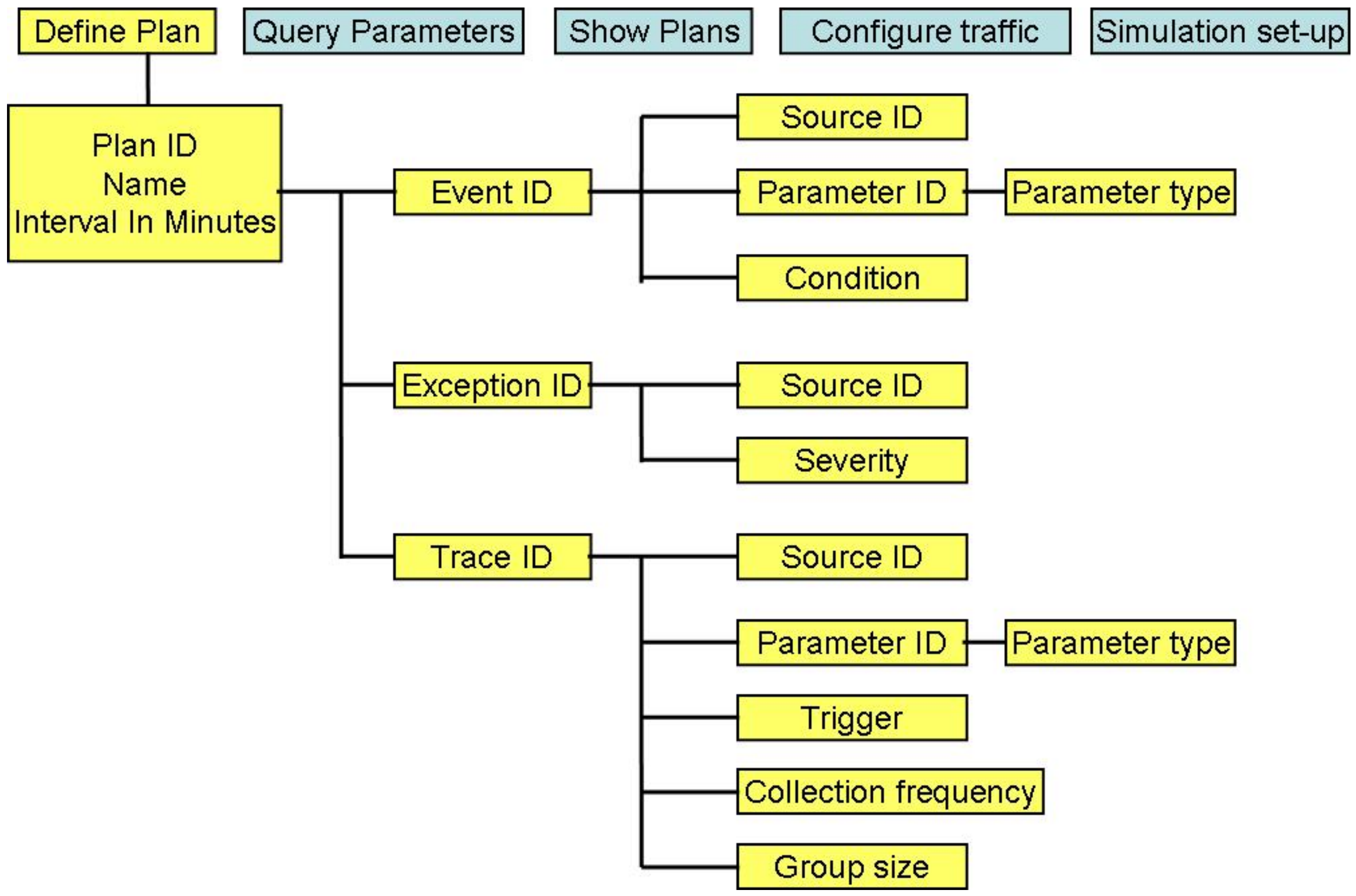
Simulator design

- **Simulator Controller**
  - Centralized point of control; similar to MES
  - Configure the entire network
  - Configure clients, equipment and data collection

- **Data exchange and consolidation**
  - XML data
  - Generate traffic patterns similar to factory floor
  - Time-stamping and synchronization at various levels
  - Analysis

Simulator design (contd)

- **Simulation Controller GUI**

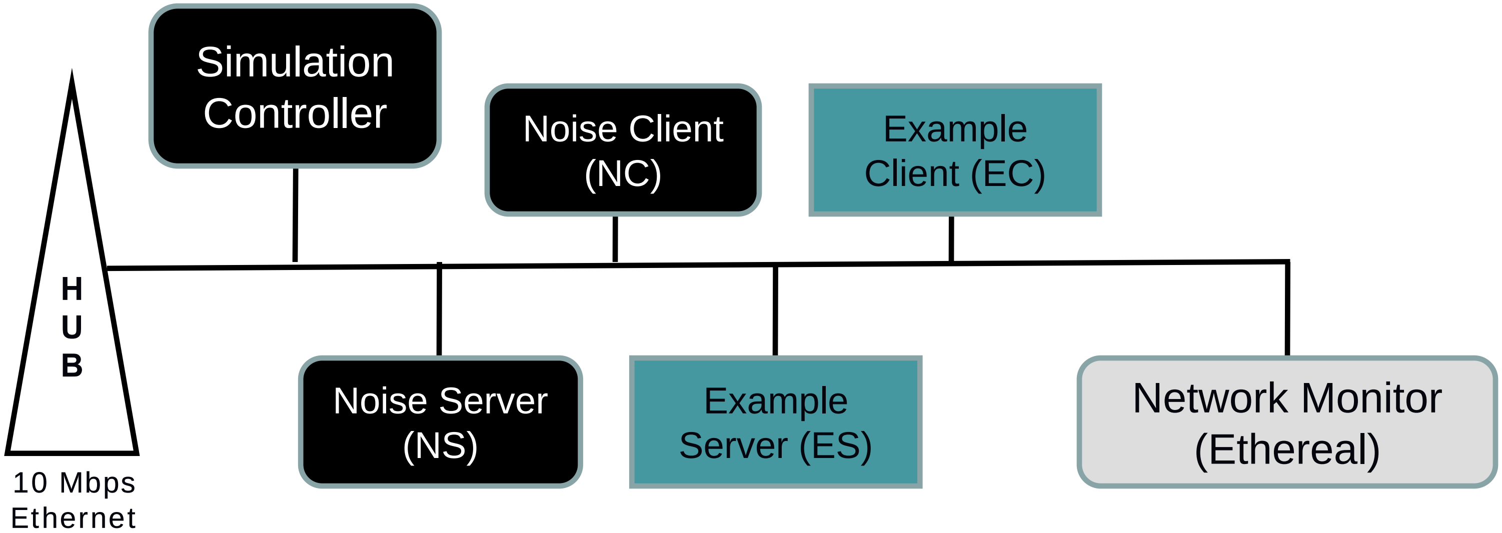


Outline

- Importance of time synchronization in semiconductor manufacturing
  - Ethernet, XML
  - Need for time synchronization
  - Time synchronization protocols
- Semiconductor factory simulator
  - NIST and University of Michigan
  - Equipment Data Acquisition Standard
  - Simulator design and implementation
- Tests conducted and project status
  - Experimental set-up
  - Interpretation of results
  - Current project status
- Future efforts and expected outcome

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

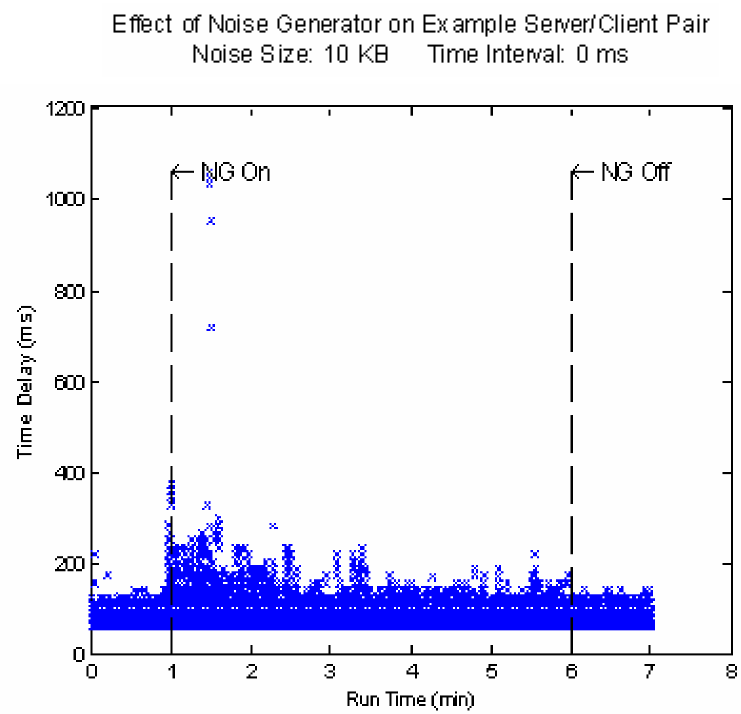
Initial experimental set-up

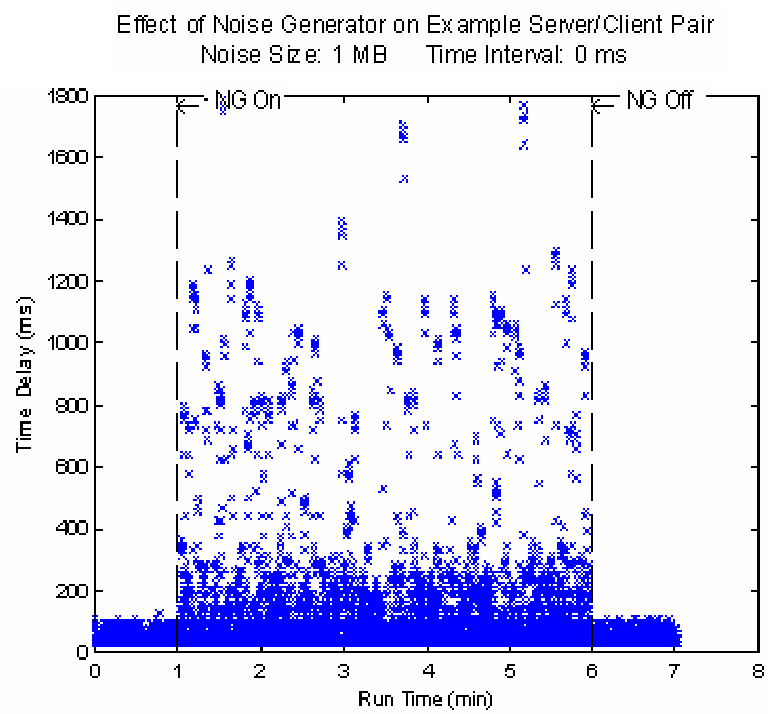


- **Experimental Conditions**
  - Data exchange between example server and example client at fixed time interval
  - Specified noise from noise server to noise client
  - Noise size and time interval configurable

Initial results

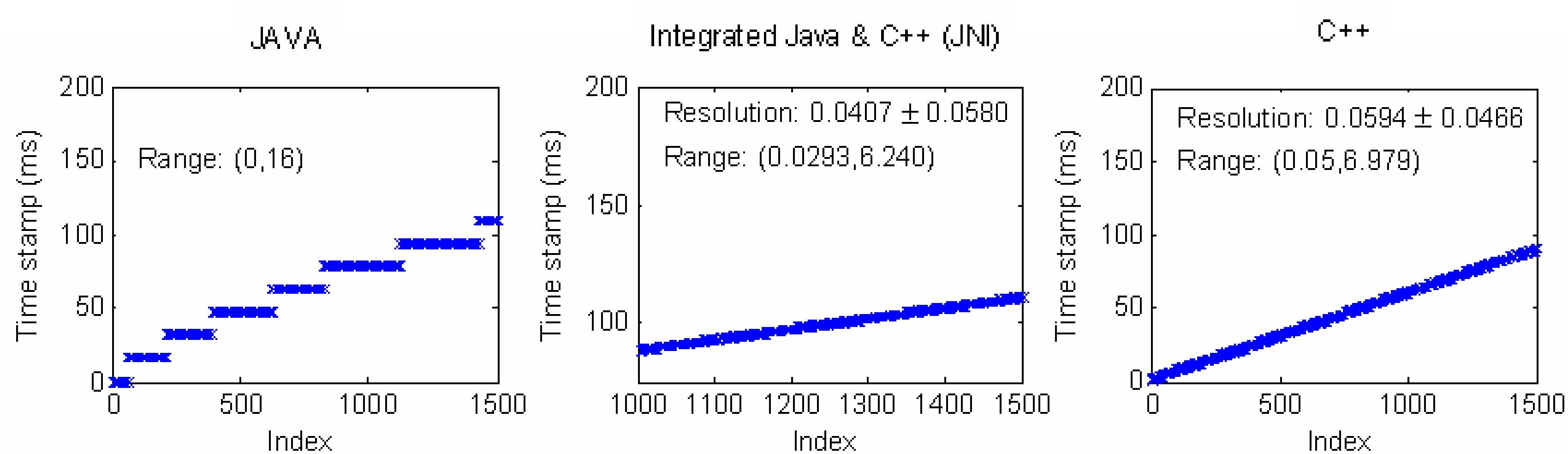
- **Time delay and delay variability between example server and example client increase with increase in noise**





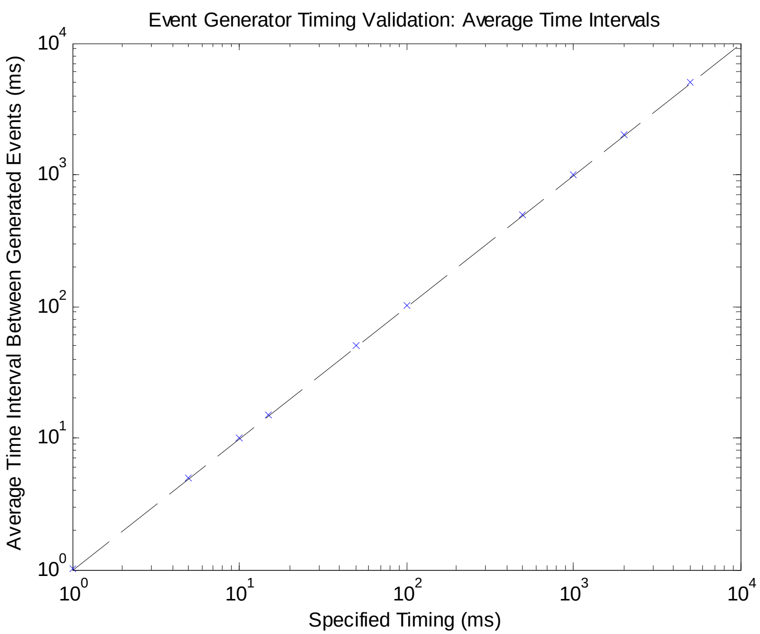
Initial results (cont)

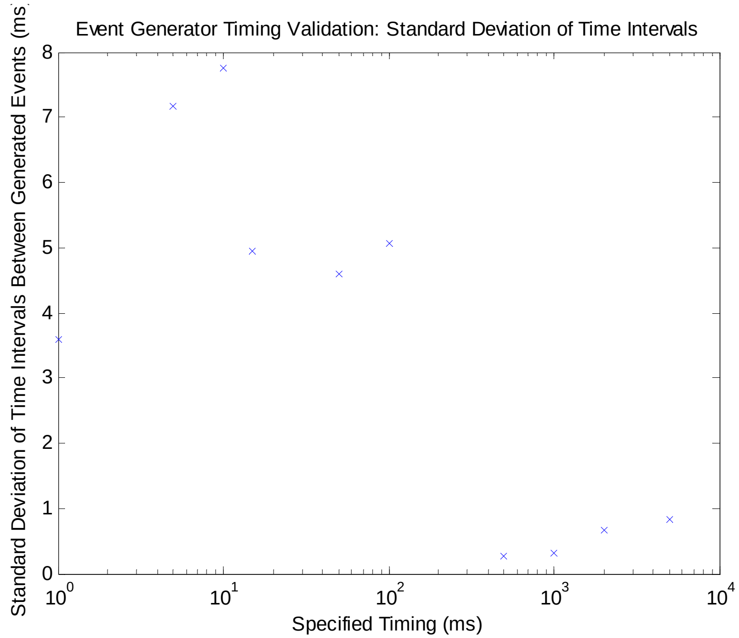
- **Java time stamping has ~10-15 ms resolution using the Windows operating system**
- **This can be improved without recoding in C++ by using the Java Native Interface (JNI) to call upon C++ code to obtain time stamps (but lose portability)**



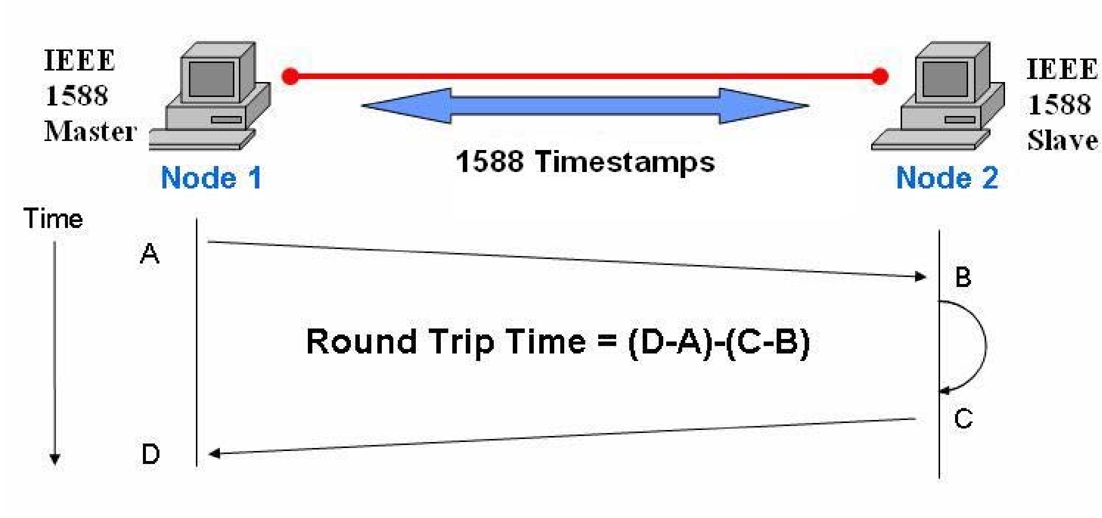
Initial results (cont)

- **Java time schedulers accurate on average but cannot achieve the 1 ms precision requirement for specified times <= 100 ms**





Tests with 1588 PCI cards



Delay between packets	Max (ms)	Mean (ms)	Min (ms)	Std Dev (ms)
250ms	1.188	0.251	0.201	0.053
1s	0.317	0.243	0.234	0.003

Application (node) processing time hampering network times

Current status

- **Simulator controller**
  - Process EDA instance documents
    - Define DCPs with required parameters
  - Noise configuration GUI integrated

- **EDA Server**
  - Package capable of receiving & handling DCPs and sending back DCRs
  - `DcpHandler` class: Accesses elements & attributes of a DCP
  - `EventGenerator` class: Generates random events at specified time intervals
  - `DcrHandler` class: Formation of Data Collection Reports (DCRs) in compliance with E134 schema

- Entire EDA loop currently takes ~185 ± 20 ms for an ~800 KB sample DCP XML file

Outline

- Importance of time synchronization in semiconductor manufacturing
  - XML, Ethernet
- Equipment Data Acquisition (EDA Standard)
  - Introduction
  - Standards overview
- Semiconductor factory simulator
  - NIST and University of Michigan
  - Simulator design and implementation
- Tests conducted and project status
  - Experimental set-up
  - Interpretation of results
  - Current project status
- Future efforts and expected outcome

Future efforts and expected outcome

- **Future efforts**
  - Application of time synchronization protocols to the factory simulator
  - Full configuration capability present at the simulator controller
  - EDA server capable of interpreting E120/E125 from different equipments and indicate parameters for DCPs
  - Noise generator capable of producing noise patterns similar to that on the manufacturing floor
  - Expanded speed and jitter study of application programming and OS environments to understand their applicability with various time synchronization capabilities
    - Investigate real-time Java capabilities (remote execution of RTS 2.0 on Solaris 10)
    - Compare time stamping on different operating systems
  - Scale simulator to entire semiconductor factory

Future efforts and expected outcome

- **Expected Outcome**
  - Determine extent and precision of time synchronization and time-stamping required at various levels of the semiconductor manufacturing floor
  - Cost-benefit analysis of deploying different time synchronization protocols
  - Highlight the importance of precise time synchronization and time-stamping on data quality
  - Effectively determine cause-effect relationships for fault detection and virtual metrology
  - Input into SEMI standards for data quality

Thank you

- **For further information**
  - **James Moyne: moyne@umich.edu**
  - **Ya-Shian Li: ya-shian.li@nist.gov**
- **Acknowledgments**
  - **NIST**
  - **NSF Engineering Research Center for Reconfigurable Manufacturing Systems**
  - **ISMI, SEMI, and SEMI Time Synchronization Working Group**
- **Questions?**