Recent Advances in IEEE 1588 Technology and Its Applications

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Agilent Technologies

Outline

- Overview of IEEE 1588
- Applications
- Standards Activity

The Status of IEEE 1588

- **Approved by the IEEE-SA Review Committee on September 12, 2002**
- **Published as IEEE 1588-2002 on November 8, 2002**
- **Available from the IEEE http://standards.ieee.org**
- **Approved as IEC standard IEC 61588 on May 21, 2004**
- **Products and installations started appearing in late 2003**
- **Two conferences have been held: 2003, 2004**
- **A PAR has been submitted to extend the standard**
- **Current information may be found at http://ieee1588.nist.gov**

Objectives of IEEE 1588

- **Sub-microsecond synchronization of real-time clocks in components of a networked distributed measurement and control system**
- **Intended for relatively localized systems typical of industrial automation and test and measurement environments.**
- **Applicable to local area networks supporting multicast communications (including but not limited to Ethernet)**

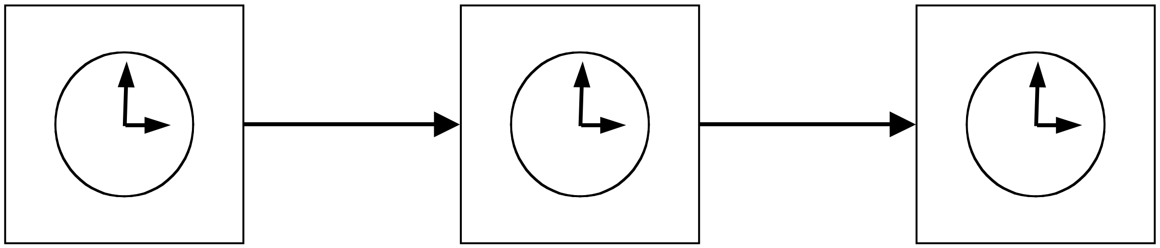
Objectives of IEEE 1588 (continued)

- **Simple, administration free installation**
- **Support heterogeneous systems of clocks with varying precision, resolution and stability**
- **Minimal resource requirements on networks and host components.**

Synchronization Basics

Step 1: Organize the clocks into a master-slave hierarchy (based on observing the clock property information contained in multicast Sync messages)

Step 2: Each slave synchronizes to its master (based on Sync, Delay_Req, Follow_Up, and Delay_Resp messages exchanged between master and its slave)

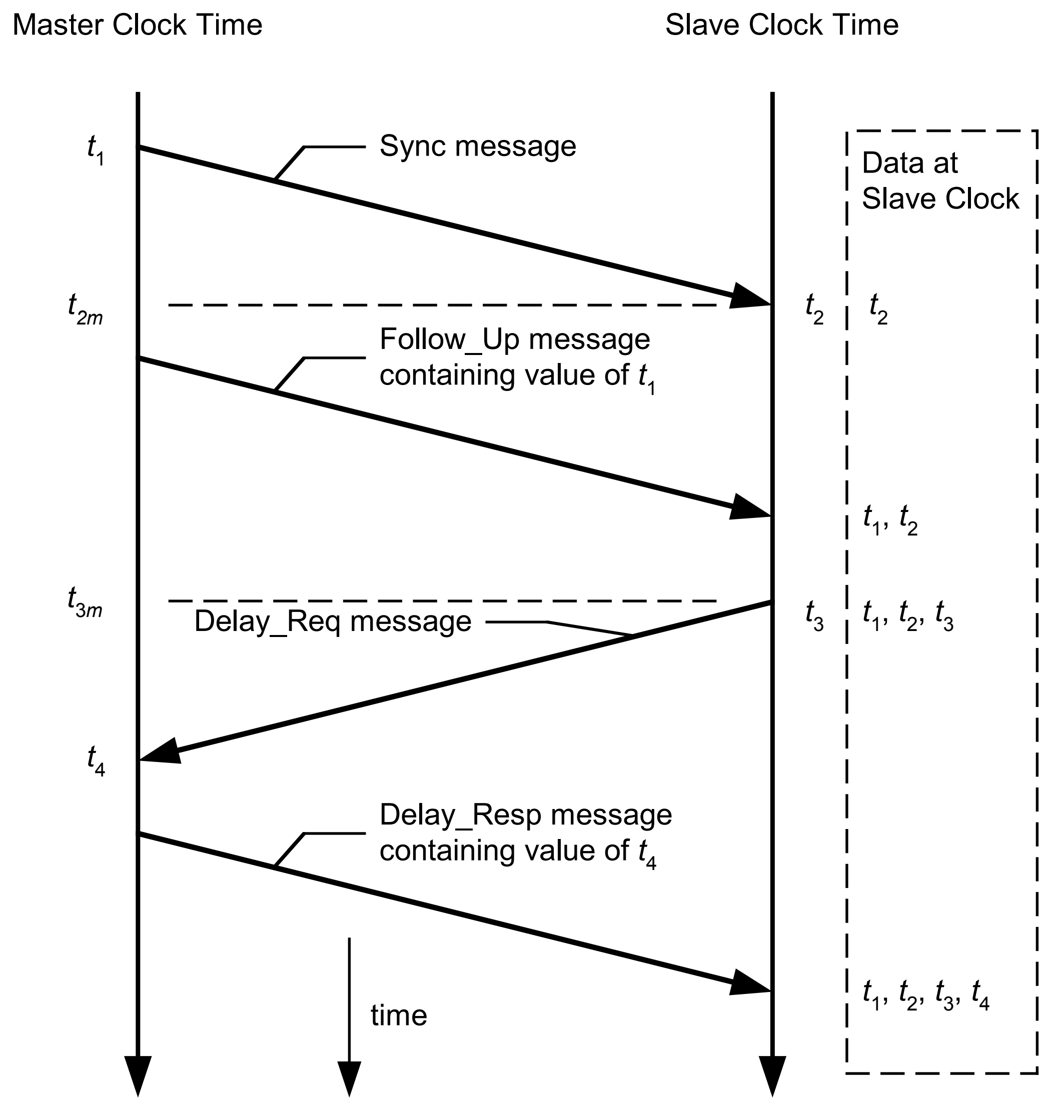


Grandmaster Clock
This clock determines the time base for the system

Slave to the Grandmaster Clock and Master to its Slave

Slave to its Master

Timing diagram

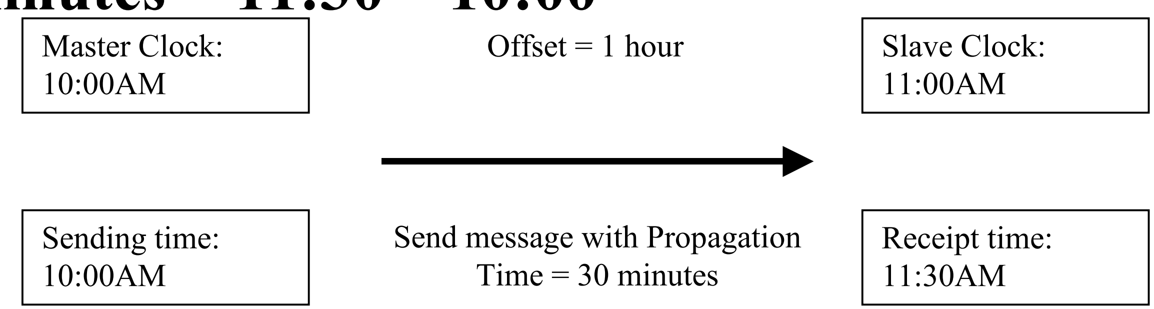


Synchronization Basics (continued)

To synchronize a pair of clocks conduct two experiments

First:

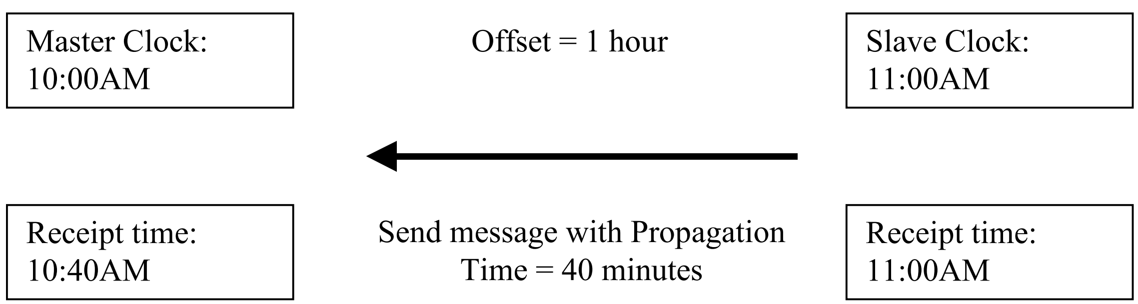
- **Send a message, (Sync message), from master to slave and measure the apparent time difference between the two clocks. MS_difference = slave's receipt time – master's sending time**
- **MS_difference = offset + MS delay**
- **For example:**
  MS_difference = slave's receipt time – master's sending time
  90 minutes = 11:30 – 10:00



Synchronization Basics (continued)

Second:

- **Send a message, (Delay_Req message), from slave to master and measure the apparent time difference between the two clocks.**
  SM_difference = master's receipt time – slave's sending time
- **SM_difference = – offset + SM delay**
- **For example:**
  SM_difference = master's receipt time – slave's sending time
  – 20 minutes = 10:40 – 11:00



Synchronization Basics (continued)

The result is that we have the following two equations:

MS_difference = offset + MS delay

SM_difference = – offset + SM delay

<u>With two measured quantities:</u>

MS_difference = 90 minutes

SM_difference = – 20 minutes

<u>And three unknowns:</u>

offset , MS delay, and SM delay

Synchronization Basics (continued)

Rearranging the two equations:

MS_difference = offset + MS delay

SM_difference = – offset + SM delay

We get:

offset = {(MS_difference – SM_difference)

– (MS delay – SM delay)}/2

MS delay + SM delay = {MS_difference + SM_difference}

ASSUME: MS delay = SM delay = one_way_delay

Then:

offset = {MS_difference – SM_difference}/2

one_way_delay = {MS_difference + SM_difference}/2

Synchronization Basics (continued)

offset = {MS_difference – SM_difference}/2

one_way_delay = {MS_difference + SM_difference}/2

<u>In our example using the two measured quantities:</u>

MS_difference = 90 minutes

SM_difference = – 20 minutes

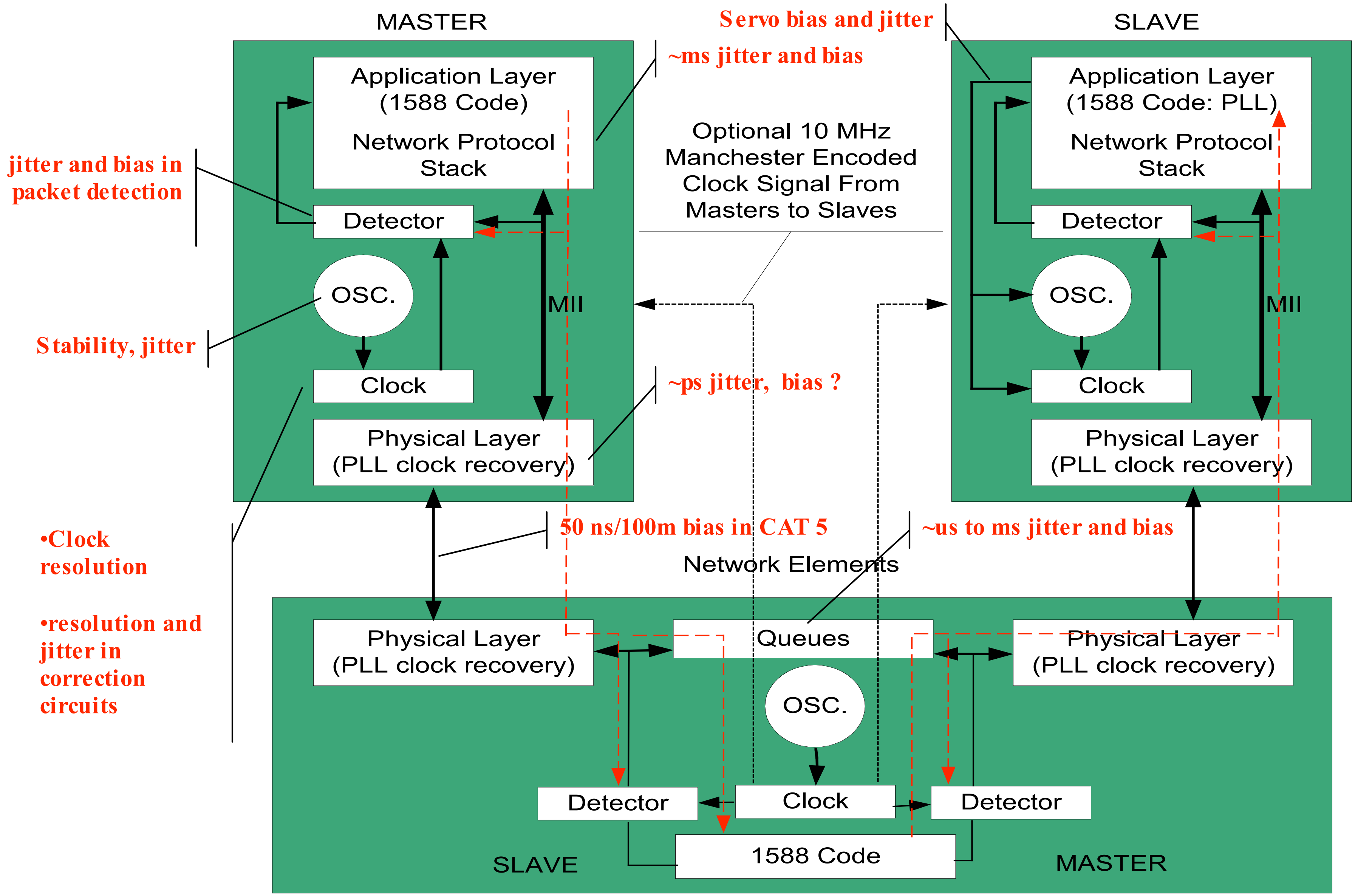
We get:

offset = {90 – (– 20)}/2 = 55 minutes (not actual 60)

one_way_delay = {90 + (– 20)}/2 = 35 minutes (not 30 or 40)

Background

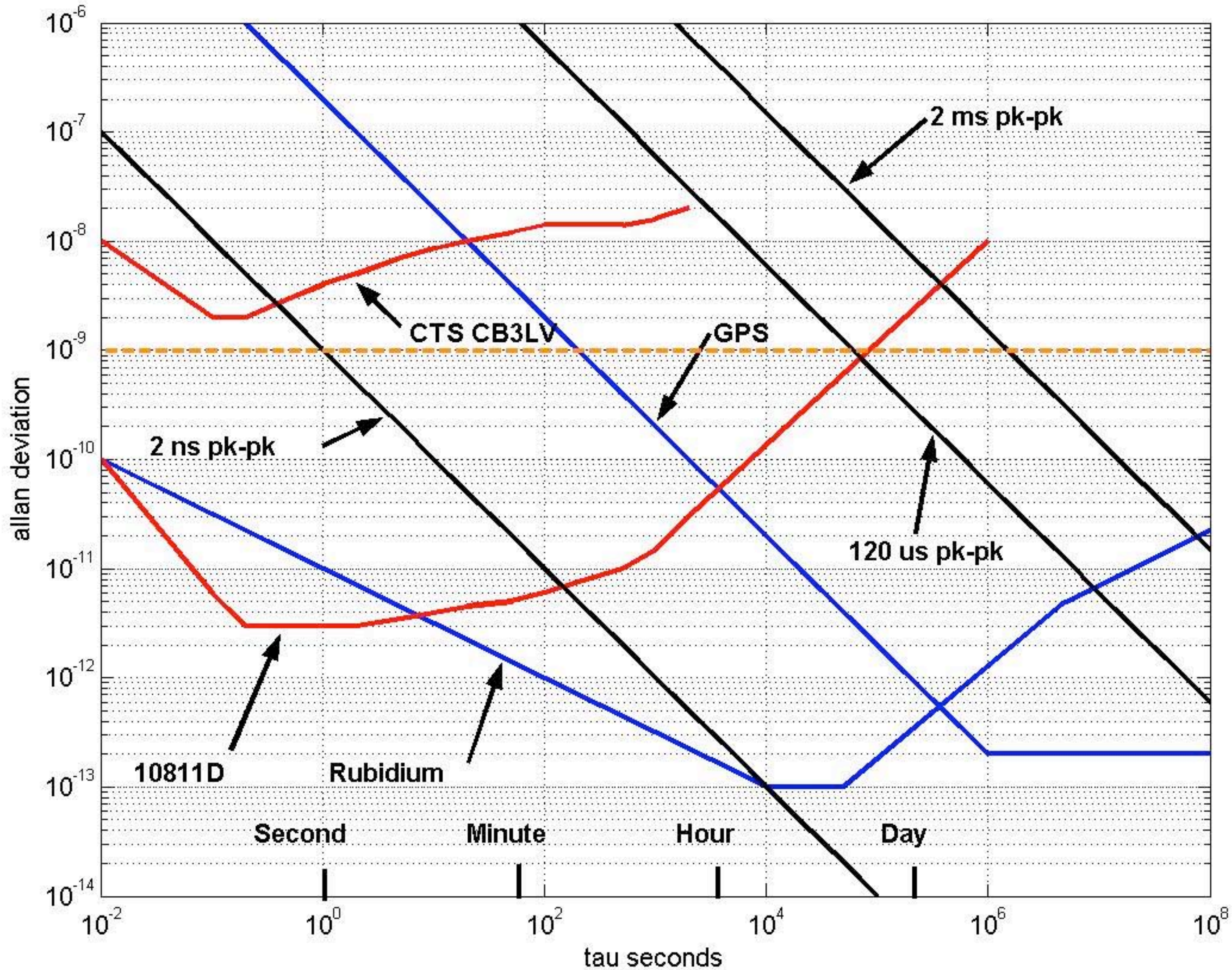
High accuracy IEEE 1588 implementation



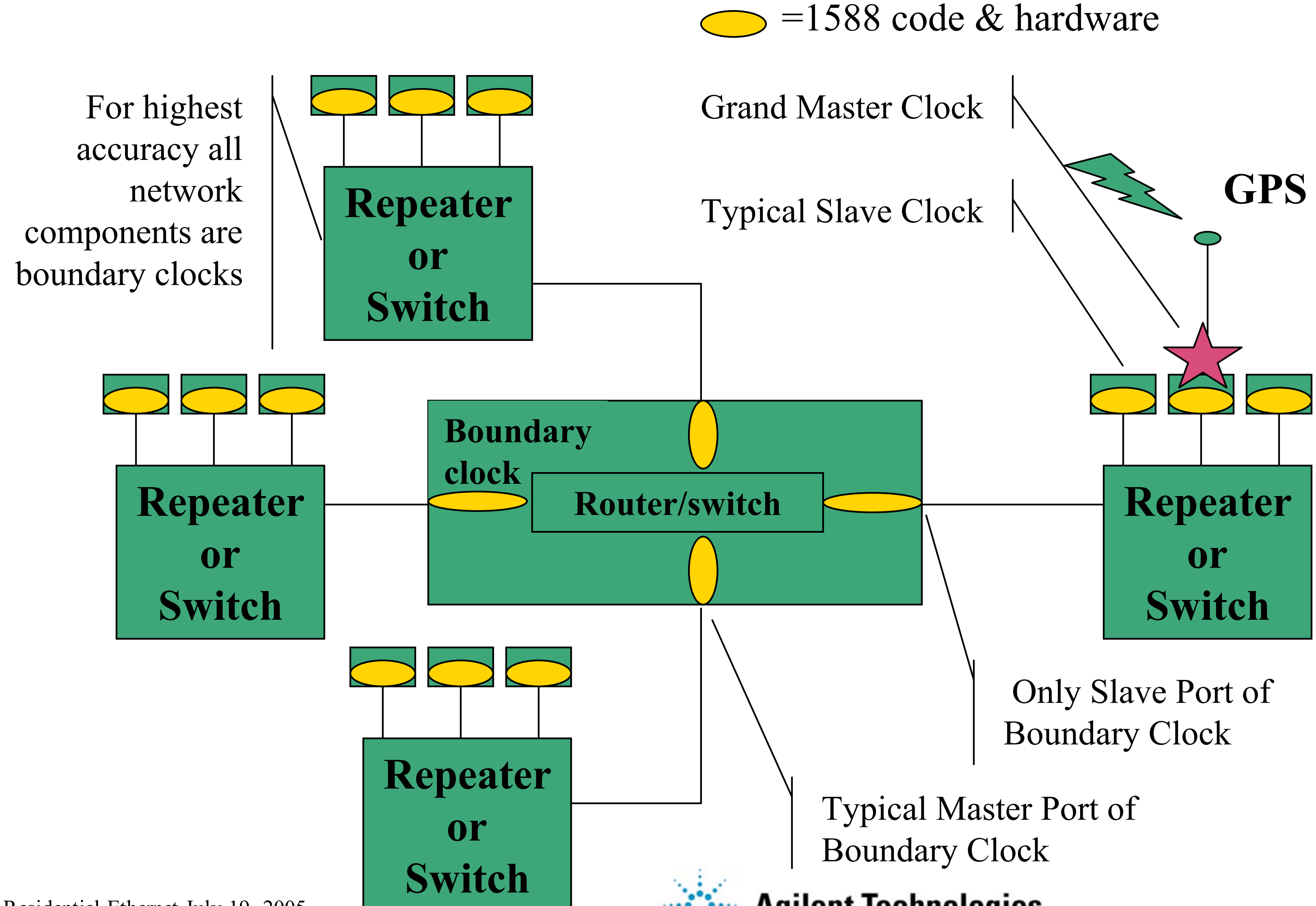
Thermal considerations

- Oscillator drift is a major contributor to synchronization errors.
- Quartz crystal based oscillators
  - Uncompensated oscillators generally in few ppm/degree range
  - Thermal compensation typically x10 to x100 better
- Atomic based oscillators
  - Several orders of magnitude less drift than quartz

Oscillators: Allan Deviations for Common Sources



1588 Multiple Subnet Topology



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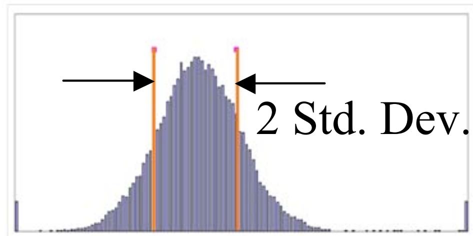
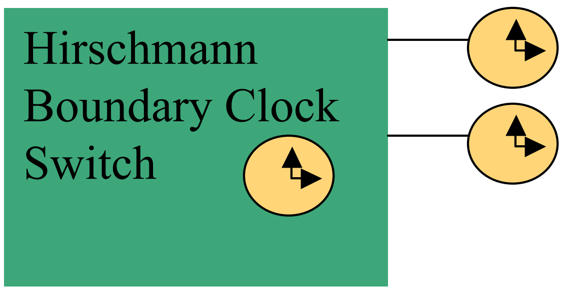
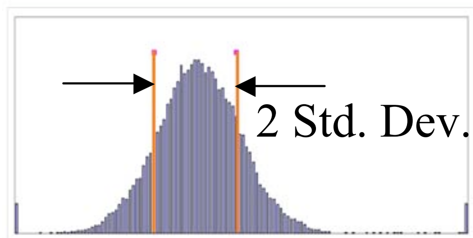
Synchronization accuracy results

Agilent (and others)

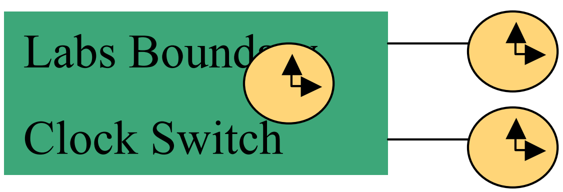


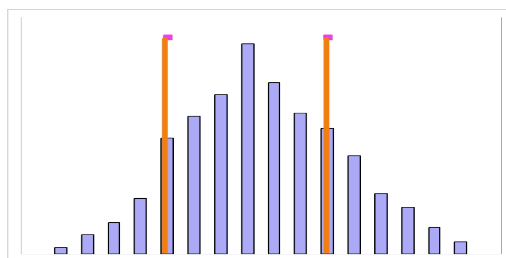
Offset: nanoseconds
Std. Dev: 121 ns
Max/min: -430,+720 ns
RCS switch, 8 hours





Offset: nanoseconds
Std. Dev: 24 ns
Max/min: -100,+100 ns
84 hours



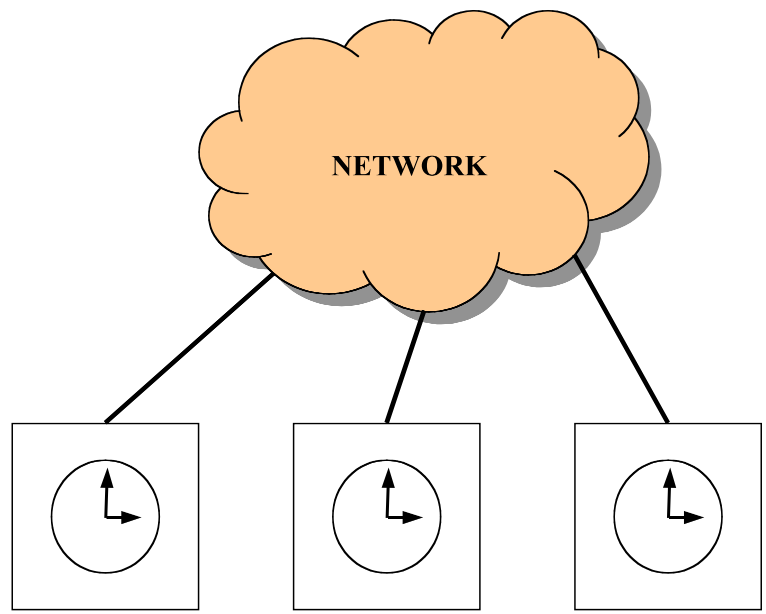


Offset: nanoseconds
Std. Dev: 15 ns
Max/min: -35,+45 ns
1 hour

For all of the above the clock resolution was 20-25 ns

IEEE 1588: Applications

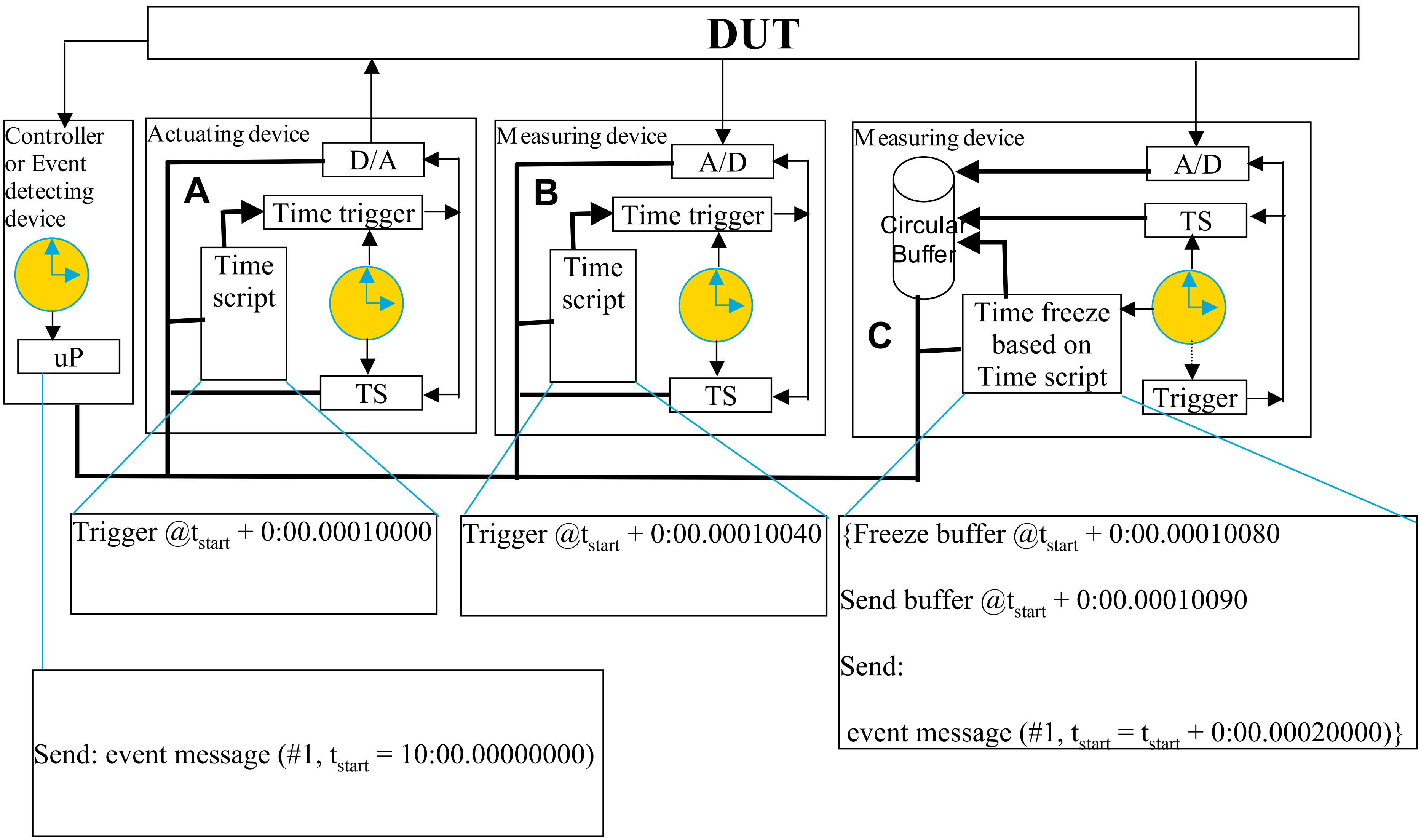
- IEEE 1588 synchronizes real-time clocks in the nodes of a distributed networked system.
- Enables a new methodology for measurement and control
  - BASED ON TIME
  - NOT ON TIME OF RECEIPT BASED EVENT NOTIFICATION.



How synchronized clocks can be used

- **Current systems actions (e.g. sampling an A/D)**
  - Start on receipt of SCPI command or hard-wired trigger.
  - Requires controlling message/trigger arrival times.
- **Time based systems**
  - Actions triggered by comparing local clock to the execution time given in a message or pre-configured in the node
  - Message can arrive ANYTIME before the execution time.
  - Precise control of arrival is unnecessary.
- **Time stamping of data at the source**
  - Determining order and relationship of events in separate devices.
  - Missing or out of sequence data events highly visible

Schedule generated triggers



Commercial IEEE 1588 Activity

Industrial automation:

- Motion control is the performance critical application
- IEEE 1588 stopped the 'non-deterministic' arguments about Ethernet
- Rockwell, Siemens (automation) major programs/product development. Many other smaller companies, particularly in Europe.

Power systems:

- GE Drives & Control: gas turbine controls based on IEEE 1588 are operational in the field
- Interest from GE Power Management (distribution & substation)

Military:

- Progeny is most active with 3 DOD contracts: 2 test related, 1 operational (ship board sonar data logging).

Commercial IEEE 1588 Activity (2)

Telecommunications:

- Proposed for synchronization of services at the edge of metropolitan area networks)
- Nortel and Semtech are most visible proponents: Field tests with carriers in progress

Test & Measurement:

- LXI Consortium, Autotescon

Commercial IEEE 1588 Activity (3)

IEEE 1588 Products Are Appearing:

- IEEE 1588 enabled Ethernet switches:OnTime Networks, Hirschmann Electronics
- 'Ethereal' protocol analyzer (open software)
- Embedded micro-processors with IEEE 1588 cores: Intel.
- Software, hardware, toolkits, consulting: Zurich University, Hirschmann Electronics, Embedded Network Solutions

Commercial IEEE 1588 Activity (4)

Second IEEE 1588 Conference held Sept. 27-29, 2004

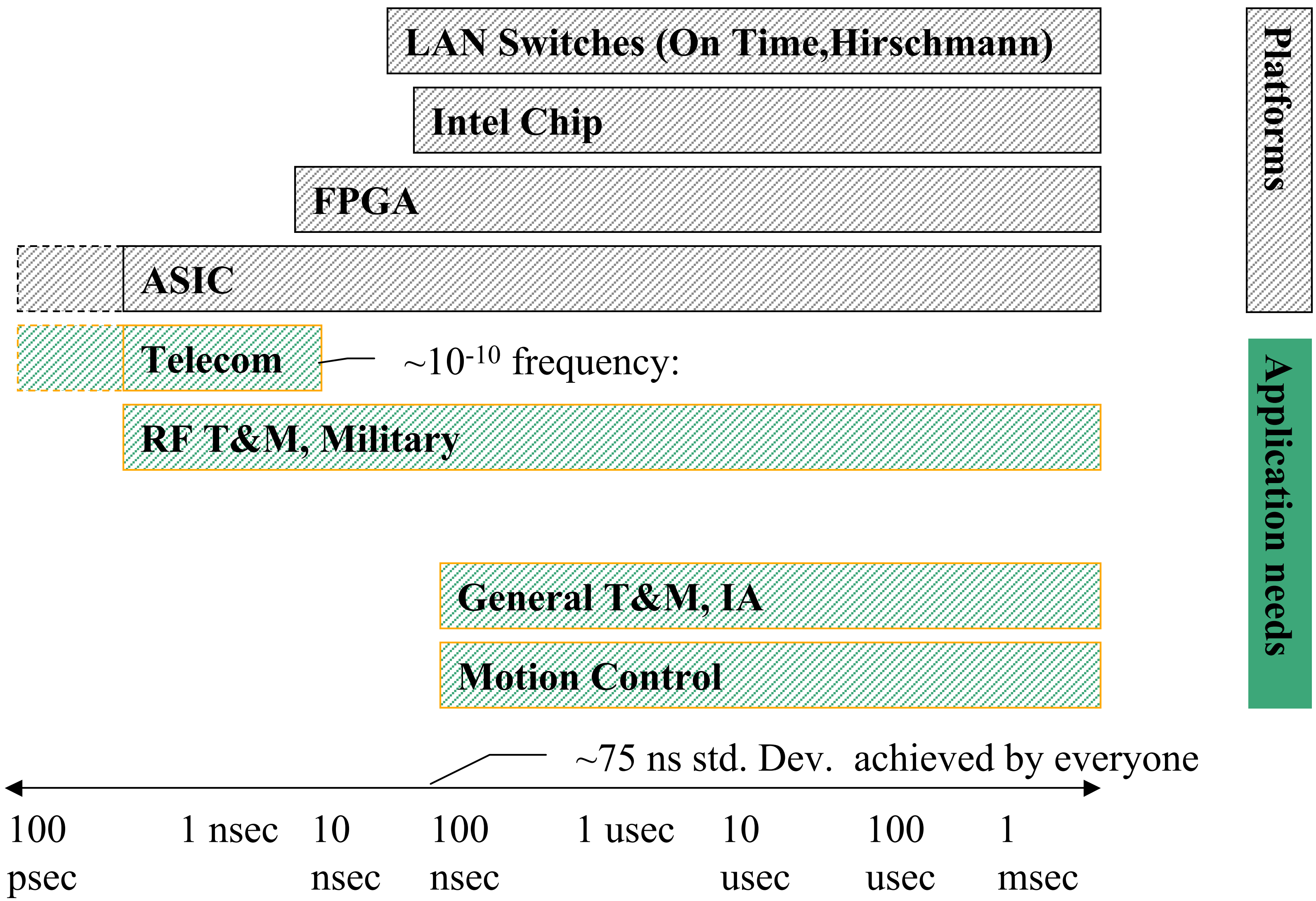
Plug-fest:

- **OnTime Networks, Hirschmann, University of Zurich, Semtech, Siemens, Rockwell, Agilent (distributed protocol analyzer).**
- **Demonstrated interoperable synchronization of products to better than 100 ns overall and ~20 for the more precise clocks.**

Considerable technical and product progress since 2003 conference.

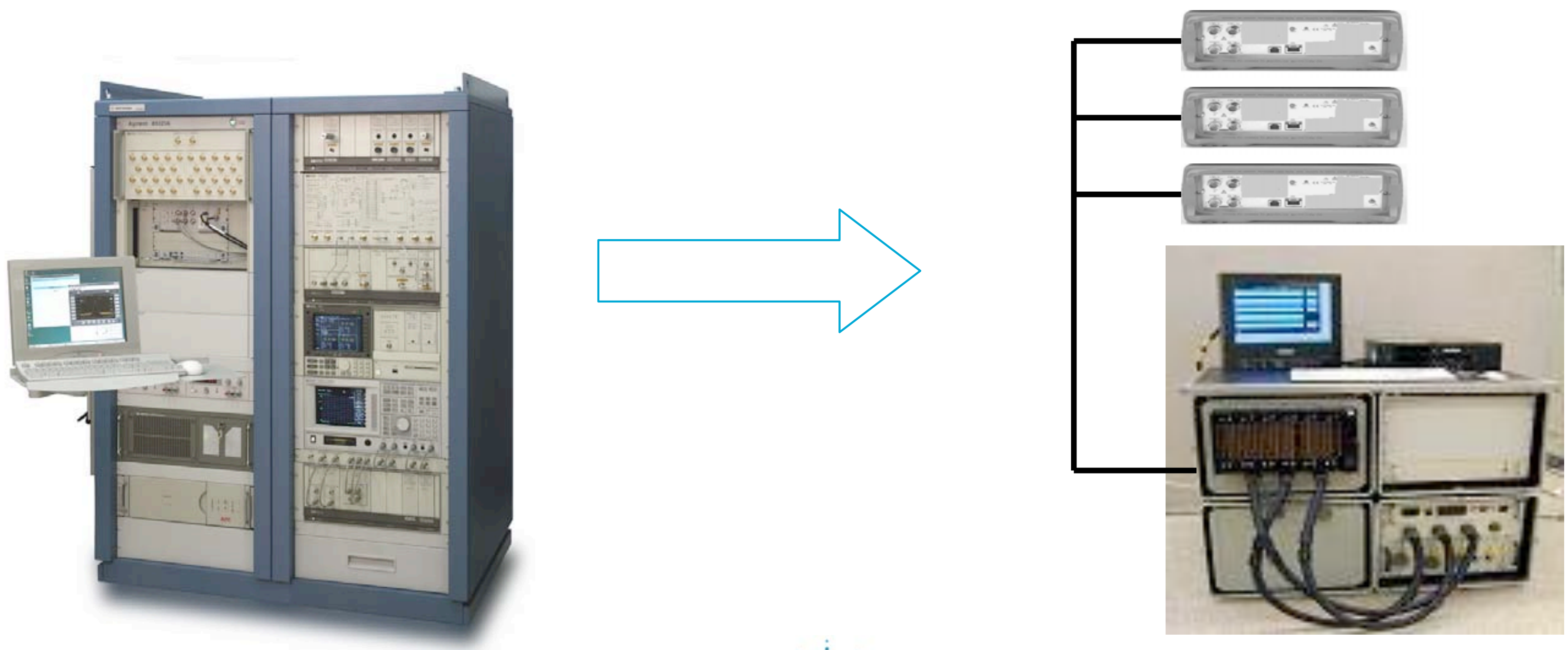
The standard will be reopened for extensions

Synchronization Accuracy



Test and Measurement

1. **Moving from bus (IEEE-488 aka. GPIB) connected instrument systems to network connected modular systems.**
2. **Synchronization needs vary widely with application**
   a. **Low to sub-nanosecond for most demanding**
   b. **Microseconds to milliseconds for less demanding**

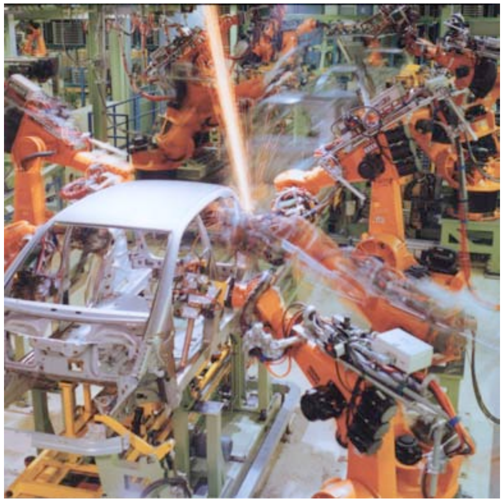


Military Systems

1. Variety of potential applications
   a. Depot and test ranges
   b. Flight test & qualification
   c. Operational systems
2. Requirements very similar to test and measurement

Industrial Automation

1. **Wide variety of applications including:**
   a. **Process control**
   b. **Robotics**
   c. **Packaging machinery**
   d. **Web-processing**
2. **Most demanding synchronization requirements are for high speed printing and similar applications**



60mph = 1 inch/ms = 1 mil/us

Power Industry

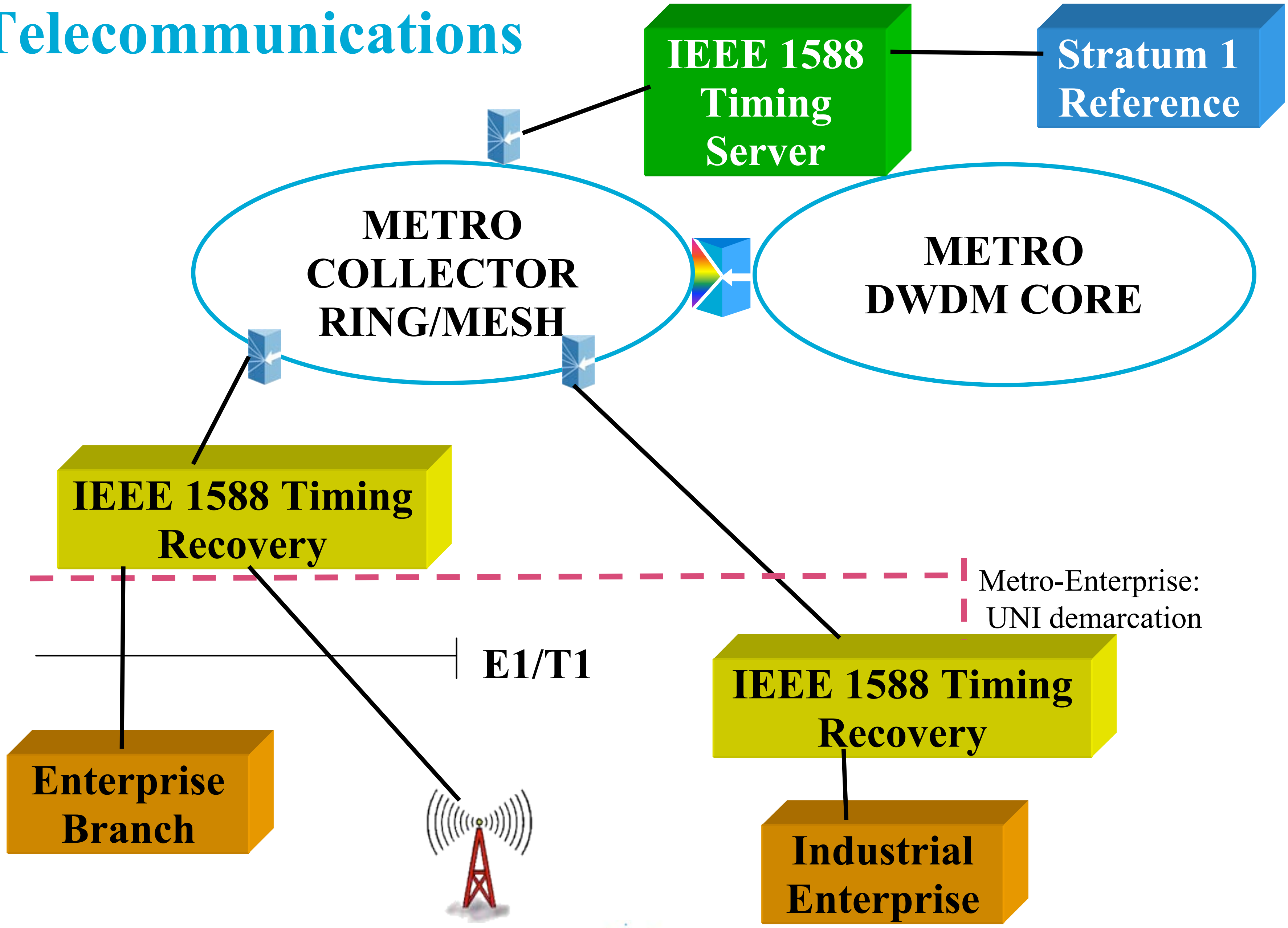
Power generation control

60 Hz -> 16.7 ms

1 deg -> 46 us

Mark VIe Distributed I/O System (Courtesy GE Drives and Controls)

Telecommunications



IEEE 1588 Standards Work Agenda Items:

- Resolution of known errors
- Formal mechanism for extensions
- Conformance requirements for testing
- Management of 1588 systems
- Map to DeviceNet
- Variable headers IPv4, IPv6
- QOS for PTP messages
- Transparent Clocks
- Layer 2 mapping, VLANs
- Short frame options, shorter sync interval
- Redundancy hooks
- Fault tolerance especially master clocks
- Security issues
- Unicast and multicast
- Best practices annex

IEEE 1588 Standards Work

Participants in Working Group (>30)

- Hirschmann
- Kuka
- Siemens-automation
- Rockwell
- Oregano
- National Instruments
- RuggedCom
- Progeny
- US Navy
- Naval Research Lab
- Schweitzer Engineering Laboratories
- Nokia
- Hyperfine
- Spectracom
- Symmetricom
- Zarlink
- Siemens-communications
- Semtech
- Agilent
- Hottinger Baldwin Measurements
- Zurich Univ. of Applied Science
- GE Power Management

Questions?

http://ieee1588.nist.gov

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