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IEEE 1588 Time Synchronization for Real-Time Distributed Systems

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Introduction

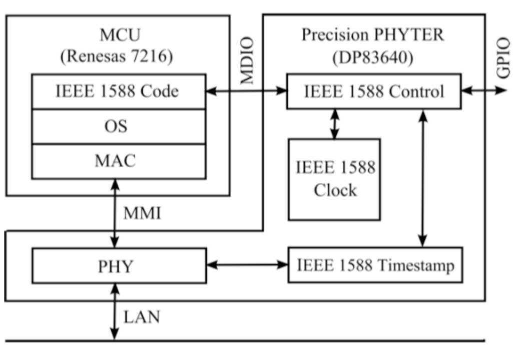
Many real-time distributed systems require some shared notion of time. When measuring or acting on the physical world, the relative times of these actions between devices in a distributed system can be of significant importance. The accuracy required for this time synchronization is application specific, and can range anywhere from seconds to nanoseconds. Some areas which can utilize accurate time synchronization are test and measurement, industrial automation and control, and power generation.

The IEEE 1588-2008 standard defines a Precision Time Protocol (PTP) to synchronize time in a distributed system over a network to the sub-microsecond range. The protocol was developed to bridge the gap between the existing common methods of time synchronization, where Network Time Protocol (NTP) may not be accurate enough and Global Positioning System (GPS) may be too expensive.

IEEE 1588 Basics

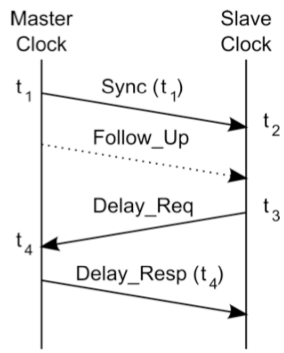
Architecture

The protocol operates on a hierarchical master-slave distribution where slave clocks synchronize their time to master clocks. A best master clock (BMC) algorithm is used to select master clocks. Basically, all clocks in a network exchange information about their stability and accuracy, and the best clock is elected as the master.



Event Messages

Timestamped event messages are used to synchronize the slave clock to the master clock. The event message sequence as shown below typically occurs every second, with the messages being send as User Datagram Protocol (UDP) packets over Ethernet (although other configurations are possible).



Mean Path Delay:

$$t_d = \frac{(t_2 - t_1) + (t_4 - t_3)}{2}$$

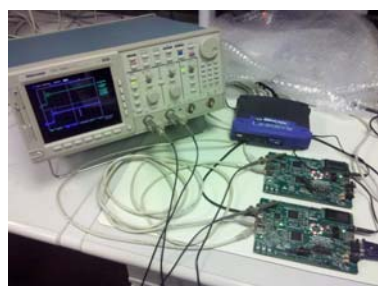
Offset From Master:

$$t_o = (t_2 - t_1) - t_d$$

Implementation

Hardware

The implementation is being developed on a Renesas 7216 Demonstration Kit with a 32-bit RISC SuperH CPU. The DP83640 Precision PHYTER from National Semiconductor is used to provide hardware support for IEEE 1588 in the form of an integrated 125MHz IEEE 1588 clock, packet detection and timestamping with 8ns precision, and synchronized event timestamping and triggering through GPIO ports.

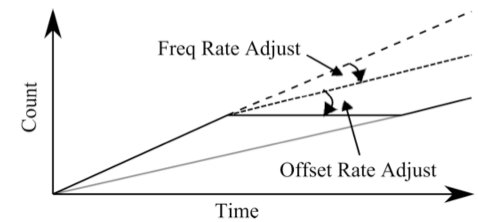


Discrete Event Semantics

The protocol itself is implemented as an actor with discrete event semantics, and is designed for use within the PTIDES (Programming Temporally Integrated Distributed Embedded Systems) programming model. The code is only executed when provided with an input event, and executes to completion without blocking. In order to provide timer functionality, the actor can produce an event to be provided to itself as input at a time in the future.

PTP Servo Algorithm

A clock servo algorithm is used to adjust the frequency of the slave clock. The goal is to match the frequency of the slave clock with that of the master clock to maintain a zero offset between the two clocks. It is important to point out that although the clock value can also be set or stepped, this is to be avoided since it can make past events appear as having occurred in the future.



Results

The basics of the protocol are implemented, and two directly connected boards are able to achieve synchronization within 25ns. Once connected through a router which doesn't support IEEE 1588, time synchronization is only accurate to around 100ns. The implementation was also successfully tested in a network with another implementation of the protocol. Future work involves fully supporting the protocol and tuning the servo algorithm.

Acknowledgments

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