REAL TIME AUTOMATION

IEEE 1588

It’s About Time

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Introduction

Synchronization becomes necessary when devices working at a distance from each other must also work in conjunction. In such scenarios, a local clock, or Master Clock, synchronizes with the device clocks networked within the same system. However, even if two clocks are set at the same rate, there is no guarantee that they will stay in synchronization.

To solve this, the process of synchronization must be continuous. Several factors can cause two identical clocks to lose synchronization. Differences in temperature, the age of the clocks themselves, and the frequency can all affect the quality of synchroniza-tion. These factors created a need for clock synchronization. IEEE 1588 was released as a standard protocol for synchronization in 2002.

IEEE 1588 will synchronize your clocks.

Synchronization

IEEE 1588 provides fault tolerant synchronization for different clocks along the same network. There is very little band-width consumption, processing power, and setup. IEEE 1588 accomplishes all of this using the Precision Time Protocol, or PTP. The time protocol synchronizes all clocks within a network by adjusting clocks to the highest quality clock. IEEE 1588 defines value ranges for the standard set of clock characteristics. The Best Master Clock (BMC) algorithm deter-mines which clock is the highest quality clock within the network. The BMC (grandmaster clock) then synchronizes all other clocks (slave clocks) in the network. If the BMC is removed from the network or is determined by the BMC algo-rithm to no longer be the highest quality clock, the algorithm then redefines what the new BMC is and adjusts all other clocks accordingly. No administrator input is needed for this readjustment because the algorithm provides fault tolerance.

The slave clocks use Bidirectional Multicast Communication to synchronize to the IEEE 1588 grandmaster clock. A 'sync' packet containing a timestamp from BMC includes the exact time that the timestamp left the BMC. The BMC may also send a 'follow up' packet that contains the timestamp of the 'sync' packet. This allows an accurate timestamp of the 'sync' packet by the BMC. There are times when the exact transmission time cannot be known until the entire packet is sent without any collisions detected. This is because of the collision detection and random back-off mechanism of Ethernet/IP communication. Once the packet is completely sent, it is impossible to alter the packet's contents.

The BMC and slave clocks trade 'sync' packets and timestamp the transmissions upon receipt. By combining the slave's offset from the master and network propagation delay, the difference of the 'sync' packet's departure and arrival time-stamps can be calculated. Using the offset measured at this point, the clock can readjust itself and reduce the offset be-tween master and slave the network propagation delay only. The delay between master and slave 'sync' packets, and vice versa, implies that IEEE 1588 operates on the assumption the network propagation delay is symmetrical. It is be-cause of this assumption that slave can determine and adjust for the propagation delay. In order to do this, the slave cre-ates a 'delay request' packet and timestamps the packet upon departure. The master clock then timestamps the packet upon receipt and sends it back to the slave, a 'delay response' packet. The network propagation delay is then deter-mined by finding the delay between these two timestamps.

The sending and receiving processes of the synchronization packets allow the slave clocks to accurately measure and offset the slave's own clock. Standard methods of clock adjustment implementation are not outlined by IEEE 1588; the protocol only provides a standard for the exchange of messages between clocks. The benefit is that clocks from different manufacturers are able to synchronize with each other.

QUALITY OF SYNCHRONIZATION

There are several factors that can affect the exactness of synchronization between clocks within an IEEE 1588 network. Frequency changes in a clock's local timing source, which may occur in between 'sync' packets, can cause a clock to lose synchronization from the other clocks in the same system. In order to counteract any possible lost synchronization, high stability timing sources are available, and the time between 'sync' packets can also be shortened. To further improve the timeline of synchronization, Temperature Controlled Crystal Oscillators (TXCOs) and Oven Controlled Crystal Oscillators (OCXOs) can be used.

A clock's resolution can also affect the precision of the timestamps sent in the precision time protocol. The higher the clock's resolution is, the more accurate the timestamp on the 'sync' packets will be. Jitter from an intermediate networking device, such as hubs and switches, can affect the system's synchronization precision.

Finally, the quality of the Ethernet-based IEEE 1588 system and how it was setup can affect the quality of synchronization. To setup the best synchronized system, one must trade-off between precision of synchronization, cost, and distance needs. For low speed events that do not depend on time, a standard NTP synchronization over internet, which allows for millisecond level synchronization, will suffice. IEEE 1588 is an excellent alternative for systems needing sub-microsecond synchronization in geographically arranged systems.

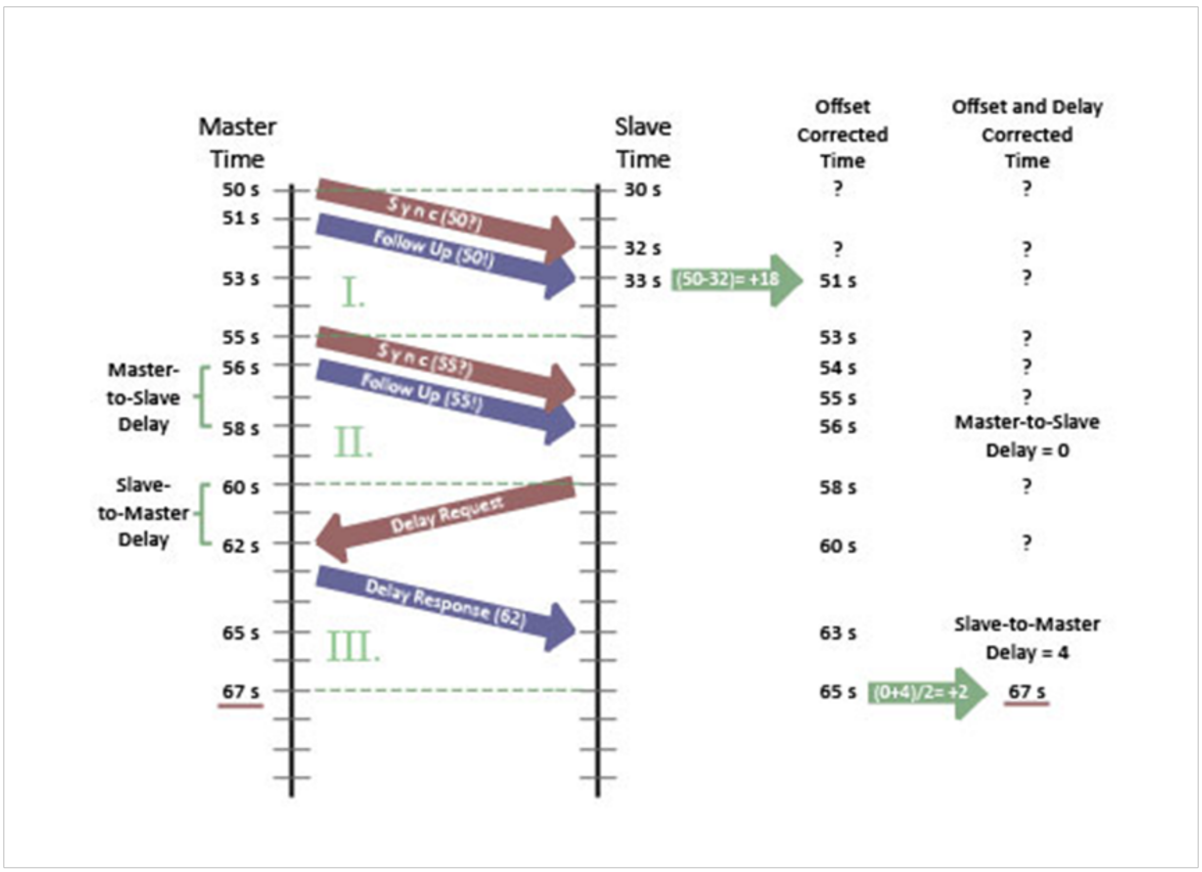

Figure 1 — The IEEE 1588 Synchronization Process

NETWORK HIERARCHIES

IEEE 1588 boundary clocks, also known as transparent switches, are an effective way to reduce jitter found in an Ethernet based IEEE 1588 system. A switch acting as a boundary clock runs the PTP protocol and is synchronized to the master clock. The boundary clock in turn acts as a master clock to all slaves within the same network. Using this setup, all internal latencies and jitter can be compensated for.

Boundary clocks do not pass 'Delay_Resp', 'Delay_Req', 'Follow_up', and 'Sync' messages. The boundary clock's port will behave like an ordinary clock in regard to synchronization with the BMC, and will behave like the BMC within a subnet. The port of the boundary clock that identifies the master clock will be selected as the slave port. Within the selected subnet, this port is a slave. This will then cause all other ports of the boundary clock to synchronize to the slave port. A parent-child hierarchy of master-slave clocks is determined by the boundary clocks. If a cyclic path occurs in the network hierarchy, the best master clock algorithm lowers the logical hierarchy to an acyclic graph.

Transparent switches are an alternative to boundary clocks. A transparent switch does not behave as a PTP node within an IEEE 1588 system. Instead, a transparent switch alters the timing contents of PTP packets to compensate for the delay caused by the switch. The switch then calculates how much time a 'sync' packet spends within the switch and modifies the timestamp of the immediate 'follow up' packet to make up for the delay. PTP nodes can operate as if they were part of a large LAN segment connected by hubs using transparent switches.

USES FOR IEEE 1588

Precise synchronization can be valuable in many applications, including:

- **Telecommunications**
- **Power Plants**
- **Industrial Automation**
- **Test & Measurement**
- **Robotic Control**