Case Studies in Facility-Wide Time Synchronization

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Abstract – Time synchronization of protective IEDs can be critical for analyzing events, compensating for channel asymmetry in distance protection and streaming synchro-phasors. Satellite-based IRIG-B time can be used to provide a precise time signal but still has limitations. This paper examines some of the limitations of IRIG-B as a time source and discusses solutions to many issues as well as alternate timing signals. Case studies examined include: time synchronization across a large industrial facility using IEEE 1588 with multiple vintages of devices, distance limits of IRIG-B signals and time offset coordination for local times.

Introduction

Time synchronization between relays and other IEDs can be either a requirement or a necessity depending on the application of the device. For example, time synchronization is a necessity for merging units used in a process bus architecture, for streaming synchrophasors and for compensating for channel asymmetry in a line current differential. For post-event analysis, proper time synchronization is not a must have, however it can eliminate false information based on inaccurate time in the analysis. Applications that require precise time synchronization require an external time source other than the IED itself. When the IED does not have an external time signal it will keep time based on its own internal oscillator. The accuracy of the time will then be dependent on that oscillator, which can have accuracy similar to a digital watch and drift by as much as plus or minus one minute per month. For protection purposes, one millisecond equates to 22 degrees at 60 Hertz. For these protective applications, micro-second accuracy is necessary. Most IEDs perform a protection pass between 16 to 8 times per power system cycle or every one to two milliseconds at 60 Hertz. Due to this protection pass rate, time synchronization to one millisecond for post-event analysis is usually sufficient.

Typical methods of external time synchronization employed include: IRIG-B clock signal, Simple Network Time Protocol (SNTP) and IEEE 1588 Precision Time Protocol (PTP).

The most common timing method is using an IRIG-B signal. The IRIG-B signal was developed by Inter-Range Instrumentation Group, which was a part of the US Army. The B designation specifies a code format of 100 pules per second. IRIG-B defines the timing signal and the signal is synced to either the time signal of the GLONASS or GPS constellations of satellites. The standard IRIG-B signal sends the present time in seconds of the year without any year information. The IEEE 1344 extensions uses control bits in the signal to provide additional time information signals including the year, leap seconds, daylight savings time, local offset time, time quality, parity, and position identifiers.

The primary limitation with IRIG-B is the number of devices and distance to devices on an IRIG-B circuit. When using a copper connection to IRIG-B this limitation is caused by the current draw of the connected devices, the impedance to the devices, and power output of the clock. The equivalent circuit of the clock output can be seen in Figure 1 below where *n* is the number of devices connected to the clock output. Each device is connected in parallel with either a serial wired connection or a co-axial cable connection. In Figure 1, the IED burden is represented by Z_r and the resistance of the wire is represented by Z_w. The wiring will have a source impedance and a return impedance. With a two-wire serial connection the resistances are typically the same; however, with a co-axial cable the center conductor may have a different resistance than the return conductor. It should also be noted that the characteristic impedance of the co-axial cable does not reflect the actual resistance or burden of the cable.

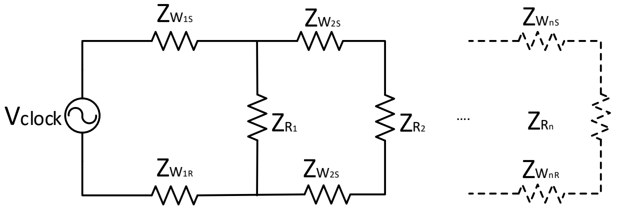

Figure 1: Clock Output Equivalent Circuit

The clock will typically have an output voltage and a maximum current that it can sustain. The limiting factor could be the output power or the voltage drop to the devices, but in practice the limiting factor is more often noise immunity. For this reason, most clock manufactures provide guidelines on the maximum number of devices and length of cable recommended for each clock output. These values are typically limited to 10 devices, and if the cable is longer than 100 meters fiber optic IRIG-B connections to the IED are recommended. Fiber optic IRIG-B signals can extend a much longer distance, but may require the use of a fiber-to-copper converter at the equipment.

Simple Network Time Protocol (SNTP) is an ethernet based protocol. With SNTP, an IED is set to the address of the SNTP server and acquires its synchronized time from that server. SNTP can be as accurate as one millisecond on a local area network under ideal conditions. Since the SNTP protocol does not have a mechanism to deal with variable network latency, it can be heavily influenced by asymmetric routes and network congestion. In a heavily congested network, errors of 100ms or more can be seen. This error and non-deterministic behavior of the signal are the main draw backs to SNTP time synchronization. Since it at best only achieves 1ms accuracy, SNTP is not suitable for protection based applications or synchro-phasors. However, it can be used for synchronization for forensic event analysis, especially if the time server can be placed onto the local area network of the IEDs and traffic can be limited to reduce error on the clock signal. SNTP has the benefit that it requires no additional wiring or hardware other than the clock itself, provided the IEDs are already on a local area network.

Precision Time Protocol (PTP) was initially defined by IEEE 1588-2002 and was revised in 2008 by IEEE 1588-2008. PTP has sub-microsecond accuracy. With this accuracy, it is as accurate as an IRIG-B clock synchronized to GPS time, and much more accurate than an NTP or SNTP clock. PTP can be synched to GPS time with a clock equipped with a GPS antenna. It provides the benefit of synchronizing a large network architecture without the need for multiple GPS synchronized clocks and provides high accuracy for protection applications and synchro-phasors. PTP achieves its accuracy by allowing PTP capable ethernet switches to calculate the network latency.

PTP can synchronize clocks across a network using a master-slave architecture between several different types of clocks: Grand-master Clock, Master Clock, Ordinary Clock, Transparent Clock, and Boundary Clock.

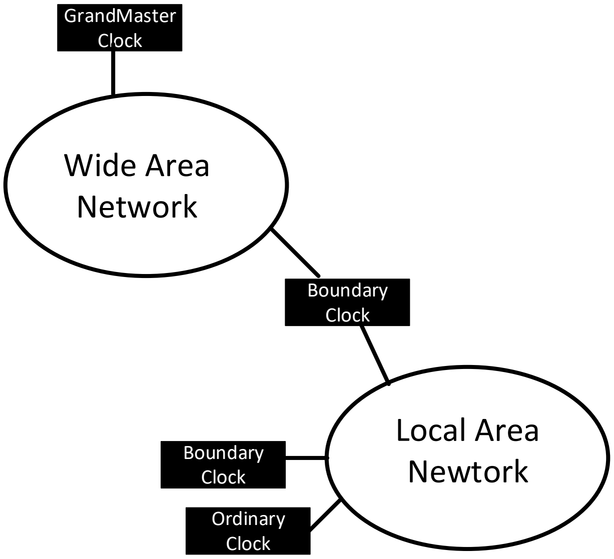

Figure 2: Boundary Clock between network segments

A grand-master clock is the ultimate source of time synchronization across a network. As the name implies, it is the “grand-master”. Master clocks acquire their timing signal from the grand-master and can become the grand-master if the original grand-master is lost due to failure or network issues. The choice of grand-master clock is based on a best master clock algorithm. This algorithm considers clock priority settings, time delay distance, clock class, clock accuracy, clock stability and clock oscillatory accuracy.

A boundary clock is meant to synchronize one network segment to another. This clock has at least two ports, with one port being the slave port that receives the synchronization signal and the other port being the synch port that it publishes the synch signal onto. An Ethernet switch could act as a boundary clock, passing the synch signal from a wide area network into a local area network (see Figure 2 above). In a process bus architecture, the protective IED could also be a boundary clock or a master clock (see Figure 3 below). In Figure 3, the IED could receive a synch signal from the station bus and then send that signal across to the station bus as a boundary clock. Alternatively, the IED could be an ordinary clock for the process bus network, using its IRIG-B signal for its synchronization over a wide area.

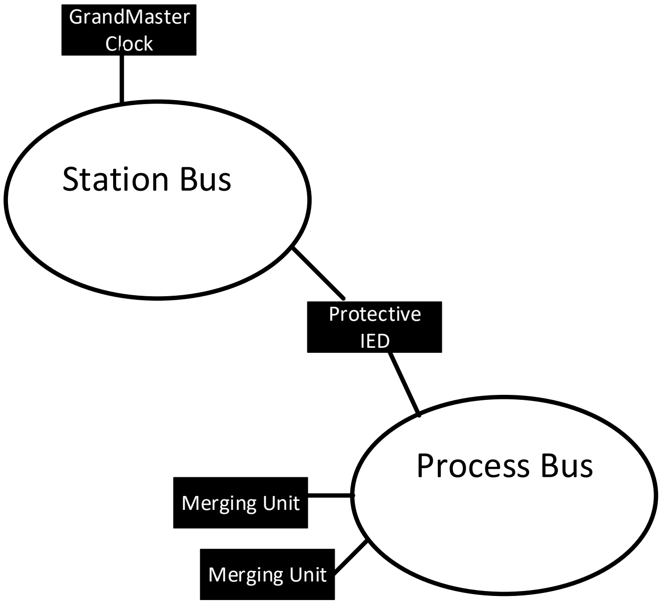

Figure 3: IED as Boundary Clock between segments

An ordinary clock is a device that is either a source or a destination for the synchronization signal. Ordinary clocks typically have a single clock port. End devices or a single clock on a network are ordinary clocks.

I. CASE STUDY I: FACILITY-WIDE SYNCHRONIZATION

Large industrial facilities occasionally require time synchronization for protection; however, most often synchronization is necessary to facilitate post-event forensics. In tightly-coordinated applications (i.e. Zone Selective using GOOSE messaging), accurate timing can be the difference between knowing why the system miscoordinated or assuming what the problem was. Additionally, in load shedding schemes that operate within a few power system cycles, correct time synchronization among devices can make the difference between guessing at a problem and knowing what the problem is during trouble-shooting activities. Inaccurate timing can lead to incorrect conclusions. With accurate timing, issues can be definitively addressed to prevent reoccurrence without adding superfluous delays into the scheme.

In the fast protection schemes required to protect the North American Power Grids, NERC requires timing accuracy of +/- 2ms per PRC-018-1. SNTP or NTP cannot guarantee this accuracy however IRIG and 1588 can. If industrial facilities continue to depend on fast-acting protection and control schemes to reduce electrical stress, enhance safety, increase useful life of assets, and maintain transient stability in much the same way Grid Operators do, industrial facilities should apply the same timing requirements.

The challenge with using an IRIG-B signal in a large industrial facility is that, because of distance limitations, it will probably require multiple IRIG-B clocks. Each clock will require a raceway to route the GPS antenna wiring to the roof to enable time synching with satellites. If an ethernet network is already in place for a DCS system and the IEDs are on the same network, SNTP can be a viable solution, but only if the network traffic can be controlled to maintain the SNTP accuracy. This would also require multiple SNTP clocks throughout the system that are synched to GPS time and would inflict the same challenges as the IRIG-B clocks.

A better alternative for facility-wide time synchronization is to use PTP. In a PTP architecture, the Grand-Master clock can be synched to GPS time and publish time signals across the facility's wide area network. Boundary clocks can then be used to place the synch signal onto the building or switchgear local area networks. Since PTP is a relatively new protocol, not all IEDs may support PTP. In that case, the boundary clock or an ordinary clock can receive the PTP synch signal for its synchronization source and output an IRIG-B signal to the legacy IEDs.

II. CASE STUDY II: LARGE CONTROL HOUSE INSTALLATION

Most control houses fall within clock manufacturer's recommendation of a maximum distance of less than 100 meters and a maximum number of devices per port of less than 10. Since most clocks have 4-8 copper IRIG-B ports, a single clock could synch 40 to 80 devices, which would be more than sufficient for most control houses. The only drawback to using an IRIG-B clock in the control house is the need to wire the signal to each relay. If a local area network already exists within the control house, it reduces the wiring to simply publishing a PTP signal to the local area network and allowing the IEDs to subscribe to the time signal.

III. CASE STUDY III: PROCESS BUS SYNCHRONIZATION

In a process bus protection architecture, the analog quantities of currents and voltages are digitized at the primary equipment and then sampled values of those analog values are transmitted through an ethernet network back to the protective IED, where the sampled values become phasor quantities on which protective algorithms can operate. Time synchronization of these values is very important because a single millisecond can cause 22 degrees of error at 60 Hertz. This error would cause maloperations if not corrected. A timing signal must be present on the network to synchronize the sampled values. On a point-to-point network, the relay itself can easily provide the timing signal. The relay can be a boundary clock as shown in Figure 3 above. In this type of architecture, it is not necessary that each IED be time synchronized with each other or even that each merging unit be synchronized with the others, however all the merging units or merging unit cores that are providing sampled values to an IED must be synchronized to each other. For example, a differential scheme will utilize currents from several different merging units. Each of those merging units must be synchronized to the other merging units in the differential scheme. If the sampled values are required by multiple IEDs in a point-to-point architecture, the merging unit can have multiple cores with each core receiving a time signal from the IEDs to which it is providing information.

In a switched-ethernet process bus, the sampled values are published to the network and then any relay that requires those values can subscribe to them. This publisher/subscriber architecture entails that all the merging units on the network must be time synchronized with each other. Also, since both the network and the time signal are used for protection, redundancy in the network and the time signal is necessary. The redundancy requirements of switched-ethernet process bus typically mean that there will need to be a grand-master and a master clock on the network.

The location of the grand-master and the master clock on a switched-ethernet network can be variable depending on the needs of the architecture. For example, the grand-master and master could both have their clock synch ports on the process bus network and publish the synch values directly. Alternatively, the master-clock could reside on the station bus and publish its clock signal to an IED that acts as a boundary clock with the master-clock, and all the IEDs would receive the time signal from the grand-master via the boundary clock.

The most important concept of the clock synch architecture for process bus is that all the IEDs must be synched, but are not required to be synched to actual time or to time across a large area. This is different than synchrophasors, which require the time to be synched to actual time and be synched across a large area.

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IV. CONCLUSIONS

Motives for the use of time synchronization can range from enabling proper operation of mission critical protection applications, to aiding in accurate event forensics. When considering time synchronization, the extent and criticality of the requirement must match the type of time synchronization and the synchronization architecture. Choices around time synchronization will impact the cost and reliability of the system, thus those choices must be considered with care.

Ultimately, should the protection specifications include all the case studies mentioned above, the best overall solution would be to utilize PTP timing since it uniquely meets all possible requirements.

BIOGRAPHIES

Terrence Smith is the lead P&C Technical Application Engineer for GE Grid Solutions North American Commercial team. He has been with GE since 2008 supporting the Grid Solutions Protection and Control Portfolio. Prior to joining GE, Terrence has been with the Tennessee Valley Authority as a Principal Engineer and MESA Associates as Program Manager. He received his Bachelor of Science in Engineering majoring in Electrical Engineering from the University of Tennessee at Chattanooga in 1993 and is a professional Engineer registered in the state of Tennessee.

Christine Crites is a P&C Technical Application Engineer for the GE Grid Solutions Commercial team, supporting the Midwest US region. Christine received her Bachelor of Engineering Science in Electrical Engineering from the University of Western Ontario in 2012 and immediately joined GE as a Technical Support Engineer supporting the industrial relay product lines in Markham, Ontario. In 2014, she took on her current role as an application engineer based out of Cleveland, Ohio. She is a registered Professional Engineer in the province of Ontario.

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[2] Reason RT430 Manual, Instruction Manual, GE Publication TM-EN-HWA-8v4.