Time Synchronisation

Applying the right IEEE 1588 clock to Achieve Sampled Value and Synchrophasor Performance

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1 Abstract

Protection systems have operated quite well using IRIG-B 1 Pulse Per Second time synchronisation for many years. The IED's internal clock is "pulled back" into line every second to allow the sub millisecond functioning of the IED. This requirement has changed little with the advent of IEC 61850 as GOOSE and MMS message services as these all operate with >1 millisecond resolution domain.

As the industry adopts Sampled Value solutions to complete the Process Bus architecture, much finer time resolution is required as less than <0.2 microsecond. Each sample of the primary voltages and currents must be highly accurately time stamped in order that the protection and power quality algorithms can time align the samples from multiple sources in the facility. This is achieved through the IEEE 1588 so called Precision Time Protocol.

PTP encompasses various clock types throughout the LAN: Grand Master, Boundary, Ordinary and Transparent Clocks using the Best Master Clock Algorithm. The system also incorporates compensation for latency, depending on the clock type, in getting the message from ultimate source to ultimate destination. The clocks generally reside in the network switches with their ports individually configured as a Master or a Slave depending on where they sit relative to the other clocks in the network. The combination of these clocks, along with any non-clock-switches as part of the legacy LAN infrastructure, will determine the end IED synchronisation accuracy and hence performance of the protection system.

This paper provides a "power engineer's explanation" of the IEEE 1588 clocks, appropriate LAN architecture, selection of clock-switch and impact of non-clock-switches on the overall time accuracy in a typical LAN.

2 Time is the essence of automation systems

Just about everything is now "Ethernet enabled", whether it is an electricity substation, a generation site, a wind/solar farm, an industrial manufacturing facility or a mining site. Automation systems are now complex Ethernet networks with dozens, hundreds, thousands of Intelligent Electronic Devices (IED). These devices are providing critical functionality and increasingly needing precision time synchronisation.

IEEE 1588, also referred to as Precision Time Protocol (PTP), is a mechanism to distribute time synchronisation with better than microsecond accuracy over the same Ethernet network to the IEDs. It eliminates the necessity for separate IRIG-B synchronisation cabling.

At first glance, IEEE 1588 appears somewhat complex with its range of clocks: Grand Master, Boundary Clock, Ordinary Clock and Transparent Clock with combinations of Master and Slave ports. Clocks reside in the LAN Switches or in specific IEDs where time must be known inherently within the IED. It is therefore useful to have a common single box switch platform for all requirements including:

- Providing the network LAN itself with high density non-blocking Gigabit switch ports with an array of various wire and fibre field replaceable communication modules for IED connection
- Configurable clocks including Boundary Clock, Transparent Clock and Grand Master Clock with direct GPS antenna input
- Providing localised legacy time synchronisation source

Naturally high reliability of the automation system, and hence of the switches and clocks themselves, is paramount, given that operational environments are nothing like a nice air conditioned office – the network must operate over temperature ranges of -40 to +85 degrees for outdoor applications in the substation yard without fans (requiring special maintenance) and special ventilation requirements. Some application may also require inclusion of dual power supplies and field installable modules just to take the worry out of relying on and maintaining/expansion of the Ethernet LAN infrastructure.

3 Demand for IEEE 1588

Of course there must be an understanding of why new technologies such as IEEE 1588 should be adopted. After all, we have been using time synchronisation in various forms since the first SCADA systems in the 1980's needed to provide a time stamp for all events with resolutions down to 1 millisecond.

In principle the electronic hardware has been able to maintain free running clocks (no specific external synchronisation) with reasonable accuracy, but over long periods of time some drift is possible between clocks in either direction. Hence it became popular to provide simple clock alignment using 1 Pulse Per Second synchronisation to ensure that each clock correctly maintained the same 1 second duration, thus eliminating time drift between clocks.

Typically SCADA resolutions have required

- 1 second to 10 minute polling
- 1 to 10 millisecond time stamp resolution between events
- >100 ms time synchronisation accuracy of the time stamp

Certainly the Inter-Range Instrumentation Group has been a mainstay of that synchronisation process several performance classes (Table 1) including IRIG-B providing:

- Amplitude Modulation
- Pulse Width Modulation (TTL)
- IRIGB-B002
- IRIGB-B003
- Number of IEDs dependant on source capability, cabling and IED burden to achieve minimum voltage on each IED

The IRIG-B system uses a special dedicated network cabling from a synchronisation source to each of the IEDs.

Table 1 IRIG Classes

Code	Bit rate	Bit time	Bits per frame	Frame time	Frame rate
A	1000 Hz	1 ms	100	100 ms	10 Hz
B	100 Hz	10 ms	100	1000 ms	1 Hz
C	2 Hz	0.5 s	120	1 minute	1/60 Hz
D	1/60 Hz	1 minute	60	1 hour	1/3600 Hz
E	10 Hz	100 ms	100	10 s	0.1 Hz
G	10 kHz	0.1 ms	100	10 ms	100 Hz
H	1 Hz	1 s	60	1 minute	1/60 Hz

The 1-Pulse-Per-Second is defined by IRIG-B as shown in Figure 1.

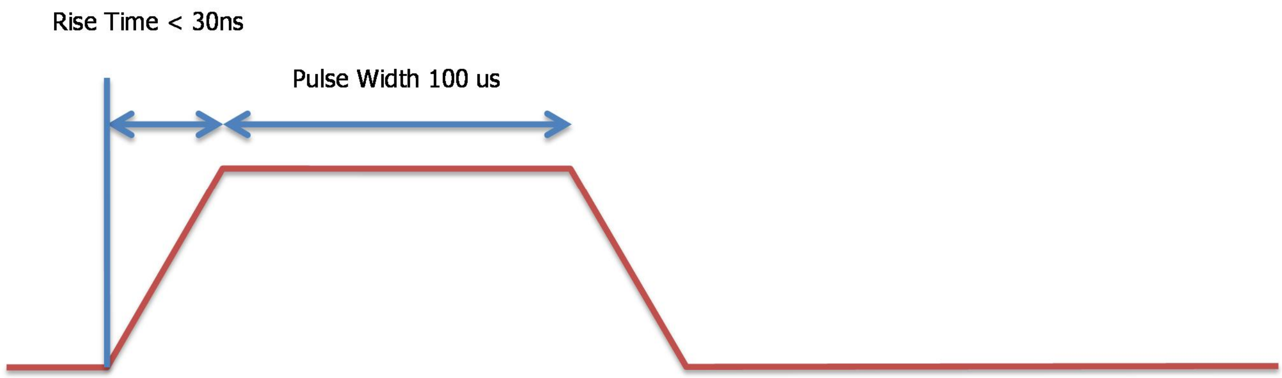

Figure 1 Specification of IRIG-B 1PPS

Distributed protection systems such as numerical Low Impedance Bus Bar protection systems have been successfully deployed using these time synchronisation mechanisms, facilitated by the fact that they were all contained within one controlled proprietary device platform.

However IEDs are now increasingly LAN connected with of course IEC 61850 rapidly being deployed due to its broader engineering process benefits. Therefore there is the opportunity to utilise the same LAN infrastructure to distribute the time synchronisation. Simple Network Time Protocol (SNTP) was developed for this purpose and provided adequate performance for SCADA applications.

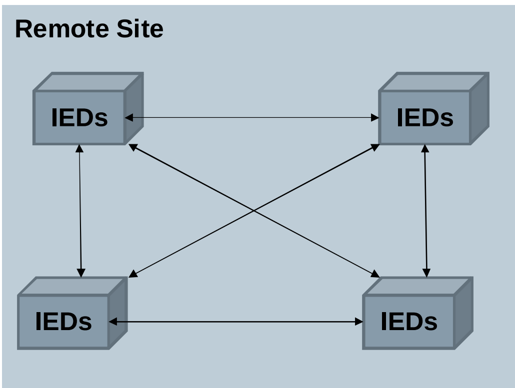

Figure 2 IEDs are LAN connected for direct communication interchange

Since 2004, IEC 61850 introduced the carriage of time critical messages between the IEDs using GOOSE mechanisms over Station and Process Bus networks. In the higher speed requirements, GOOSE requires 4 ms function-to-function latency. However time stamping per se was still only required with the same precision as traditional SCADA i.e. still just “millisecond” resolution.

However IEC 61850 benefits are maximised with the deployment of Sampled Values under IEC 61850-9-2. Sampled Values is the process of sampling the primary current and voltages at 80 or 256 samples per cycle (0.25 or 0.078 millisecond intervals) as shown in Figure 3 at 80 samples per cycle within the 1 second interval indicated by the arrows.

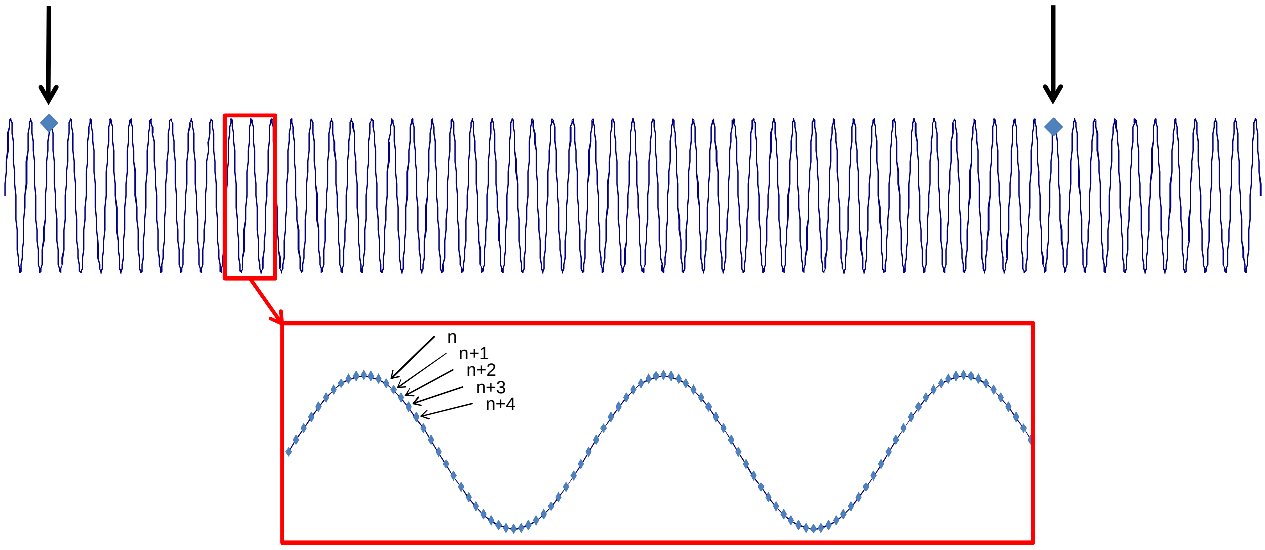

Figure 3 Sampled Values within a 1-Pulse-Per-Second window

Each of these samples needs to be accurately time stamped so that they can be used by the IEDs (protection or metering) in conjunction with other samples taken from other sensors elsewhere in the substation as clearly incorrect calculations will occur if using the “5th sample” in a cycle with the “15th sample in the cycle. This is compounded by the requirement for publishing Merging Units from a variety of suppliers working with a variety of subscriber IED suppliers (e.g. current sensor suppliers, Voltage sensor suppliers, several protection suppliers and meter suppliers) so there is no common controlled proprietary platform.

The process of synchronisation must also cater for the geographical spread of the individual Merging Unit providing the Sampled Values as shown in Figure 3. This presents a significant latency issue of distributing the time source sequentially along a string of IEDs.

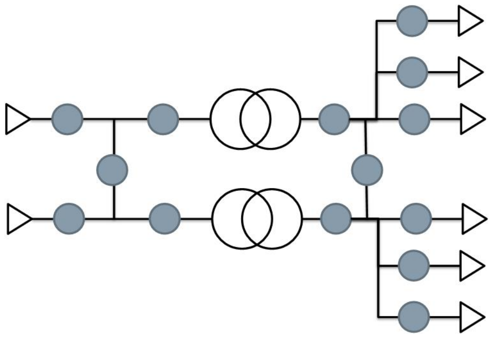

Figure 4 Simple substation with 14 Sampled Value sources

Consequently IEC 61850 Sampled Value requirements demand a much more onerous time synchronisation accuracy and resolution that previously achievable. IEEE 1588 was specifically devised for such requirements less than 1 millisecond resolution.

IEEE 1588 also provides for more than just a 1-PPS signal, including the ability to synchronise the actual clock time- not just the same 1-second interval. This means the Merging Units can all be accurately synchronised so the samples can be identified according to their actual point in time of the sample. That is not to say that each Merging Unit is taking the sample at exactly that same "microsecond" but the actual time is known and hence any interpolation is able to be done accurately by the subscribing IEDs.

4 The Clocks

4.1 Grand Master

At some point, a Grand Master Clock represents an ultimate reference source of time. GPS is the common use system for distributing satellite based time synchronisation. In the recent past, a "forest" of GPS antennae often sprung up on top of buildings linking to individual IEDs. Now a single antenna is connected to the clock to create an IEEE 1588 Grand Master Clock, which then distributes the source clock 'sync messages' over the LAN, eliminating the need for an external stand-alone GPS clock unit.

4.2 Ordinary Clock

An Ordinary Clock must have its own time i.e. tell the time in its own right and must have the ability run as a free running independent clock. However the Ordinary Clock must also be able to be synchronised from another Clock if there is an appropriate Master available as shown in Figure 5. This one port of the Ordinary Clock would be set as the Slave to a Master Clock, i.e. it receives a synchronisation signal from another clock determined as its Master

If there are other downstream clocks, this Ordinary Clock will set all its other ports as Master in order to synchronise those other clocks (which have their connection ports set to Slave).

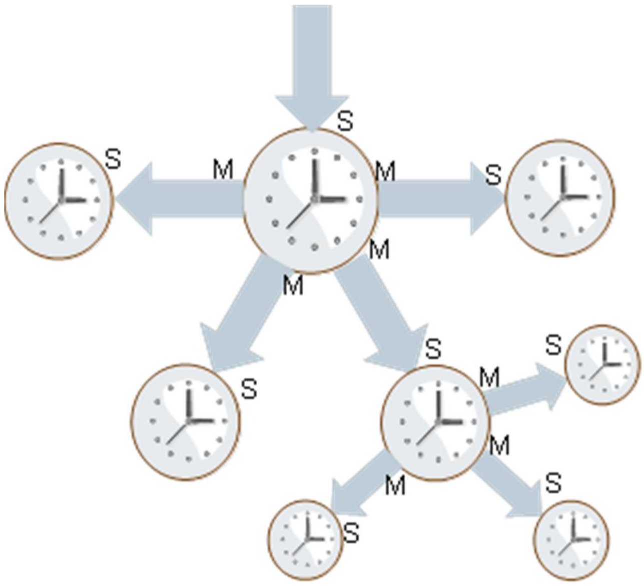

Figure 5 Cascaded Ordinary Clocks with Master-Slave port assignments

4.3 Boundary Clock

The Boundary Clock has two roles in addition to the capabilities of an Ordinary Clock mentioned above:

1. It sits as the source Master within own Time Domain, i.e. all clocks within this domain are in synchronism to this Boundary Clock
2. If there are multiple Master Clocks on the network they determine amongst themselves using the Best Master Clock (BMC) algorithm as shown in Figure 6, which shall become the primary Master Clock and which shall become the Backup Master Clock(s).

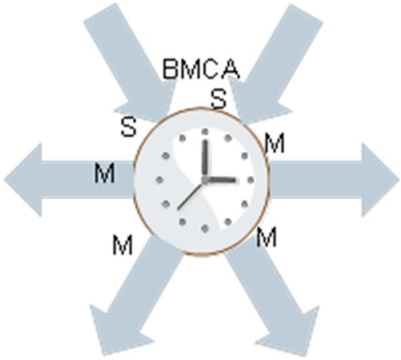

Figure 6 Best Master Clock Algorithm selects time reference for its downstream time domain

4.4 Transparent Clock

On the other hand, a Transparent Clock is not a "Clock" at all, i.e. it can't "tell" time in its own right. However it can receive a sync message and pass it on to other clocks, i.e. none of its ports are Masters or Slaves. The Transparent Clock is effectively a "timer" which can adjust the time synchronisation message for internal latency of the Transparent Clock. In Figure 7, it is receiving a message stating the time is "--:--.75". The Transparent Clock has an internal latency (residence time) of "2" and hence the outgoing synchronisation messages are corrected to show the time as "--:--.75 + 2" for all downstream clocks as shown in Figure 3. The downstream Clocks are still synchronised to the upstream Ordinary/Boundary Clock using the corrected Transparent Clock message.

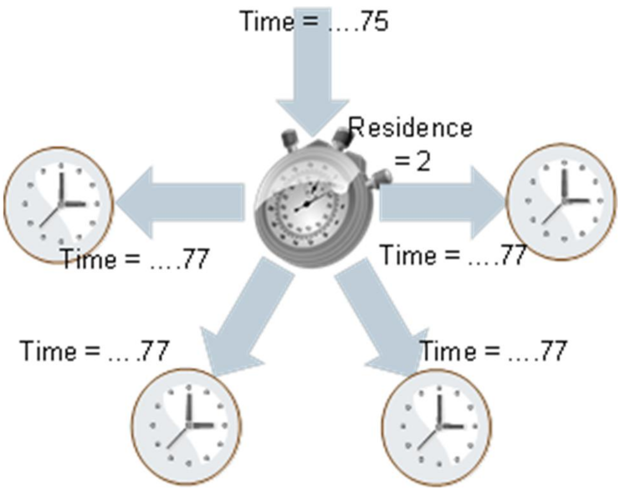

Figure 7 Transparent Clock "adjusts" the time message for residence time, but is not a clock itself

4.5 Legacy Clock Support (IRIG-B)

The final aspect is to recognise that there are many "legacy" devices that still need either a full IRIG-B time frame or at least a "1 Pulse Per Second" synchronisation. The RSG2488 optional PTP module therefore also provides the choice of these legacy outputs in order to allow a common hardware platform throughout the time synchronisation domain as shown in Figure 8. Distribution of the legacy time synchronisation source can provide significant benefits in reducing the associated independent cabling.

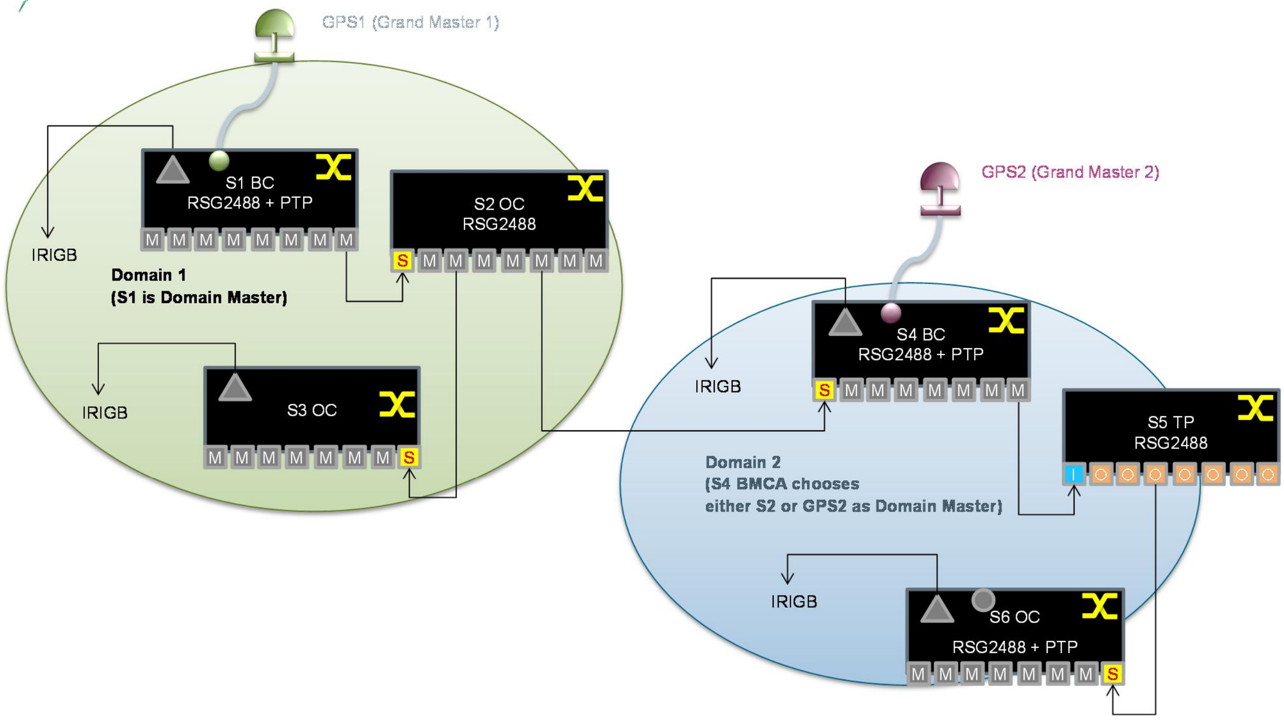

Figure 8 Complete substation LAN time synch domain with IRIGB support

Figure 8 shows two Grand Master sources and hence switch 1 (S1) in Domain 1 and switch 4 (S4) in Domain 2 must use the BMCA to decide which shall be used as the time reference in the respective domains.

Within the Domains there may well be combinations of Ordinary Clocks and Transparent Clocks together with "localised" legacy source time synchronisation requirements.

It is to note that IEC 61850-9-2LE (issued by the UCA International Users Group) specifies the Merging Units to have a fibre optic 1PPS time synch input as it was released prior to the viability of IEEE 1588 for these applications. IEC 61869 will soon define Merging Unit equipment and will include IEEE 1588 synchronisation.

As can be seen in Figure 9, a field switch providing connectivity to primary plant has a significant port density requirement with large bandwidth requirements for several Merging Units at each location.

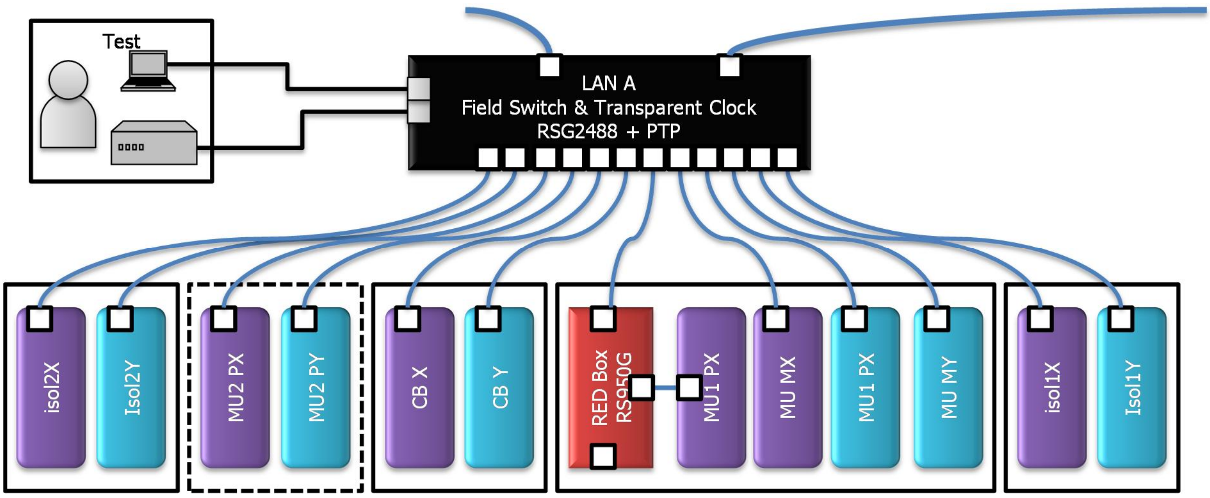

Figure 9 Field Switch port density and synchronisation distribution

5 Evolution of IEEE 1588 with Substation LANs

Various LAN architectures have been devised to provide the reliability demanded of real time critical infrastructure. Some of these concerns relate to network recovery times even associated with eRSTP networks. There has therefore been the evolution of the two “bumpless” architectures of High-availability Seamless Redundancy (HSR) and Parallel Redundancy Protocol (PRP). These mechanisms essentially send messages simultaneously on two different IED ports. If the IED is a single port “Single Attached ode” IED, it is necessary to use a Redundancy ox (Red Box) to interface the IED to the two paths. The receiving IEDs simply use the first message it received on either of its ports, thereby ensuring bumpless operation in the event of a break in the communication path for any reason.

IEEE 1588 Precision Time Protocol (PTP) will work over both HSR and PRP networks provided there is just a single Grand Master source.

However as is typical in substation requirements, there may be two Grand Master sources in order to provide hardware redundancy of the Grand Master itself. In this case, two potential sources of time messages exist, each issuing duplicate messages nominally representing the same time. It is still necessary that each IED is synchronised to the same Grand Master. Implementation of individual Boundary Clocks in each IED as shown in Figure 10 will not necessarily achieve that and hence there is currently some ongoing standardisation work between the IEC and IEEE Working Groups to determine the final solution. In the meantime PRP/HSR must use a single Grand Master or the networks bust be configured such that the two Grand Masters operate over independent LANs, potentially using

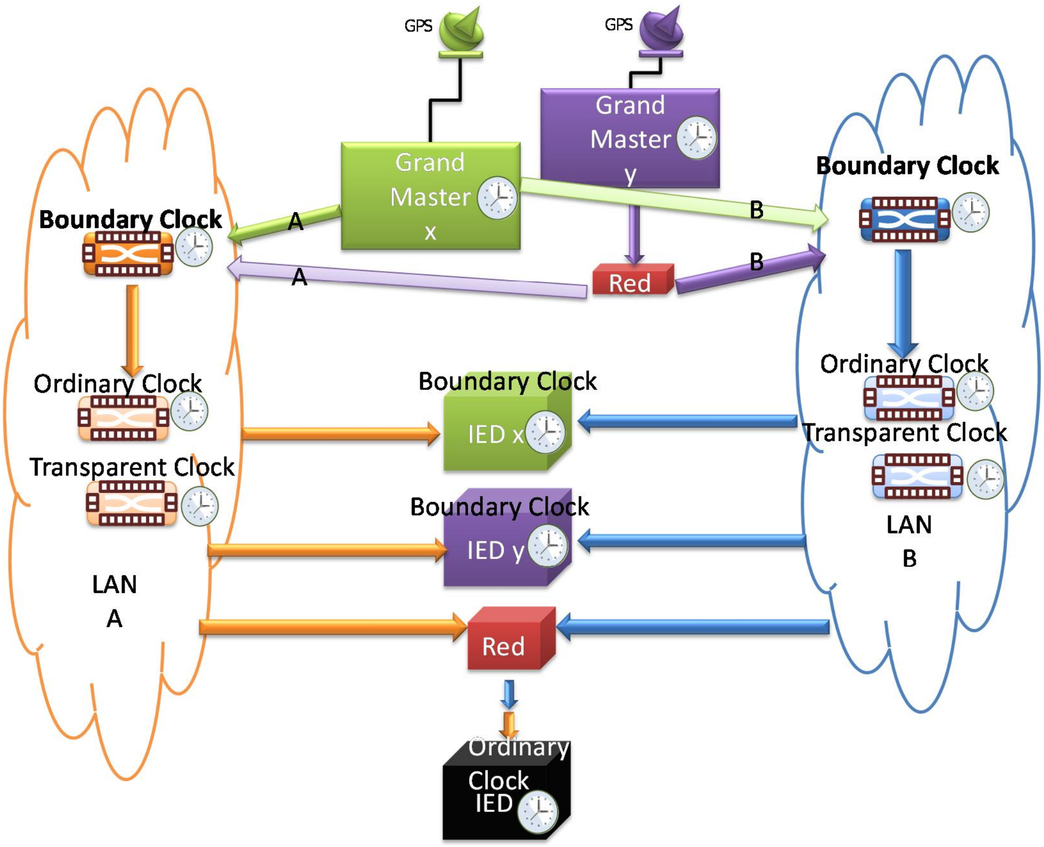

Figure 10 PTP over PRP

6 Conclusion

IEEE 1588 Precision Time Protocol provides the fundamental capabilities to achieve the sub-microsecond precision critical in Substation Automation Systems.

Several types of Clocks can be configured for different purposes throughout the LAN and must be provided with the same hardware reliability as the IEDs themselves. It is also useful to provide legacy synchronisation sources such as IRIG-B but over much reduced cabling requirements.

The overall switch requirements can therefore be summarised as

- Substation rugged construction
- GPS antenna connection as Grand Master
- Configuration as Ordinary/Boundary/Transparent Clock
- High port density
- Layer 2 switch operation
- 1 Gb/s bandwidth
- IRIG-B outputs

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Biography: Rodney Hughes

Rod Hughes has over 33 years' experience in the power industry across New Zealand, Australia and internationally specifically involved in protective relay, instrumentation and metering solutions. He is recognised as a thought leader in deployment and management of intelligent systems and is one of the longest serving members of the CIGRE Australia B5 Panel, including winning two Merit Awards. He is always keen to assist the industry at large, and is a prolific contributor to protection and IEC 61850 forums on LinkedIn. He has served in senior management roles with a vendor (including France for three years), utility and consulting firms including his own private consulting focused on IEC 61850 deployment and change management advisory along with vendor-agnostic training services. He is now also the Business Development Manager for Siemens Ruggedcom responsible for support of network solutions for the power industry.