Remote Synchronization of Multiple Ultrafast Multi-channel Time Taggers

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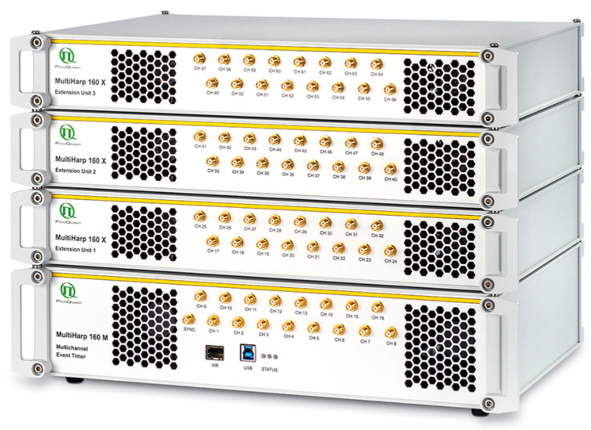
PicoQuant

Devices for Time-Correlated Single Photon Counting (TCSPC) and continuous time tagging of photon arrival times play a central role as crucial building blocks for emerging quantum technologies. Recent technological initiatives towards quantum communication / quantum internet demand smart concepts that allow time synchronous measurements at different places with sub-nanosecond precision. Here, we present a new scalable concept of multi-channel event timers which are compatible with White Rabbit technologies [1] for accurate long-distance synchronization. The relative timing precision across devices synchronized via the White Rabbit timing protocol is benchmarked in different network topologies.

[1] J. Serrano, P. Alvarez, M. Cattin, E. G. Cota, P. M. J. H. Lewis, T. Wlostowski et al., „The White Rabbit Project", Proc. ICALEPCS TUC004, Kobe, Japan (2009).

Scalable multi-channel event timers

With the MultiHarp 160, PicoQuant recently released an event timer with 16+1 input channels with 5 ps time resolution and <45 ps rms jitter as a new member of the MultiHarp product family. It is scalable via extension units of 16 channels up to 64+1 independent synchronous input channels. The data from all input channels are handled via a single data stream that is accessible via the USB 3 interface.



The MultiHarp 160 comes with an ultra-short dead time (<650 ps, no dead time across different channels), an additional data interface to external FPGAs to enable high throughput onthe-fly analyses, and a variety of different features for hardware control and device synchronization.

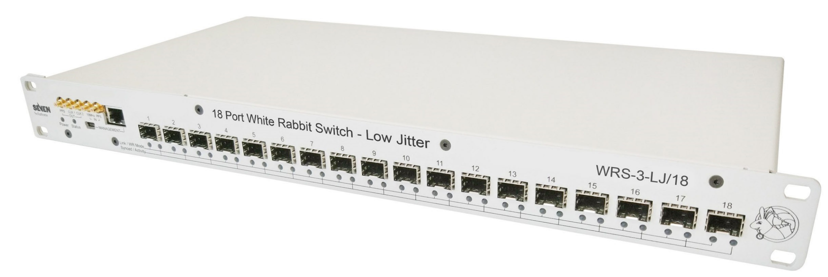
The White Rabbit interface is one of these synchronization features. It is dedicated for a precise synchronization of devices over large distances.

White Rabbit

White Rabbit is a collaborative Open Source project aimed at realizing an Ethernet-based network permitting simultaneous sub-nanosecond synchronization and data transfer at Gigabit speed. To achieve this, it employs both modified Synchronous Ethernet (SyncE) and modified Precision Time Protocol (PTP v2.0). It is standardized as PTP IEEE-1588-2019 High Accuracy.

In a White Rabbit network, time is distributed in a tree topology from a grandmaster device down to other devices. On each link there exists a master-slave relationship between the two devices, with the master passing down its own time information to the slave. Through the use of optical fibers and the calibration of devices, the propagation delay of the White Rabbit messages can be measured very precisely. This way, the devices can be synchronized to a much better degree than through normal PTP.

A White Rabbit capable switch is a special device that can receive timing infomation from another White Rabbit device on one port and distribute it to all others. This way, arbitrarily large networks can be constructed. One such device is the WRS-3-LJ/18 White Rabbit Switch low jitter, produced by Seven Solutions (Granada, Spain), offering 18 ports.

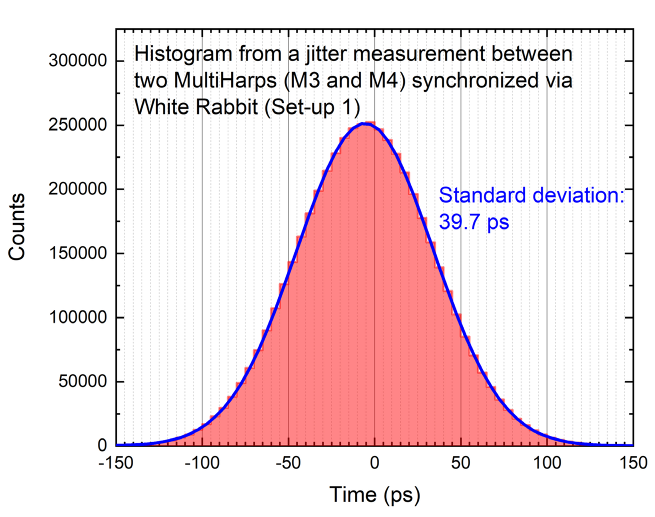


Multi-device synchronization of event timers via White Rabbit

Five multi-channel event timers were connected through low-jitter White Rabbit switches in four different timing network topologies of varying complexity. The devices shown at the top of the topology diagrams act as the timing masters who pass their timing reference to the devices below. This is done via optical fibers connected to transceivers at the device's White Rabbit ports (SFP-1000BX10-U4 and SFP-1000BX-D4). This way, all event timers in the networks are synchronized.

The signal from a pulse generator (PicoQuant PDL 800-D) was fed through an impedancematched 5-way passive fan-out into one input of each of the event timers. The quality of the synchronization is benchmarked by recording the pulse arrival times at all 5 devices and analyzing the jitter in their time differences.

Different optical fiber lengths were used for each experiment (0.6 m, 1 km and 5 km). No significant impact of the fiber lengths on the jitter was observed.



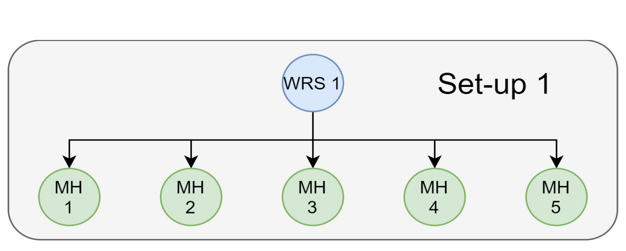
Device Identifier	Product Name	Jitter between two local channels
MH1	PicoQuant MultiHarp 160 (MH160-M)	32 ps rms
MH2	PicoQuant MultiHarp 160 (MH160-M)	32 ps rms
MH3	PicoQuant MultiHarp 150 (MH150-16P)	40 ps rms
MH4	PicoQuant MultiHarp 150 (MH150-16P)	34 ps rms
MH5	PicoQuant MultiHarp 150 (MH150-8P)	32 ps rms
WRS1	Seven Solutions White Rabbit Switch (WRS-3-LJ/18)	
WRS2	Seven Solutions White Rabbit Switch (WRS-3-LJ/18)	

Set-up 1:
The White Rabbit switch is the timing master for 5 event timers that are on the same hierarchy level. The synchronization in this topology hardly affects the jitter across the devices. All observed rms jitter values (ranging from 38.2 ps to 40.5 ps) are still within the official event timer's jitter specifications.

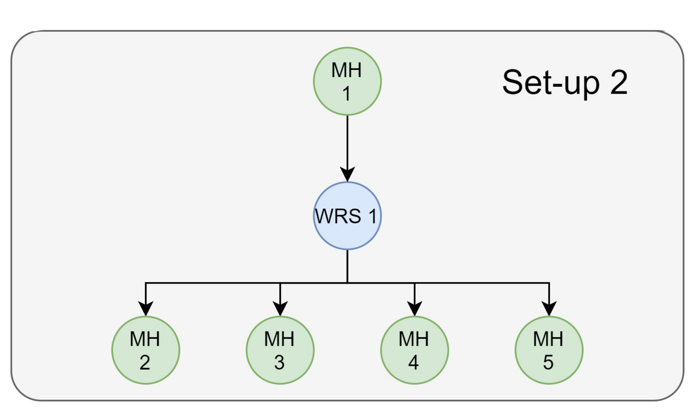
Set-up 2:
One event timer is the timing master and passes its timing reference to the other 4 event timers via the White Rabbit switch. The jitter results are similar to setup 1.

Set-up 3:
In this setup, another layer is added compared to setup 1 by adding a second White Rabbit switch. The spread of the observed jitter values is larger compared to the setups 1 and 2. While most pairs show almost jitter values as low as before, the results from the pair MH2/MH3 indicates that an increasing complexity of the topology can lead to larger jitter across synchronized devices compared to the device specifications.

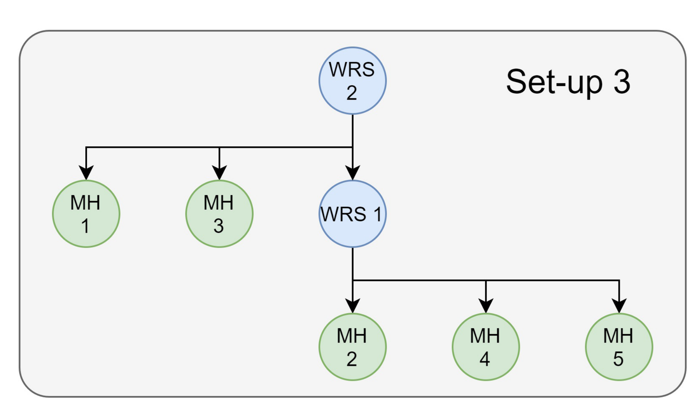
Set-up 4:
This setup is the topology with the most layers that can be constructed with 5 event timers and 2 switches. In addition, a data rate around 920 MBit/s was exchanged between PC1 and PC2 over the same fibers used for the synchronization (iperf3 benchmark in TCP/IP mode over a 1Gbit/s Ethernet connection using IPv4). No degradation of the timing jitter was observed while benchmarking the data rate.



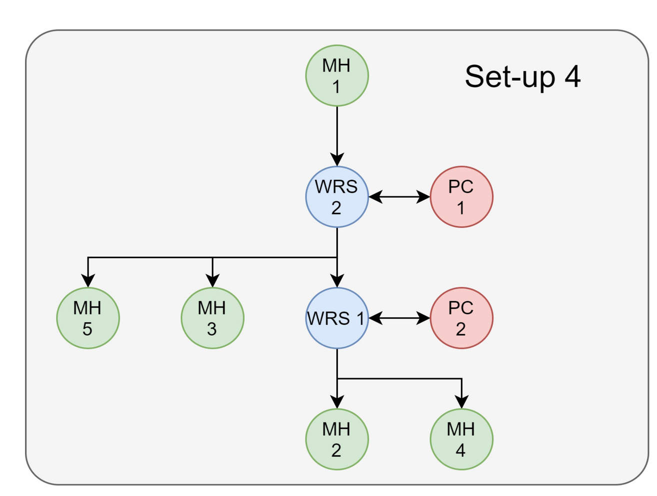
Set-up 1	MH1	MH2	MH3	MH4	MH5
MH1		38.7ps	39.0ps	38.7ps	38.2ps
MH2	38.7ps		39.9ps	39.7ps	40.0ps
MH3	39.0ps	39.9ps		39.7ps	40.5ps
MH4	38.7ps	39.7ps	39.7ps		39.9ps
MH5	38.2ps	40.0ps	40.5ps	39.9ps	



Set-up 2	MH1	MH2	MH3	MH4	MH5
MH1		38.8ps	39.3ps	39.2ps	39.0ps
MH2	38.8ps		38.5ps	40.2ps	40.0ps
MH3	39.3ps	38.5ps		39.8ps	40.1ps
MH4	39.2ps	40.2ps	39.8ps		40.0ps
MH5	39.0ps	40.0ps	40.1ps	40.0ps	



Set-up 3	MH1	MH2	MH3	MH4	MH5
MH1		39.5ps	41.5ps	39.4ps	38.3ps
MH2	39.5ps		46.3ps	40.5ps	39.9ps
MH3	41.5ps	46.3ps		44.9ps	43.9ps
MH4	39.4ps	40.5ps	44.9ps		39.5ps
MH5	38.3ps	39.9ps	43.9ps	39.5ps	



Set-up 4	MH1	MH2	MH3	MH4	MH5
MH1		41.0ps	40.1ps	41.5ps	38.0ps
MH2	41.0ps		40.7ps	39.4ps	40.5ps
MH3	40.1ps	40.7ps		44.9ps	43.5ps
MH4	41.5ps	39.4ps	44.9ps		39.5ps
MH5	38.0ps	40.5ps	43.5ps	39.5ps	

Conclusion

In this experiment we tested the applicability of White Rabbit synchronization for MultiHarp devices and demonstrated the flawless interoperability with the WRS-3-LJ/18 by the world leading White Rabbit component manufacturer Seven Solutions.

For the investigated topologies, the White Rabbit synchronization of the event timers comes with little to no reduction of the timing precision compared to the precision between local channels. This enables precise time-synchronous event timing at different locations. The Ethernet performance of the White Rabbit switch was close to the theoretical maximum and the Ethernet transmission did not influence the timing precision.

Acknowledgments

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