PROTOTYPE OF WHITE RABBIT NETWORK IN LHAASO

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Abstract

Synchronization is a crucial concern in distributed measurement and control systems. White Rabbit provides sub-nanosecond accuracy and picoseconds precision for large distributed systems. In the Large High Altitude Air Shower Observatory project, to guarantee the angular resolution of reconstructed air shower event, a 500 ps overall synchronization precision must be achieved among thousands of detectors. A small prototype built at Yangbajin, Tibet, China has been working well for a whole year. A portable calibration node directly synced with the grandmaster switch and a simple detectors stack named Telescope are used to verify the overall synchronization precision of the whole prototype. The preliminary experiment results show that the long term synchronization of the White-Rabbit network is promising and 500 ps overall synchronization precision is achievable with node by node calibration and temperature correction.

INTRODUCTION

The Large High Altitude Air Shower Observatory (LHAASO) project is a dedicated instrument for searching the origin of galactic cosmic rays, which consists of 4 sub-detector arrays. The 1km^2 complex array (LHAASO-KM2A) includes 5635 scintillation electron detectors and 1221 muon detectors. 500 ps (rms) overall synchronization precision must be achieved among the spread thousands of detectors to guarantee the angular resolution of reconstructed air shower event. [1][2] A small prototype based on the White Rabbit (WR) network [3][4] is built at Yangbajin, Tibet, China on August, 2014. This paper talks about the deployment and synchronization monitor of the prototype.

DEPLOYMENT

Components and Topology

This prototype contains 4 WR switches and 50 WR customized nodes (48 electron detectors and 2 muon detectors). Rubidium clock constrained GPS receiver takes the clock and frequency source of the whole network. The four WR switches is used to build a four layer hierarchy WR network. The grandmaster switch (GMS) uses the frequency from GPS receiver and synchronizes its time (seconds counter) through NTP protocol from GPS receiver. Each WR node synchronizes its local clock against the GMS through fibres of one hundred meters and uses the synchronized clock to timestamp the events. Detail information of each component is listed below:

- 8040C, Rubidium Frequency Standard
- XL-GPS, produced by symmetricom
- WR switch, version V4.0.1
- Compact Universal Timing Endpoint (CUTE) [5], customized WR node, WRPC version V2.1. [6]

Locations

The prototype is deployed in the ARGO experiment hall whose altitude is around 4300m. The locations of WR switches and nodes are showed in Figure 1.

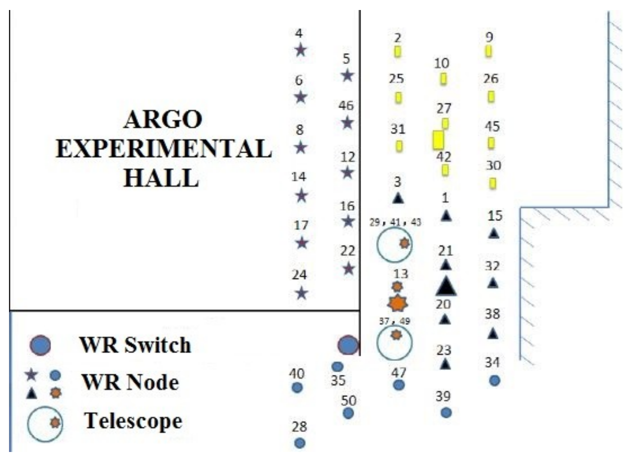

Figure 1: Locations of WR Switches and Nodes

Rubidium Frequency Standard, GPS, GMS and host computers are put in the ARGO Experiment Hall with small temperature variations, while the other three switches are put together in a waterproof steel box out of the Experiment Hall. A normal switch is used to connect the GPS network interface (acts as NTP server), host computer and all four WR switches for remote control.

The telescope is a pyramid of several WR nodes for monitoring the synchronization between the nodes. One node is on the top of another node to make sure they detect the same signal simultaneously.

Calibration Procedure

By following the calibration procedure given in the document [7], a node by node calibration is applied on all WR devices to conquer the differences caused by the components diversity.

As the bad control of the power noise in these boards, the synchronization precision (standard deviation value of the Pulse Per Second (PPS) skew) of each link is decreased to 100ps. Then the synchronization accuracy (absolute mean value of the PPS skew) less than 200 ps after calibration is accepted.

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ISBN 978-3-95450-148-9

Temperature Correction

Previous experiments have shown that the temperature variations have significant impacts on the synchronization performance of CUTE WR nodes. It can be reduced using the method discussed in [8] and a unified temperature coefficient is used for all nodes.

SYNCHRONIZATION MONITOR

The prototype has been working for about a year. Several methods are applied to measure and monitor the synchronization performance of the WR based network.

Portable Calibration Node

A portable calibration node (PCN) is a normal CUTE WR node put in a water sealed, vibration protected box. It is directly connected with and synced to the GMS through a shield optical power composite cable. So it can be used as a reference clock for other distributed WR switches and nodes to monitor the synchronization performance. Figure 2 shows the measured PPS skew between PCN and GMS while Figure 3 is that between PCN and other switches after the prototype is deployed. The latter measurement lasted for more than 20 hours when the temperature varied from 10 to 26 centigrades.

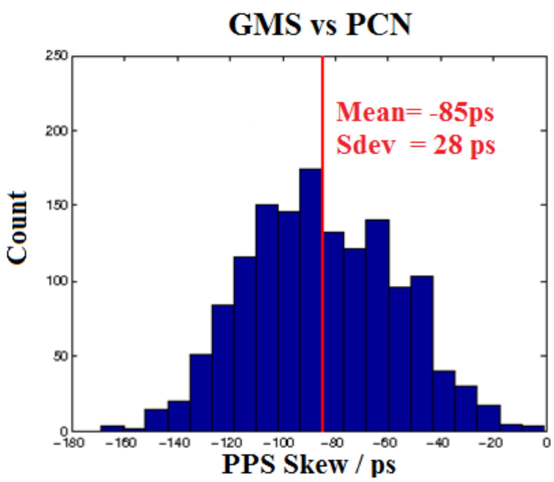

Figure 2: PPS skew between PCN and GMS

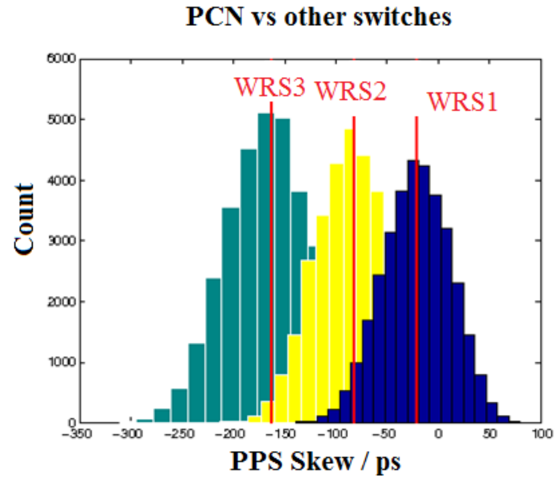

Figure 3: PPS skew between PCN and other switches

Table 1: PPS Skews Between PCN and CUTE WR Nodes

Node Index	Accuracy (mean) / ps	Precision (sdev) / ps
2	-138	100
5	-56	28
8	28	28
12	-27	150
16	5	28
17	-15	162
24	97	156
32	-40	34
39	-28	41
42	-157	135
44	-102	26
50	-45	34

Table 1 lists the measured PPS skews between the PCN and some CUTE WR nodes. Each measurement contains more than 300 samples. As the WR protocol is integrated with the detector electronics, the bad synchronization precision of some nodes is caused by the power noise of the main board which will be reduced in the future design.

Remote Status Monitor

In order to monitor the running status of the WR nodes, a simple network protocol is applied to get the values of timing related registers periodically. The WR link will rebuild after detecting a very large “clock offset” or “skew” value. It is done by remote restarting the WR switches or power off and on the WR nodes manually.

In the future, the etherbone protocol [9] will be integrated into the WRPC core to get a better remote

ISBN 978-3-95450-148-9

control, as well as supporting remote flash update and multi-boot.

Telescope Results

The telescope described before is used to monitor the synchronization performance between these nodes. The timestamps offset of each synchronizing detection between node 29 and 41 are recorded which can be used to represent the synchronization deviation between the nodes. Figure 4 and 5 show how the mean and standard deviation of the timestamps offset changes over time (Modified Julian Date). Each dot represents the statistics results of the timestamps offset recorded in a hour. Figure 6 shows that the timestamps offset has an almost linear relationship with the temperature difference between the two nodes. It changes about 2 nanoseconds when the temperature difference varies nearly 35 centigrades during the experiment.

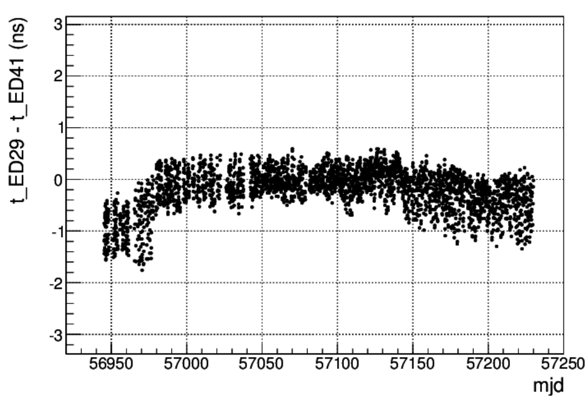

Figure 4: mean of the timestamps offset changes over time

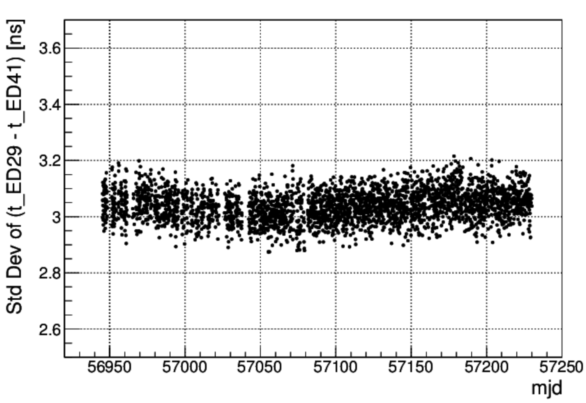

Figure 5: standard deviation of the timestamps offset changes over time

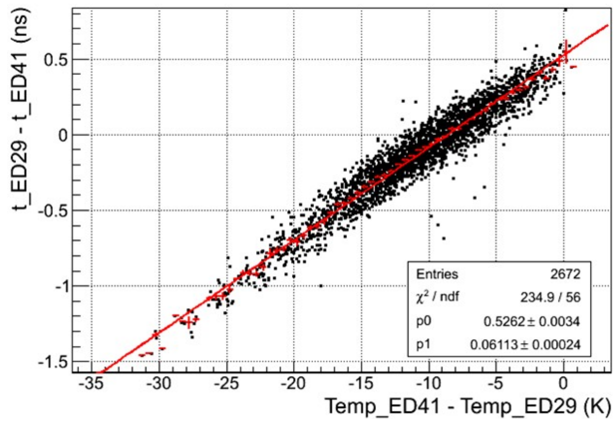

Figure 6: mean of the timestamps offset changes over temperature difference

The synchronization performance contains the contributions of the detectors and the WR network. The large standard deviation of the timestamps offset (~3ns) is mainly caused by the detectors. And as the temperature effect on the WR network has been reduced with dynamic correction, the temperature coefficient is also mainly determined by the detectors.

The results show that the long-term synchronization performance of the WR network is promising and temperature correction is also needed for the whole detector node when the ambient temperature changes a lot.

CONCLUSION

The prototype arrays of LHAASO is deployed at Yangbajin, Tibet, China and has been working well for nearly a year. Several bugs are found and reported to White Rabbit development team during the operation time and some of them have been resolved. It shows that the long term synchronization of the White-Rabbit network is promising and 500 ps overall synchronization precision is achievable with individual calibration and temperature correction. Power noise reduction, etherbone support, remote update and some other improvements will be added into the next update.

ACKNOWLEDGEMENT

This work is supported by the National Science Foundation of China (No. 11275111). The authors would like to thank Huihai He, Jia Liu, Hongkui Lv and the White Rabbit team at CERN for their help.

REFERENCES

[1] G. Gong and et al, "Sub-nanosecond timing system design and development for LHAASO project," in Proceedings of ICALEPCS, Grenoble, France, (2011).

[2] Q. Du and G. Gong, "A packet-based precise timing and synchronous DAQ network for the LHAASO project," Nuclear Instruments and Methods in, Physics Research A, vol. 732, pp. 488–492, (2013).

ISBN 978-3-95450-148-9

[3] J. Serrano, P. Alvarez, M. Cattin, E. G. Cota, P. M. J. H. Lewis, T. Włostowski et al., "The White Rabbit Project," in Proceedings of ICALEPCS, TUC004, Kobe, Japan, (2009).

[4] P. Moreira, J. Serrano, T. Wlostowski, P. Loschmidt, G. Gaderer, "White Rabbit: Sub-Nanosecond Timing Distribution over Ethernet", IEEE Precision Clock Synchronization for Measurement, Control and Communication 2009, pp1-5, Brescia, October 2009.

[5] W. Pan, Q. Du, and G. Gong, "Development of a White Rabbit Interface for Synchronous Data Acquisition and Timing Control," in Real Time Conference (RT), 2012 18th IEEE-NPSS, Berkeley, CA, Jun. 2012.

[6] M. Lipinski, T. Wlostowski, J. Serrano, and P. Alvarez, "White Rabbit: a ptp application for robust sub-nanosecond synchronization", ISPCS, Munich, Germany, (2011).

[7] G. Daniluk. White Rabbit calibration procedure v1.0.Website: http://www.ohwr.org/documents/213

[8] H. Li, G. Gong et al., "Temperature Effect on White Rabbit Timing link", IEEE Trans. Nuclear Science, Vol. 62, Issue 3, pp 1021-1026 2015.

[9] M. Kreider et al., "Etherbone – A Network Layer for the Wishbone SoC Bus", WEBHMULT03, Proceedings of ICALEPCS'11, Grenoble, France, (2011).

ISBN 978-3-95450-148-9