Sub-nanosecond synchronization node for high-energy astrophysics:

The KM3NeT White Rabbit node

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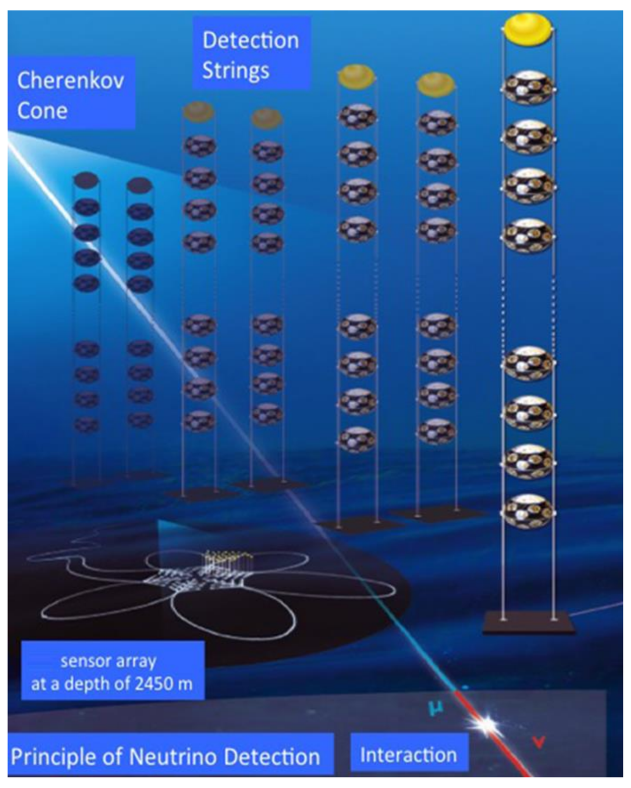
KM3NeT experiment

KM3NeT is an European research facility in the Mediterranean sea which will house a neutrino telescope of cubic kilometer scale. Cherenkov light from secondary particles induced by neutrinos, will be detected by an array of optical modules consisting in high pressure resistant glass vessels with photomultipliers inside. This vessel is called the Digital Optical Module (DOM) and it is composed of 31 small 3 inch PMTs distributed around the glass sphere, which collects the Cherenkov light and transform it into electronic signals. 18 DOMs are arranged on string-like structures anchored on the sea bed and kept vertical by buoyancy system, the so-called Detection Units. The Detection Units are connected with submarine Junction Boxes and through them to shore for power feed and data transmission. The DOM contains a printed circuit board, the Central Logic Board (CLB), which controls the readout systems, the synchronization protocol and the rest of the instrumentation devices.



Central Logic Board

The DOM Central Logic Board (CLB) is the main electronic board in the readout chain of the KM3NeT. In order to synchronize the DOMs, the CLB integrates the White Rabbit protocol which provides a global time with 1 ns of resolution. The CLB takes care also of the read-out of several instruments. It is based on a Kintex-7 FPGA

Firmware

The firmware of the DOM is based on two LM32 microprocessors. One of them is dedicated to the White Rabbit protocol which directly manages the tunable oscillators and the optical link traffic, in order to achieve a time synchronization of sub-nanosecond level with the Grand Master clock of the on-shore station. The rest of the modules are managed by the second microcontroller. 31 TDCs are responsible to record the arrival time and the width (with 1 ns of resolution) of the hits incoming from the PMTs. All the data, together with some other slow control monitoring information (as temperature, humidity, tilt meter, compass, currents, etc.) are put in UDP packets and connected to an IP/UDP packet buffer stream selector (IPMUX). This IPMUX splits the data into separate streams, based on UDP port number and sends them to the shore station via the endpoint, a normal Ethernet MAC but it has time stamping capabilities allowing sub-nanosecond timing precision, such that it facilitates the Precision Time Protocol (PTP-IEEE588). The block diagram of the firmware is shown in figure 1.

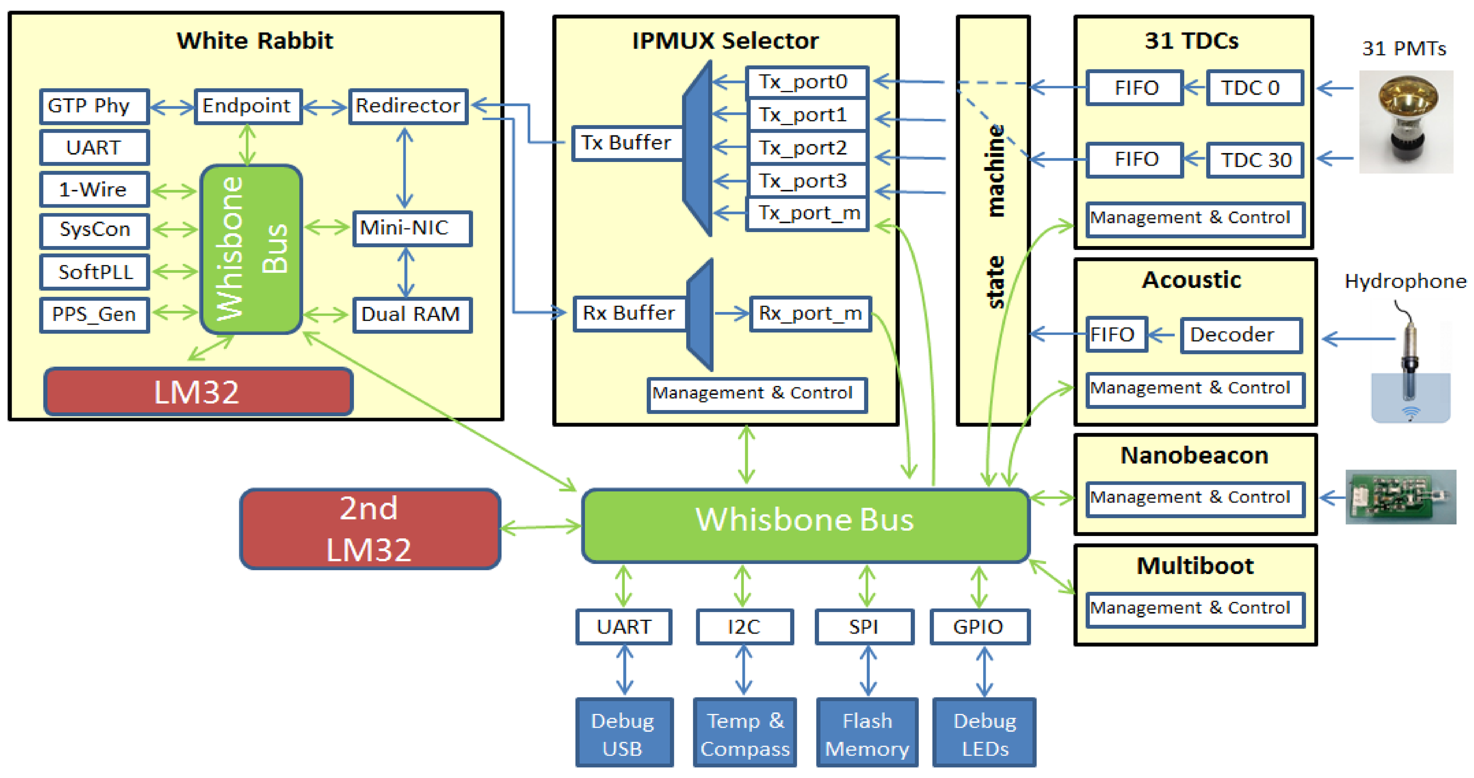


Figure 1. CLB firmware architecture.

Time calibration

For the calibration of the whole experiment, three factors must be taken into account: the calibration of the devices at the shore station, the calibration of the devices which form the sea infrastructure up to the Detection Unit, and the calibration of the DOMs. Figure 3A shows the results of continuously measuring the Round Trip Time (RTT) between master and base in the laboratory. It is observed that the same RTT is always obtained with a stability of 50 ps. In the laboratory a PMT of each DOM of the same line is illuminated using fibers of equal length, thus, the light will arrive at each PMT with the same delay with respect to the GPS time of the master, so the temporal difference between the moment when the light is emitted and the moment when the PMT receives it provides the temporal calibration for each DOM according with the equation: $T_0^{lab} = T_{flash} - T_{measured}$. The results of these measurements are shown in figure 3B.

KM3NeT optical network

KM3NeT uses the White Rabbit (WR) synchronization protocol, which needs optical fiber network to synchronize and send data. White Rabbit forms a hierarchical network topology based on bidirectional master-slave links. In the White Rabbit Network (WRN) a master node receives the clock from a GPS and it is responsible for distributing it to the rest of the WR devices within the WRN.

This WR technology has been modified for using in the KM3NeT experiment, where instead of having a bidirectional link for each node, the master clock is distributed from a single point, located at the shore station, to all DOM slaves. Thus, each DOM has a completely separate uplink to the shore station. Due to this big asymmetry of the system, as a consequence of the difference of paths between uplinks and downlinks, it has been necessary to adapt the WR technology to adapt a hybrid technology, where standard White Rabbit is used between the shore station and the bases of the Detection Units. The DOMs are synchronized taking into account only the downlink path from the master and without exchange of packages between master-slave.

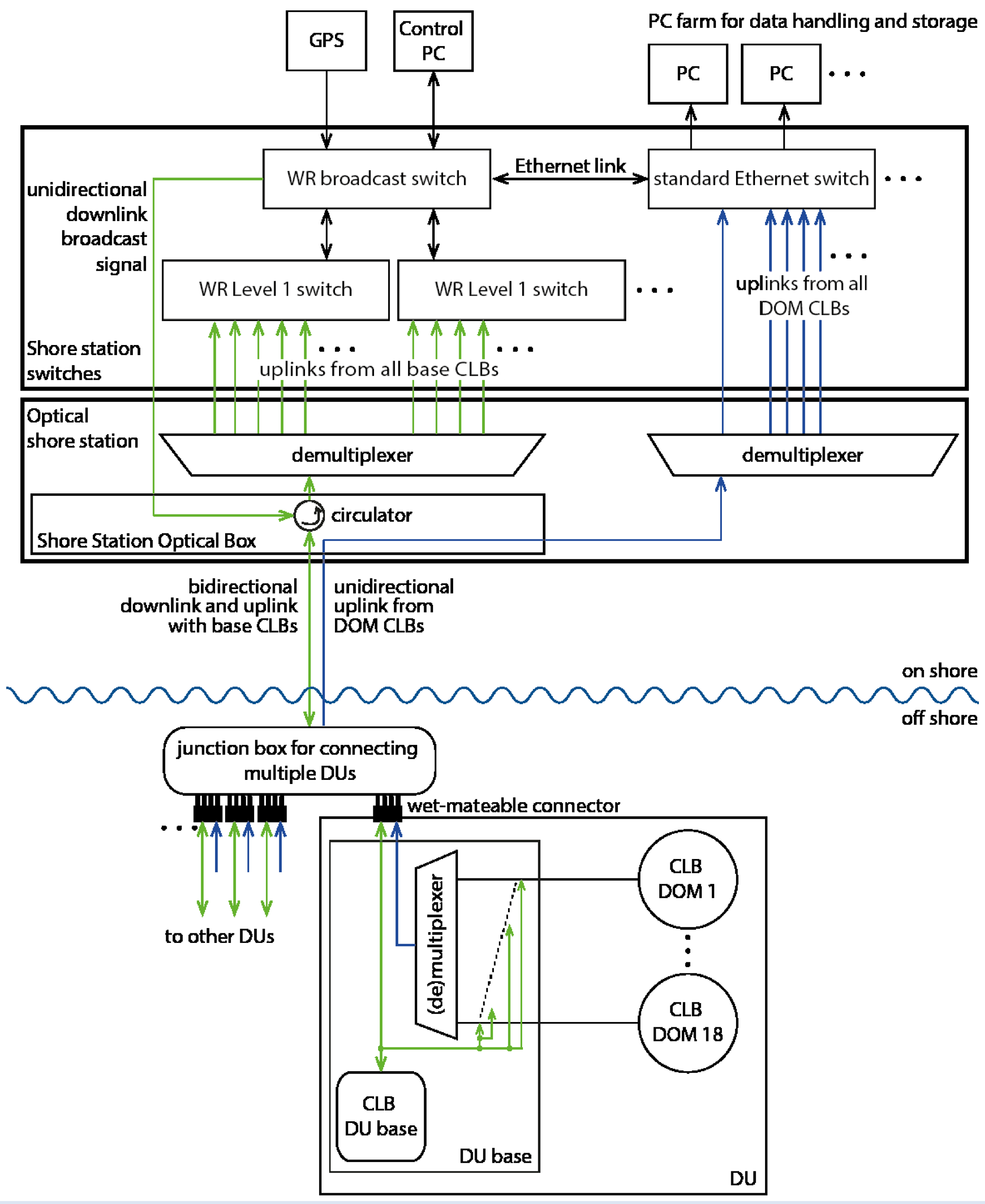


Figure 2. The KM3NeT Optical Network topology.

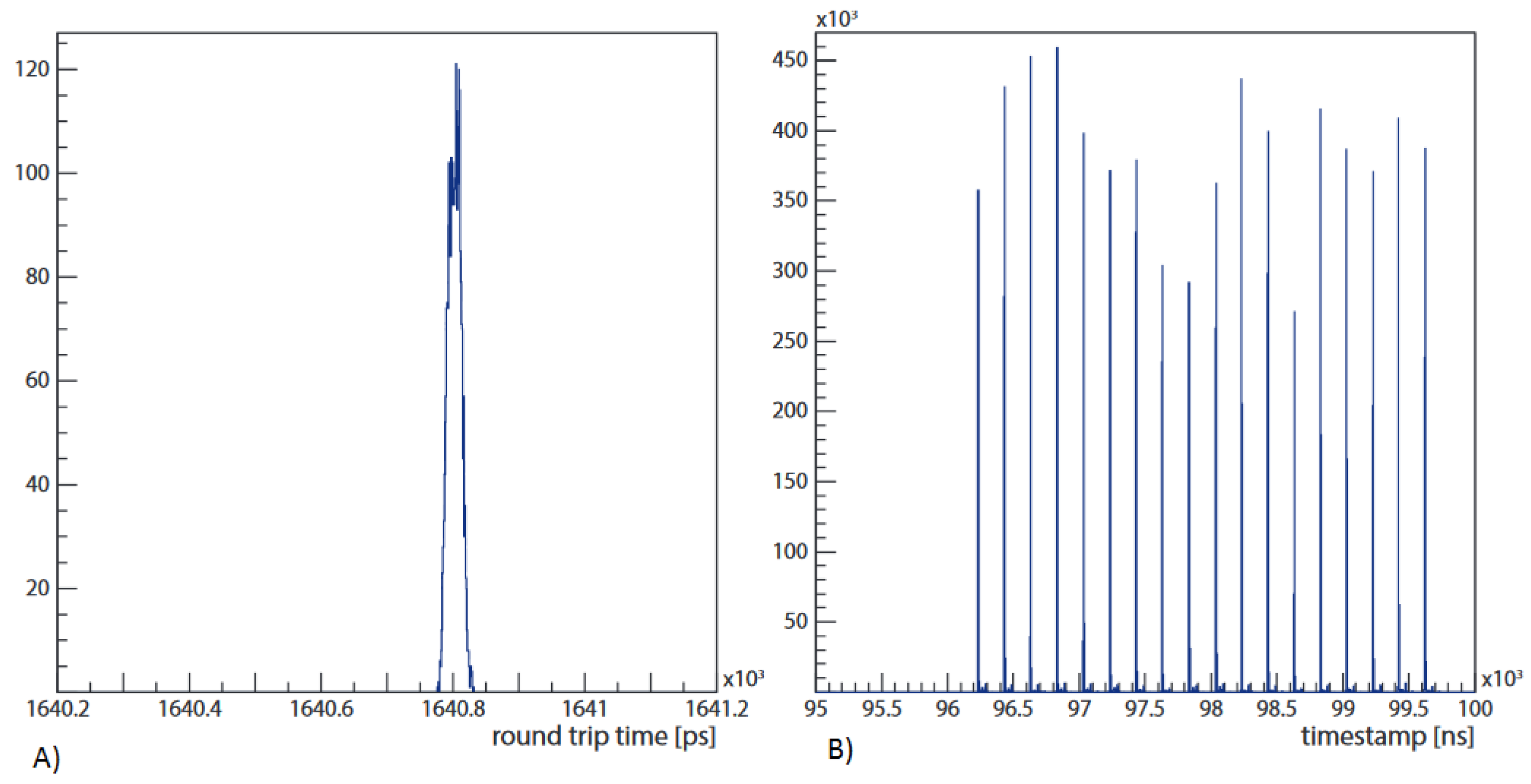


Figure 3. The KM3NeT Time calibration measurements.