KM3NeT Data Acquisition using VDSL2

Introduction

The KM3Net neutrino detector will be used to study astrophysical sources by detecting the high-energy neutrinos that these sources may emit. The detector is deployed on the seabed and consists of a large three-dimensional array of about 10.000 Optical Modules which contain light-sensitive Photo Multiplier Tubes. Neutrinos are detected indirectly, after an interaction inside or in the vicinity of the detector. The produced charged particles emit Cherenkov light, which can be detected by the Photo Multiplier Tubes. From the known positions of the Photo Multiplier Tubes, and the measured arrival times of the Cherenkov photons, the signal produced by these charged particles can be distinguished from the background.
The main purpose of the Data Acquisition system is to convert the analogue signals from the Photo Multiplier Tubes into a format suitable for the physics analysis. To achieve this, the Data Acquisition system has the task to prepare the detector for data taking, convert the analogue signals from the Photo Multiplier Tubes into digital data, transport the data to shore, filter the different physics signals from the background and store the filtered data on disk.
One of the major demands for the Data Acquisition system is the time measurement accuracy. This requires a high timing accuracy for the communication between Shore Station and neutrino detector. There are two options:

1. Use a real time high bandwidth transmission system with known propagation delays such that all timing can be measured on a single location at shore taking GPS time as a reference (time is stamped on shore).
2. Use local time stamping and a low bandwidth store and forward transmission system. Such a system needs distributed clocks which are synchronous and calibrated taking GPS time as a reference (time is stamped in the Optical Module).

In this paper option 2, based on copper wires in the Vertical Strings is described. The Vertical String dominates the major cost of the off-shore part of the detector. This paper describes a very simple solution for the infrastructure of the Vertical String; just one copper pair to each Optical Module. The components used in the modules of the Vertical String are based on industry standard-, cost effective- and proven-technology. Therefore this solution promises to be economical, reliable and manufacturable.
The description in this paper is based on a few assumptions but these assumptions can change without affecting the basic ideas described; the assumptions are only used to serve as an example.

To describe such a system, important issues have to be understood like bandwidth, copper behavior and available components.

Bandwidth estimation

The bandwidth needed for data transport can be estimated. Below follows a calculation based on a 10 KHz average trigger rate per Photo Multiplier Tube and a 0.5 ns timing resolution.
Per PMT:

- 10 KHz average trigger rate per Photo Multiplier Tube
- Up to 1 second measurement frame @ 0.5 ns resolution, corresponds to $2*10^9$ = **31** bits
- Time Over Threshold 2..100 ns width (@ 0.5 ns resolution) = **8** bits
- Photo Multiplier Tube ID [1..<64] = **6** bits
- Optical Module (OM) ID [1..<32] = **5** bits
- Total 31 + 8 + 6 + 5 = 50 bits
- Raw bandwidth = 50 bits @ 10 KHz = 500 Kbps

To minimize computing overhead, these 50 bits should be byte- and word-aligned to 64 bits. This increases the bandwidth to 640 Kbps. When an Optical Module is equipped with 32 Photo Multiplier Tubes [1] then the bandwidth per Optical Module is 21 Mbps. When a string is equipped with 24 Optical Modules then the bandwidth for each Vertical String is 500 Mbps.
This data rate increases due to packet headers and multiplication by a safety factor. Other experiments (like ATLAS [2]) use a safety factor of 5. The safety factor for KM3NeT should be studied. With a safety factor

of 5, the bandwidth per Vertical String stays below 3.1625 Gbps which is widely used in current Ethernet standards [3].
To accommodate the bandwidth an optical approach is needed for the long distance connection between the Shore Station and the detector-site. However, in the Vertical Strings in the detector, distances are smaller and the bandwidth per Optical Module is lower. With a safety factor of 5 the bandwidth per Optical Module is ~100 Mbps. For this bandwidth one can choose an optical approach as well as an electrical approach. Table 1 summarizes the advantages and disadvantages when using either approach and shows that it is worth to investigate the solution with copper in the Vertical String.

	Optical	Electrical
Advantages	• Using a standardized protocol (Gigabit Ethernet) timing calibration can be implemented easily.	• Robust • Data transport and power over the same wires
Disadvantages	• Fragile • Need separate copper for power distribution.	• Complex timing calibration mechanism • The copper network for a Vertical String needs to be coupled in an intelligent way to the long distance optical network.

Table 1: Advantages and disadvantages of optical or electrical network within the detector

Data communication over copper

General

Research centers and telecommunication industries embrace the thought that for data communication from client to client in a world wide span, the backbone will be optical data communication. Due to local infrastructure or costs, at some point along the transmission path a conversion in transmission technique needs to take place. This conversion will be from fiber to copper or wireless. Almost every technique is well defined and registered by independent standardization offices like ITU, IEEE, Bellcore etc.
In the world of today, almost all houses are connected via a copper wire to a telecommunication network. For a long time this network was used for telephone services only, but over the past 20 years it is also used for data transport. High speed Internet access and High Definition Television (HDTV) are becoming standard; the bandwidth demand is ever growing.
Although fiber to every home is the ultimate answer, it is not yet an economically viable solution for overbuilding existing copper networks. This is because fiber takes a long time to deploy and the cost of deployment runs between USD 1,000 and 1,800 per subscriber. However, in Greenfield building scenarios, fiber to the home (FTTH) is frequently seen as the best way forward [4].
There has been an evolution from ADSL [5], ADSL2 [6], ADSL2plus [7] to VDSL [8], followed by VDSL2 [9]. The VDSL2 standard provides enough bandwidth over copper for “triple play” (Telephone, Internet and Television). For telecommunication industries this is a very cost sensitive mass market. It is worth to investigate if VDSL2 might be an economical solution for the KM3NeT data transport in the Vertical String.
Figure 1 shows an application model as defined in the VDSL2 standard. Traditionally the General Switched Telephone Network (GSTN) occupies a frequency band up to 4 KHz. The Broadband Network may occupy the frequency spectrum above 4 KHz. Both GSTN and Broadband Network are coupled into the same copper pair via a Low Pass Filter and a High Pass Filter respectively.

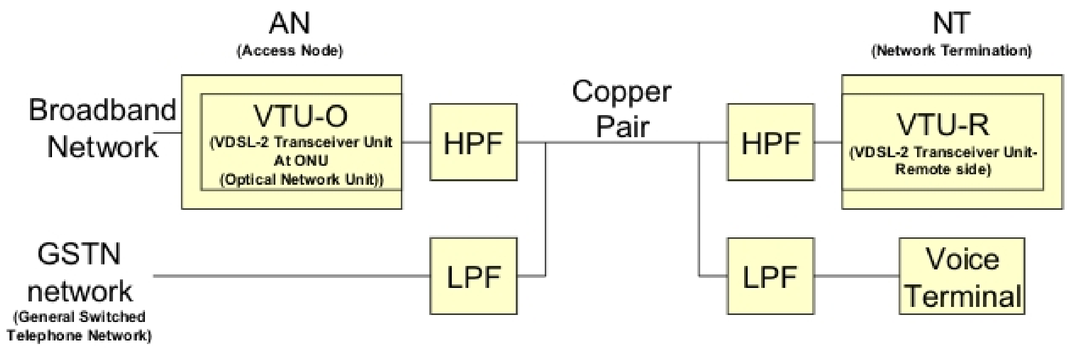

Figure 1: *Data with Plain Old Telephone Service (POTS) application model for remote deployment with splitter (ITU G.993.2 standard figure 5-7)*

The VDSL2 Broadband Network frequency band spans from 25 KHz to 30 MHz. This bandwidth can accommodate up to 200 Mbps (upstream + downstream). VDSL2 is based on Orthogonal Frequency Division Multiplexing (OFDM) [10]. The bits to be transmitted are distributed over many different carriers. Each carrier is Quadrature Amplitude Modulated (QAM).
The model in Figure 1 can be redefined for VDSL2 use in KM3NeT (see Figure 2). A single copper pair can transfer DC power, a high bandwidth data communications channel and a dedicated channel for timing.

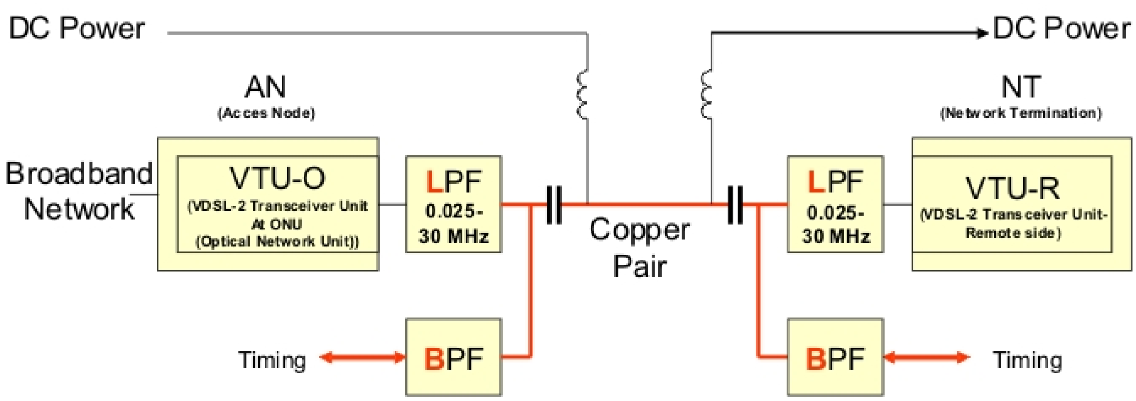

Figure 2: *Application Model for KM3NeT*

Twisted pair architecture

VDSL2 is supposed to operate on subscriber loops that are typically built out of 26 AWG to 19 AWG unshielded twisted pair (UTP). Bingham [11] tries to model a typical subscriber line. It is clear that a typical subscriber line is not the prefect medium to convey such an amount of bandwidth. KM3NeT, as opposed to the telecommunications industry, has the advance that it can define the properties of its copper interconnect by design while the telecommunication industry needs to build upon the subscriber loop between the Central Office (CO) and the Customer Premises Equipment (CPE) that is already installed for years.
For KM3NeT it is foreseen to use AWG24 twisted pair housed in an equal pressured oil filled deep sea cable. The impedance of a twisted pair in air is about 100 ohm. Since the impedance scales with the square root of the dielectric constant the expected impedance in oil will be in the order of 70 ohm.
The loop attenuation as function of frequency depends on skin-effect for the used frequency spectrum and will not change by the use of an oil- instead of an air-filled cable. Loop attenuation in general is described and modeled in Bingham [11, chapter 3.5.6] and follows the formula $\alpha = 20.3$ dB/Km/$\sqrt{\text{MHz}}$. For 30 MHz (VDSL2 upper frequency limit), a twisted pair of 300 meters has an attenuation of 33.4 dB and for 50 MHz this attenuation becomes 43.2 dB. The dispersion of the twisted pair in oil will slightly increase but OFDM is specially designed to overcome a huge amount of dispersion.

Timing

General

A system that uses a store and forward mechanism needs to create a timestamp at the origin of an event, i.e. at the output of the Photo Multiplier Tube in the Optical Module. This means that each Optical Module needs an exact time reference that is *locked* on to the reference clock at the Shore Station. When all clocks in the system are locked then this ensures that all clocks are synchronous but their local time has an offset. For each Optical Module, this timing offset can be measured by the Shore Station, by sending a timing calibration signal back and forth as shown in the example in Figure 3.

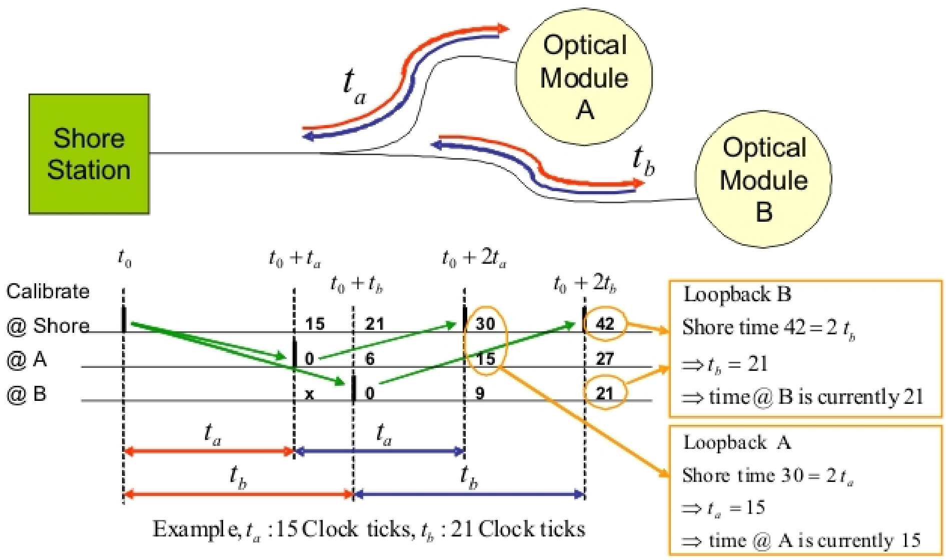

Figure 3: *Timing Calibration example*

The actual path that must be calibrated consists of a long distance path (shore to Vertical String) and a short distance path (within the Vertical String). The long distance path uses an optical connection, whereas the short distance path may be optical or electrical.

Timing Calibration over an optical connection

Over the past years the industry widely adopted Ethernet [12] as a standard for serial data transport. Apart from data transport, such a system could be used for timing calibration as described below.
Gigabit Ethernet is based on 8B/10B coding [13]. The power of 8B/10B coding lays in the fact that it solves three important properties that are of a concern for any serial connection.

1) Bit synchronization
It combines "clock" and "data" in one single serial stream by defining a maximum "run length", meaning that there are enough edges in the serial stream such that a bit-clock can be recovered at the receiver end (bit synchronization).
2) DC-Balance
By adding 2 bits for each byte one can choose 256 code groups from a set of 1024. When the run length is set to 5 (never transmit more that 5 consecutive 1's or 0's) then there are not enough DC balanced code groups to map each 8B character directly onto one 10B code group. Therefore most of the 8B characters are mapped onto two 10B code groups; one positive with more ones, the other negative with more zeros. "Running disparity" balances the number of positive and negative code groups.
3) Word synchronization and Special code groups
As well as the 10B code groups used for normal data transmission, there are some extra 10B code groups which satisfy the 5 bit run-length criterion. Those code groups are used for word synchronization and can be used to transmit special code groups.

For the timing system in KM3NeT property 1 and 3 are of special interest. The recovered bit clock (property 1) is synchronous and locked to the transmitter (TX) and is used as the local clock at the receiving side (RX). The special code groups (property 3, for example "Carrier Extend") are used to mark a timing calibration signal as can be seen in Figure 4. At the receiving side (RX), the detected calibration signal has a fixed delay with respect to the receiver recovered clock (RxRecClk).

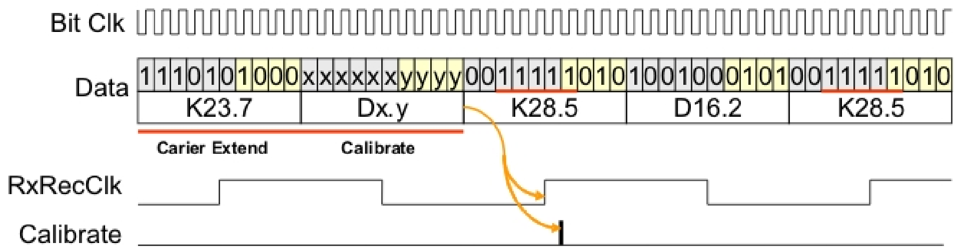

Figure 4: *Timing Calibration over an 8B/10B channel*

The calibrate signal sent from node "A" that is received in node "B" over the forward path, needs to be sent back immediately to the node "A" (see Figure 5).
Normally there is no direct link between the receiver (RX) and the transmitter (TX) in node "B". Data is usually received in a buffer, than interpreted by some intelligent device and eventually a reply is sent back to the transmitter via some buffering.
Timing calibration however, needs a fixed (preferably short) data path in the receiving node "B" from receiver (RX) to Transmitter (TX). A special data packet is used to put node "B" in a state where it forwards the calibration signal transparently from receiver to transmitter without going though any buffers.

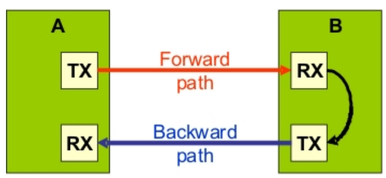

Figure 5: *Timing Calibration over an 8B/10B channel*

Timing Calibration over a copper connection

Although the VDSL2 standard [9] defines an 8 KHz Network Timing Reference (NTR) it appears that this feature is not always implemented in the available VDSL2 chipsets. The standard does not define the NTR timing resolution; it may not be sufficient for the KM3NeT timing system.
The VDSL2 band plan stretches up to 30 MHz so a KM3NeT timing calibration system can use frequencies above. A timing calibration signal is modulated onto a carrier f_1 and transferred from transmitter (TX) to the receiver (RX) (See Figure 5). The received calibration signal from node "A" needs to be sent back immediately, using a carrier frequency f_2.
The preferred modulation scheme is Binary Phase Shift Keying (BPSK). This type of modulation is easily made by using Direct Digital Synthesis (DDS) techniques [14, 15].
Figure 6 explains how a node can be locked onto the transmitter clock and how a timing calibration signal can be transferred from a transmitter to a receiving node.

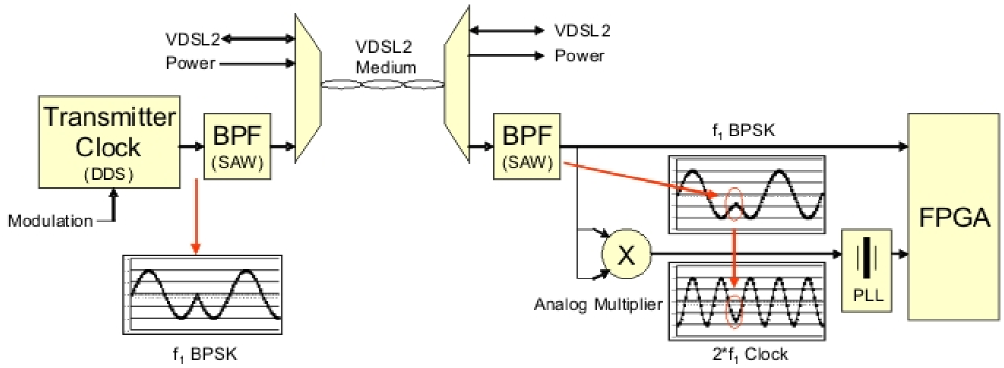

Figure 6: *Schematic overview of the timing calibration principle*

A calibration signal is sent at an exactly known phase of carrier f_1. Phase switching is preferably done at the zero crossing since this will minimize transients in the recovered carrier [16]. The BPSK signal is coupled into and out of the VDSL2 medium via band pass filters. Suitable filters are Surface Acoustic Wave (SAW) filters. Such filters have an excellent band pass characteristic and a very low group delay distortion and are widely used in telecommunications equipment.
Carrier regeneration is easily done when the analogue representation of the BPSK signal is multiplied by itself. The result is a double frequency component without modulation. Due to the limited bandwidth of the SAW filters there will be some distortions on the recovered carrier. These distortions are removed by feeding the recovered carrier through a Phase Locked Loop (PLL). The output of the PLL will be a very stable, low jitter clock that is locked to the DDS generated transmitter clock which is used to demodulate the received BPSK signal (see Figure 7). Demodulation is done digitally by an FPGA.

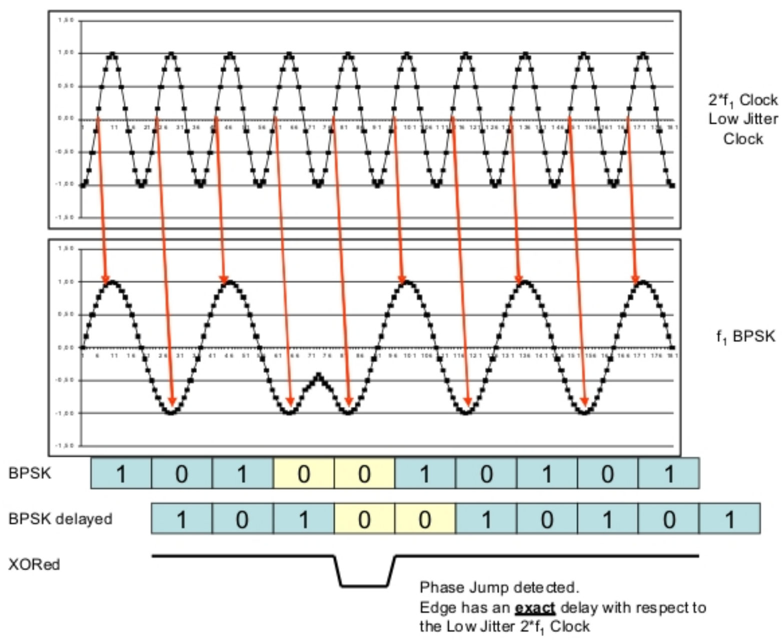

Figure 7: *BPSK demodulation*

The carrier frequencies (f_1, f_2) should be chosen such that:

1) they are > 30 MHz (above the VDSL2 band)
2) f_1 and f_2 have an "n/m" relationship
3) reference period divided by the time of "n" cycles f_1, is an integer value
4) reference period divided by the time of "m" cycles f_2, is an integer value

The “n/m” relationship makes sure that once every ‘n’ cycles of f_1 and/or once every ‘m’ cycles of f_2, both carrier frequencies have a fixed phase relationship (i.e. have their zero crossing at the same time). Rules 3 and 4 ensure that this is exactly the case on each reference period. The 1 second timing reference from GPS is an integer multiple “k” of the reference period.
Once every second the Global Positioning System (GPS) “second” tick is send as a system “heartbeat” (see Figure 8). This heartbeat is aligned with the start of a reference period and is an exact timing moment in a “heartbeat packet” which also contains the current Universal Time Coordinated (UTC).
A data transmission protocol enables us to send data that is BPSK modulated on carrier frequencies f_1 and f_2. The data transmission protocol [13, 17] should have some special code groups to be able to uniquely code the timing calibration signal.

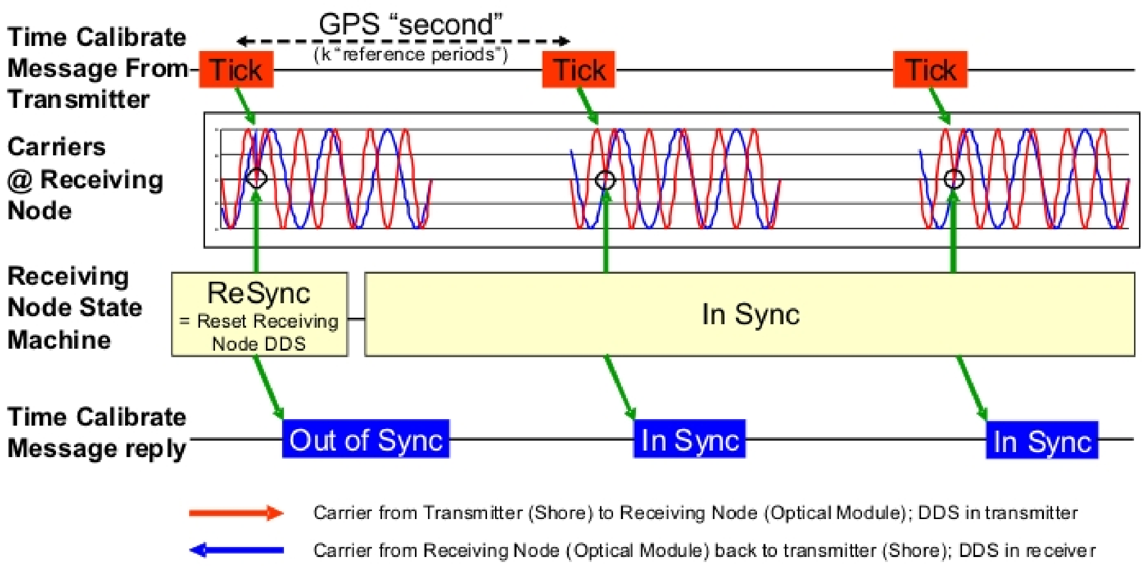

Figure 8: *Time calibration mechanism*

With each heartbeat, the receiving node is checking whether its f_2 carrier generator is “in sync” with the received f_1 carrier. Note that f_2 is generated with a DDS that is locked onto f_1. If f_2 is out of phase then an “Out of Sync” message will be replied to the transmitter. If this happens repeatedly then the f_2 generator needs to be reset such that it will be synchronous and in phase with f_1.
Since f_2 is locked to f_1, at the next heartbeat the receiver will find itself in synchronization and the reply will be an “In Sync” message. In this way the receiving node is able to keep track of the exact time while the transmitter knows whether the receiving node is synchronized and the transmitter can measure the exact propagation delay.

Data Acquisition System

Optical Module

The Optical Module is a glass sphere which contains 32 Photo Multiplier Tubes [1]. The Time-Over-Threshold output of these Photo Multiplier Tubes is digitized in a 32 channel Time to Digital Converter (TDC). This can be done by a dedicated Integrated Circuit such as the 32 channel High Performance Time to Digital Converter [18]. A study is being made if a 32 channel TDC can be created in a part of an FPGA. This FPGA is also used for formatting the Time-Over-Threshold data into 64-bit words.
The measurement time of the whole detector is sliced into small periods, called measurement frames, for which all data of the detector needs to be collected on a processing unit at shore. This is important since this single processing unit needs to be able to overview the measurement data of the whole detector in order to find events (see chapter Shore Station below).

All data in such a measurement frame is put into buffers from which packets are built. General information such as the UTC is included in each packet. Those packets are sent to a processing unit at shore using User Datagram Protocol (UDP). To transfer the information efficiently jumbo frames are used.
Building the UDP packets (such as adding checksums) is mostly done in the FPGA.
Initialization of the environment is done by a slow control CPU. Apart from initialization, slow control creates the possibility to set high voltage and threshold for the Photo Multiplier Tubes and monitor the environment (temperature, voltage, current, compass and Vertical String position). Slow control is sharing the same data communication path to shore but it has a higher priority than normal data transport. The Slow Control CPU can be part of the FPGA however it could well be more cost effective to use a separate low cost CPU.
The Optical Module is divided in two parts (two half glass spheres) which can be assembled and tested separately. All Photo Multiplier Tubes of such a part connect to a multiplexing PCB which takes care of the interfacing to the central logic PCB. This multiplexing PCB can also be connected to a tester during manufacturing.

Master Module in the Vertical String

All communication between the Shore Station and the Optical Modules as well as the distribution of power, is done via a Master Module.
The VDSL2 standard defines the names “Central Office (CO)” and “Customer Premises Equipment (CPE)” as the end-points of a connection. The Master Module contains CO VDSL2 chips that, on one side, connect to all CPE in the Optical Modules and on the other side connect to an Ethernet switch. The Ethernet switch also connects to the local slow control processor. A wideband port of the switch is connected via a Dense Wavelength Division Multiplexing (DWDM) system to the Shore Station. Figure 9 shows a possible solution for this connection. This figure shows how two wideband ports provide redundancy of the data path to the Shore Station (see chapter “reliability” below).

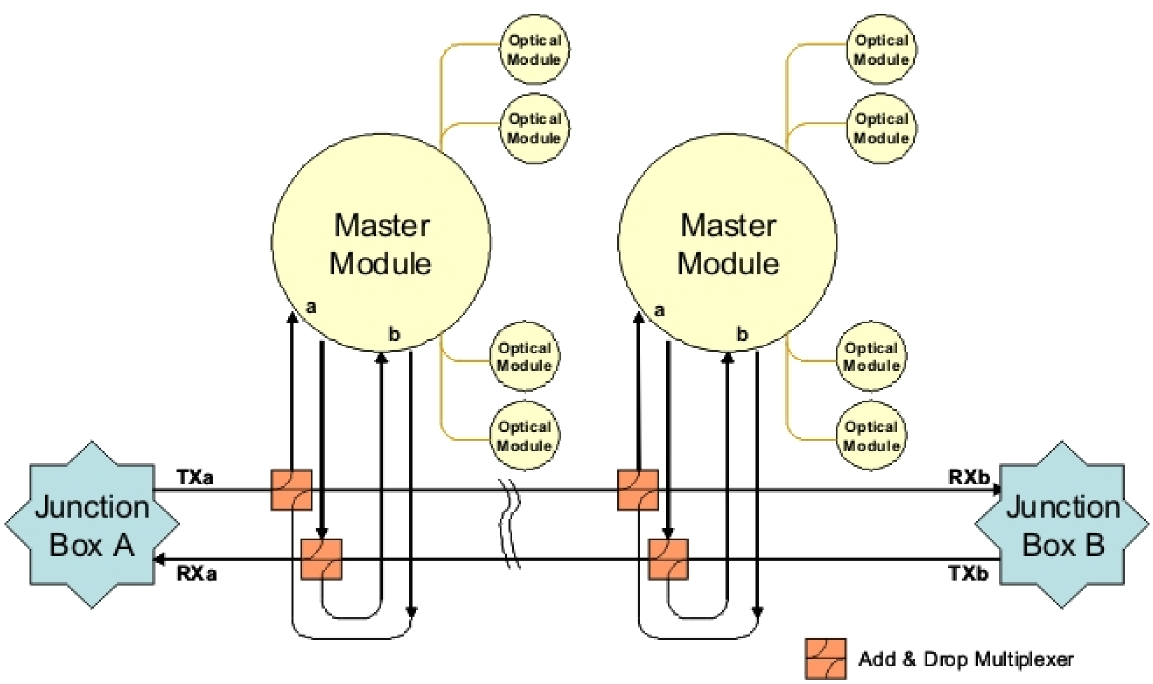

Figure 9: *DWDM Branch Cable*

The topology in Figure 9 can be realized with a conventional optical approach (i.e. a laser as a transmitter and an APD as a receiver on each fiber). If one can avoid an off-shore laser then the reliability can be increased. This can be realized by using an off-shore reflection modulator [23].
The power (380 VDC) for the Vertical String is distributed in the Master Module. Each output can be switched on separately. The current to each Optical Module can be monitored. When this is done on both

sides of a twisted pair then current leakage can be monitored as well. To provide redundancy the power for a Vertical String can be supplied by either Junction Box [21].
The Master Module couples the long distance timing calibration system (shore to Master Module) to the short distance timing calibration system in the string (Master Module to Optical Modules). Both timing calibration systems are independent and require their own measurement (see Figure 10). A Master Module receives the heartbeat time calibrations packets from the Shore Station and sends them back directly to shore for time calibration measurement of the long distance connection. The same heartbeat packets are also sent over the timing calibration carrier to the Optical Modules. Each Optical Module directly sends the heart-beat packet back to the Master Module for time calibration measurement of the short distance connection. The short distance timing calibration measurement in the Master Modules is done by a TDC that can be of the same type as used in the Optical Module (used there for time stamping of the data from the Photo Multiplier Tubes).

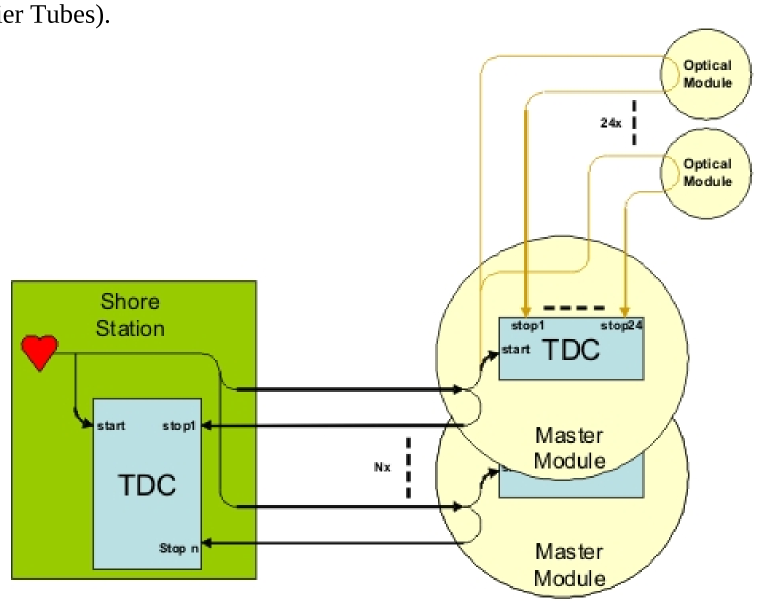

Figure 10: *Time calibration system overview*

The Master Module has the same form-factor (a glass sphere) as the Optical Modules. The optimal location for the Master Module is halfway the Optical Modules in the Vertical String. This minimizes the distance of twisted pairs in the Vertical String. Half the twisted pairs serve the Optical Modules above the Master Module the other twisted pairs serve the Optical Modules below. Thus the maximum number of twisted pairs in the vertical cable is half the number of Optical Modules. This architecture minimizes the diameter and therefore the drag of the vertical cable in the water. It also minimizes cross talk and DC-power loss. Furthermore it maximizes the VDSL2 Rate Reach ratio (see Figure 11; [19]).

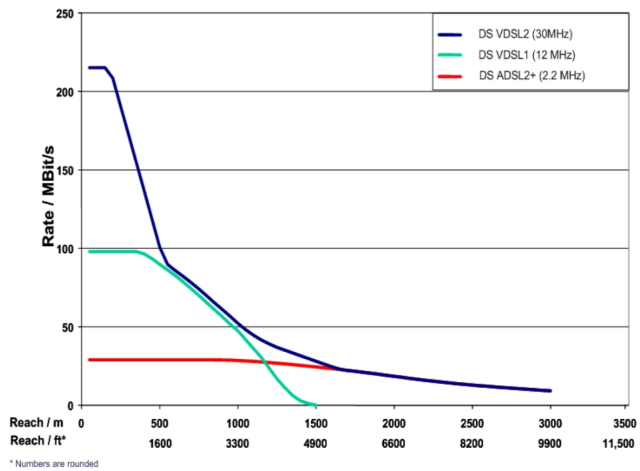

Figure 11: *VDSL2 Rate Reach ratio*

When space and power dissipation permit, the Master Module could house additional systems: such as acoustic position measurement, optical bacon etc.

Shore Station

A Dense Wavelength Division Multiplexing (DWDM) system connects the Shore Station via a Junction Box to all Master Modules. The amount of DWDM fibers is highly dependant on the architecture of the detector. Currently a four-ring architecture is foreseen which leads to eight DWDM systems from each Junction Box (see Figure 12). Each DWDM system feeds a Branch Cable from a Junction Box. The Branch Cables are feed from both sides (Junction Box “A” and “B”). The Master Module of each Vertical String is connected to the Branch Cable. For redundancy each Master Module can communicate through both Junction Boxes (see Figure 9 and Figure 12).

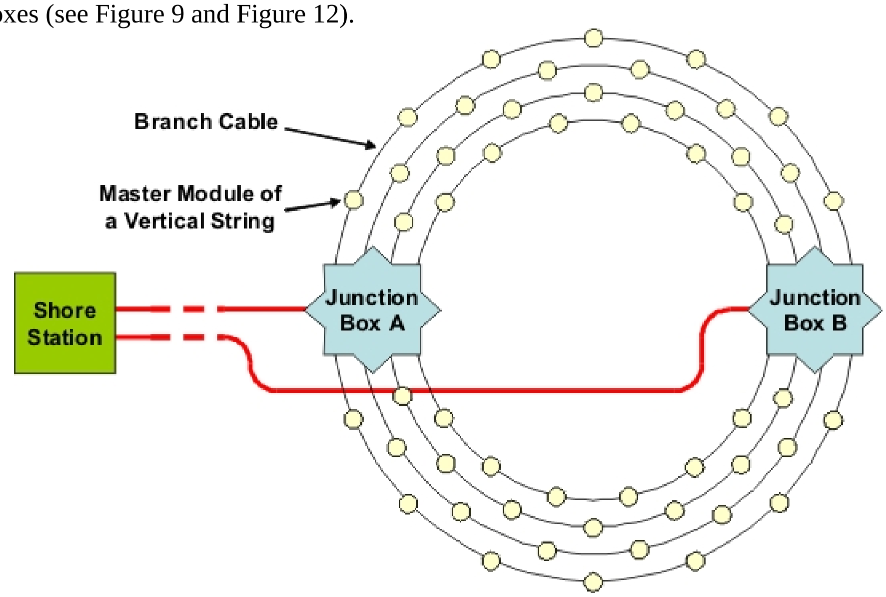

Figure 12: *Schematic overview of the detector architecture*

The DWDM system at the Shore Station must be split into individual optical channels; one for each Master Module in the Vertical Strings. The optical channels are converted to electrical signals that are connected to an interface which permits to implement timing calibration over the data path. The GPS at the Shore Station generates heartbeat calibrations packets which are sent to the Master Modules for time calibration measurement of the long distance connection (see Figure 10). The timing calibration measurement at the

Shore Station is done by a TDC that can be of the same type as used in the Optical Module (used there for time stamping of the data from the Photo Multiplier Tubes).
In order to select events, an overview of the whole detector measurement data is mandatory. This data is sliced into measurement frames and needs to be sent to a single processing unit. This concept is described as “all data to shore” [20] (Figure 13).
A huge data switch is needed to couple the processing units to the data streams coming from DWDM system. The nature of the data traffic is burst like since all detector data is sent in parallel after each measurement frame and must be routed to a single processing unit. This requires large data buffers to average the data streams. The architecture of this switch and the data flow in the system has to be studied.

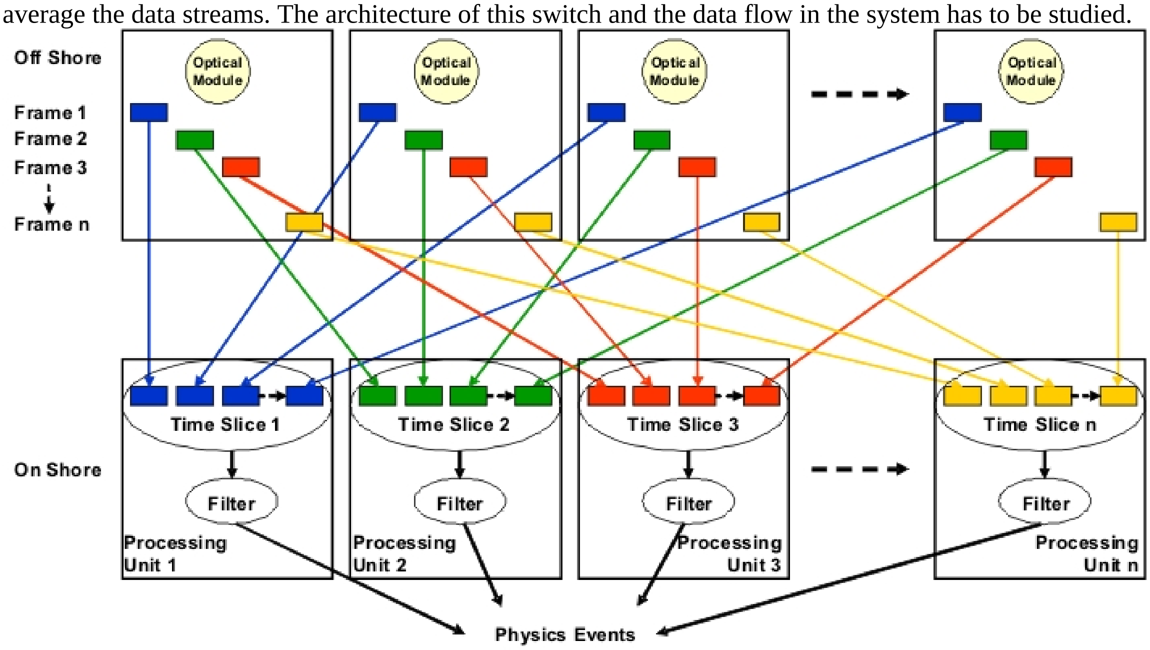

Figure 13: *Time sliced data processing*

Design Objectives

Power dissipation

The total power dissipation of the Optical Module must be low. This eases the thermal management within the Optical Module and lowers the cost of the power distribution.
Currently, a total of 7 Watt per Optical Module is foreseen [21]. Table 2 gives an estimation of the power dissipation of the different parts of the Optical Module.

Part	Power [Watt]
32 Photo Multiplier Tubes @ 50 mW	1.6
TDC	0.7
FPGA	1.5
VDSL2 chipset	1
Slow Control & CPU	0.5
Sub Total	5.3
Power converter efficiency	90%
Total	5.9

Table 2: *Power dissipation in the Optical Module*

Reliability

The reliability of electronics is described in the paper: “Reliability analysis of electronics” [22].

It is obvious that off-shore electronic systems for KM3NeT need to be highly reliable since they are not accessible during their lifetime. However a small number of failures are expected. Failures in the central part of the detector can be catastrophic. Redundancy is used to avoid disastrous single point failures.
The connection between the Shore Station, Junction Box via the Branch Cable to a Master Module is vulnerable to single point failures. Redundancy is created by using two separate paths via two Junction Boxes (see Figure 9 and Figure 12).
The power distribution system is vulnerable to overload and short circuits. A single overload condition can disable a large part of the system. To avoid such a situation resettable fuses are used at strategic locations. Slow Control monitors voltage and currents of the power distribution system. In case of anomalies Slow Control is able to switch off parts of the system.
Table 3 shows how a failure propagates in the detector and shows resulting detector loss.

Malfunctioning part	Effected	Detector loss
Photo Multiplier Tube	1 Photo Multiplier Tube	0,0003 %
Optical Module	32 Photo Multiplier Tubes	0,01 %
Master Module	1 Vertical String	0,24 %
Branch Cable; single failure	0	0 %
Branch Cable; double failure	Partial Branch between the two failures (= ‘n’ Vertical Strings)	n*0,24%
Junction Box; single 100% failure	0	0 %
Junction Box; double partial failure[1]	Partial detector	m*100%; (0 < m < 1)
Junction Box; double 100% failure	Complete detector	100%
Shore Cable; single failure	0	0 %
Shore Cable; double failure	Complete detector	100%

Table 3: *Failure propagation analysis*

Proven technology

For all the proposed technical elements a COTS (Component Of The Shelf) solution or almost COTS solution is available now. There are well-known producers over Europe who can contribute to this design.

Cost effective

VDSL2 chipsets are being deployed for High speed Internet access and High Definition Television (HDTV). For telecommunication industries this is a very cost sensitive mass market. Currently there are a number of VDSL2 test roll-outs and it is expected that in the near future ADSL will be replaced by VDSL2.
Combining data transport and power over a twisted pair in the Vertical String minimizes the cost. A feasibility study is being done to learn whether it is possible to feed the copper wires of the twisted pair through the glass sphere without using a connector. Since deep sea connectors are very expensive, this will save a lot of money.
Because most sub-systems have to be built on specifications it is difficult to give exact prices. Table 4 gives a rough cost estimation for one Optical Module.

Part	Cost [€]
32 Photo Multiplier Tubes	3200
32 High Voltage Base and Discriminator PCB	1600
Electronic parts total	1000
Mechanical parts total	1000
Total	6800

Table 4: *Cost estimation for one Optical Module*

Part	Cost [€]

[1] A partial failure only occurs when <u>both</u> Junction Boxes Branch fail to feed the <u>same</u> Branch Cable.

Electronic parts total	4500
Mechanical parts total	1000
Total	5500

Table 5: *Cost estimation for one Master Module*

The cost estimation above includes parts and the sub-assembly but not the cost of test systems and manpower needed to validate the assembled Optical Modules and Master Modules.

Flexible

Although the functionality of a single part of a system is well described, it can be necessary to implement changes even after the production of the hardware has completed. Remotely reprogrammable hardware (FPGA) makes major changes possible.

Prospects

Quality assurance

Due to the huge amount of assemblies that must be produced in a very short time it is absolutely necessary to use automatic testing. Using Electronic Identifier chips on electronic sub-assemblies eases creation of automatic generated test reports and the traceability of the various parts. Apart from an Electronic Identifier each assembly must have a humanly readable identification, created from the Electronic Identifier, as well.

Scalability

Other instrumentation or a future type of Vertical String can be connected to a Branch Cable tap. This connection provides 380 VDC and an optical DWDM channel to shore. An instrumentation application is free to define its own means of communication as long as this fits to the properties of the DWDM channel.
Normally a Junction Box has a number of spare Branch Cable connectors. If there are enough spare connectors available then they can be used for future expansion.
When the detector is operational and performs well, the question may arise in the future, to extend the volume of the detector even further. The architecture allows for an increment in power consumption and bandwidth to a certain limit. Above this limit an extra Junction Box with its own shore cable has to be added. Branch Cables can be added between the newly added Junction Box and existing other Junction Boxes. This improves reliability even further.

Validation tests required

Due to the stringent timing requirements, the timing calibration concept as proposed above has been simulated but should be validated.
The data transmission on a twisted pair in air is measured but should be validated for the oil filled Vertical String cable.
The power requirements (especially for the Optical Module) should be validated.
The optical budget for the long distance Optical connection should be validated.

References

[1] E. Heine, A.H. Kruijer, H.Z. Peek, P. Timmer. "Multi PMT setup"

[2] http://bosman.home.cern.ch/bosman/safety_factor_intro.txt

[3] IEEE Std 802.3ak-2004, "Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-CX4"

[4] Per-Erik Eriksson and Björn Odenhammar. VDSL2: Next important broadband technology. Ericsson: http://www.ericsson.com/ericsson/corpinfo/publications/review/2006_01/files/vdsl2.pdf

[5] ITU-T G.992.1 "Asymmetric digital subscriber line (ADSL) transceivers http://www.itu.int/rec/T-REC-G.992.1/en

[6] ITU-T G.992.3 "Asymmetric digital subscriber line transceivers 2 (ADSL2) http://www.itu.int/rec/T-REC-G.992.3/en

[7] ITU-T G.992.5 "Asymmetric Digital Subscriber Line (ADSL) transceivers - Extended bandwidth ADSL2 (ADSL2plus)" http://www.itu.int/rec/T-REC-G.992.5/en

[8] ITU-T G.993.1 "Very high speed digital subscriber line transceivers" http://www.itu.int/rec/T-REC-G.993.1/en

[9] ITU-T G.993.2 "Very high speed digital subscriber line transceivers 2 (VDSL2) http://www.itu.int/rec/T-REC-G.993.2/en

[10] J.H. Stott. "The how and why of COFDM". http://www.ebu.ch/en/technical/trev/trev_278-stott.pdf

[11] Bingham, John A. C. ADSL, VDSL, and Multicarrier Modulation. John Wiley & Sons, Inc. 2000.

[12] IEEE Std 802.3, "Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications"

[13] A.X. Widmer, P.A. Franaszek. A DC-Balanced, Partitioned-Block, 8B/10B Transmission Code. IBM J. Res. Develop, Vol. 27, No 5, September 1983.

[14] http://www.analog.com/dds

[15] http://www.xilinx.com/ipcenter/catalog/logicore/docs/dds.pdf

[16] H.Z. Peek, P.P.M. Jansweijer. "BPSK FFT Simulation for VDSL2 in KM3NeT"

[17] http://www.epanorama.net/documents/audio/spdif.html
IEC-60958-3

[18] J. Christiansen. "HPTDC High Performance Time to Digital Converter"

[19] http://www.infineon.com//upload/Document/VDSL2_WP_072005_v1.1.pdf

[20] J.A. Aguilar et al. "The data acquisition system for the ANTARES neutrino telescope". Nuclear Instruments and Methods in Physics Research A 570 (2007) 107–116.
http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6TJM-4M57P2K-5-F&_cdi=5314&_user=606230&_orig=search&_coverDate=01%2F01%2F2007&_sk=994299998&view=c&wchp=dGLbVlb-zSkWA&md5=5a892cfbd5053dd2bed6e9b0efa93204&ie=/sdarticle.pdf

[21] E.Heine. "Power system".

[22] E.Heine. "Reliability analysis of electronics".

[23] J.J. Hogenbirk, M. v.d. Hoek. "All Optcial Concept".