

# ASSESSMENT OF GIGABIT ETHERNET TECHNOLOGY FOR THE LOFAR MULTI-TERABIT NETWORK

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## ABSTRACT

The LOFAR radio telescope, which is currently being developed, can be considered as a massive digital data processing instrument for astronomy. The telescope requires an aggregated data transport bandwidth of order twenty Terabits per second. A logical transport network is proposed that can be mapped onto emerging technology in a flexible way. For interfacing the equipment to the network we analyze ten Gigabit Ethernet technology being developed for the PC market and becoming commercially available in the coming years. Network management and throughput aspects will be discussed in relation to the required flexibility in operational conditions.

## INTRODUCTION

LOFAR is an aperture synthesis array with over hundred antenna stations, each with order hundred dual polarization receptors [1]. The antennas are divided over so called antenna stations, which are spread out over an area of over twenty million hectares. The signals are digitized at the stations and the resulting data needs to be transported from the stations to a central processing facility. Signals from each receptor are digitised using 14-bit Analogue to Digital Converters sampling at a sample frequency of 64 MHz. A Global Positioning System (GPS) synchronized Rubidium clock is used to timestamp the measured data with an accuracy better than 1 ns and a precision of order 1 ps. Signals from a cluster of receptors will be combined and after pre-processing this results in an output data rate of nearly ten Gigabits per second, which matches well to emerging data transport standards. The actual number of receptors per cluster varies from five till twenty depending on the amount of pre-processing [2].

There are two kinds of data transport networks each providing about half of the capacity. One network is optimised for data transport from the remote antenna stations using a single fibre and the other is for transport from all the antennas within 10 km from the central processing system. The long-range network will be based on next generation DWDM telecom technologies, as is discussed in [3]. For the short-range network we propose to use ten Gigabit Ethernet transport technology.

We start with a summary of the LOFAR network configuration and functional requirements. Based on these, a logical architecture is defined and mapped onto a physical one. The long-range network will face incremental interface capacity upgrades within a time span of four years. However, the short-range network has to have full transport capacity right from the beginning.

## NETWORK ARCHITECTURE FOR LOFAR SHORT-RANGE NETWORK

The short-range network transports the full bandwidth and can serve about half of the clusters. By reconfiguring the central processing facility all available processing power can be used to combine the signals of the clusters to form multiple full bandwidth beams from a single big antenna station. The clusters in the remote stations are served by the long-range network, which will reach its full bandwidth in a later phase of the project. This means that in the initial operation phase of LOFAR additional pre-processing like beam forming is needed at the remote stations to limit the bandwidth to a data rate, which can be handled by the transport layer.

To realize this ultra high bandwidth data transport and to meet the LOFAR requirements in a cost effective way, a fibre cost dominated short-range data transport network based on low cost ten Gigabit Ethernet interface technology is proposed. Basic point-to-point connections from the clusters to the central processor are based on fibre optic data links

operating in the 1.3  $\mu\text{m}$  window. LOFAR requires mainly upstream data transport bandwidth from the clusters and stations to the central processing facility. The required downstream bandwidth for control of the clusters is very limited.

The geometrical distribution of LOFAR stations does allow for a hybrid network design. Different 10GbE physical layer specifications with different physical media dependencies are applied to meet LOFAR requirements in a cost effective manner. A specific technology is chosen based on the distance of the stations from the central processing platform. For station distances less than 300 meters, a 10 Gigabit Ethernet WWDM Physical Media Device (PMD) over 50 micron Multi Mode Fibre (MMF) is used operating at 850 nm. For station distance exceeding 300 meters, 10 Gigabit Ethernet WWDM PMD's over Single Mode Fibre (SMF) are adopted.

An important issue is the required routing flexibility to provide options for dynamically reconfiguring the antenna constellation, in order to meet the observation demands of the users and to improve the system's availability.

We propose an easily configurable network based on 10GbE transceiver technology being developed for the emerging ten Gigabit Ethernet market. This cost-effective technology uses aggregate data pipelines between ten Gigabit Ethernet ports at the clusters and the multi-beam forming correlator at the central processing facility. The proposed network approach provides dynamic reconfiguration of the antenna and processing constellation to meet observation requirements and can be evaluated using current one Gigabit Ethernet technology.

## **GIGABIT ETHERNET NETWORK DESIGN OPTIONS**

Here, the following issues related to the design options are highlighted:

1. Optical transceiver types;
2. Cabling performance;
3. Implementation example;

### *Optical Transceiver Types*

There are three kinds of interfaces, which are described individually in IEEE P802.3ae as 10 Gigabit Media Independent Interface (XGMII) (Clause 46), XAUI (Clause 47), and 10 Gigabit Sixteen Bit Interface (XSBI) (Clause 50) respectively. We adopt the 10 Gigabit Attachment Unit Interface (XAUI) demonstration for the following reasons:

1. The Media Access Control (MAC) – Physical Layer Entity (PHY) interface of XGMII is a parallel buss with a 74-pin interface; The XAUI is a serial bus with a 16-pin interface. Therefore, the XAUI reduces the 74 pins from XGMII to 16 pins, which enables lower IC costs.
2. Multiple independent implementations are able to interoperate and enable pluggable optical transceivers. In the implementation, XAUI allows both board level connections and external interfaces for XENPAK. XENPAK enables plug-in modules to the XAUI to increase product flexibility by allowing PMD specific plugins for different applications.
3. Longer trace lengths enable higher density ICs (e.g. multiple MACs) and offer greater flexibility in board layout resulting in cost reduction of system components.

## **10-GIGABIT ETHERNET CABLING**

There are several key design considerations for 10GbE cabling. A few to mention are: network topology including distances, and the number of connectors; fibre cabling type and the performance at a specified wavelength including attenuation and bandwidth; optical link loss budget; the use of mode-conditioning patch cords; etc. For MMF, 10GBASE-S over 50  $\mu\text{m}$  is selected. This technology is based on MMF operating at 850 nm wavelength. It allows for a maximum distance of 300 meters and a channel insertion loss at the 2.55 dB level.

Next, the important optical fibre and cabling ITU-T recommendations related to 10GbE SMF are presented. The first one to discuss is the ITU-T recommendation G.652, which covers dispersion un-shifted fibre. It meets the minimum requirements specified in IEC60793-2 B1.1 (dispersion un-shifted single mode) and IEC60793-2 B1.3 (low water peak single mode). Actually it covers 85% of the installed base of SMF, such as Corning SMF-28 fibre, Corning SMF-28e

fibre, Lucent Single-Mode fibre, and Lucent AllWave fibre. It works with 10GbE at a small risk. The ITU-T recommendation G.653 covers dispersion shifted fibre. It does not meet 10GbE optical fibre and cable specifications, which are equivalent to IEC 60793-2 B2. This kind of fibre is not currently manufactured. There is a moderate risk for 10GbE. The ITU-T recommendation G.655 covers non-zero dispersion shifted fibre. It does not meet current 10GbE optical fibre and cable specifications, which are equivalent to IEC 60793-2 B4. Typical products are Corning MetroCore Fibre, Corning LEAF Fibre, and Lucent TrueWave RS Fibre. It has a low risk for 10GbE applications, and also it is transmit dependent.

### IMPLEMENTATION EXAMPLE

A Physical Media Device block diagram is presented in Figure 1, which is based on 10GBASE-LX4 interfaces and an implementation example is depicted in Figure 2. In the following the main functions are described.

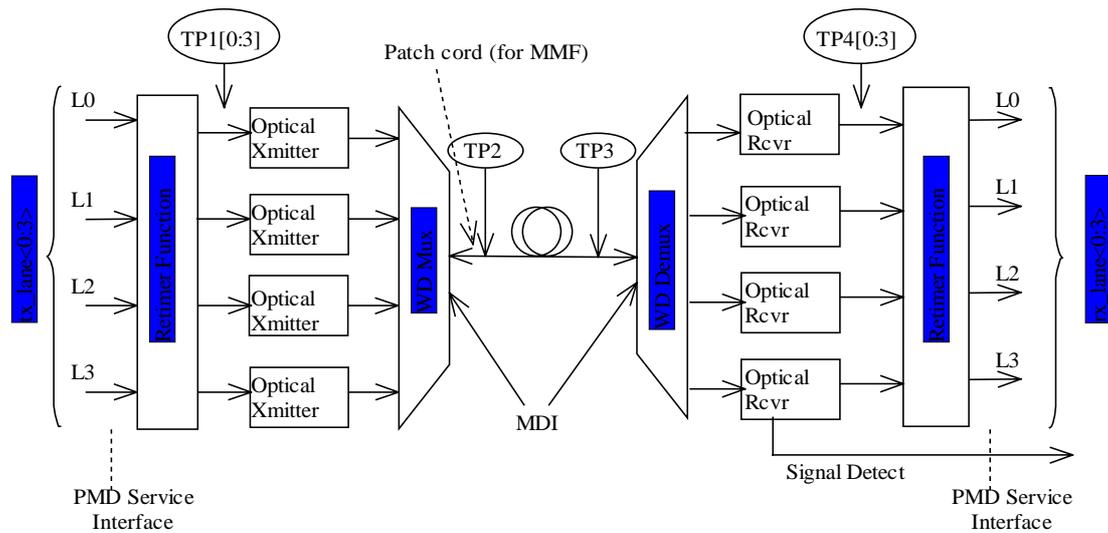


Fig.1. Physical Media Device block diagram.

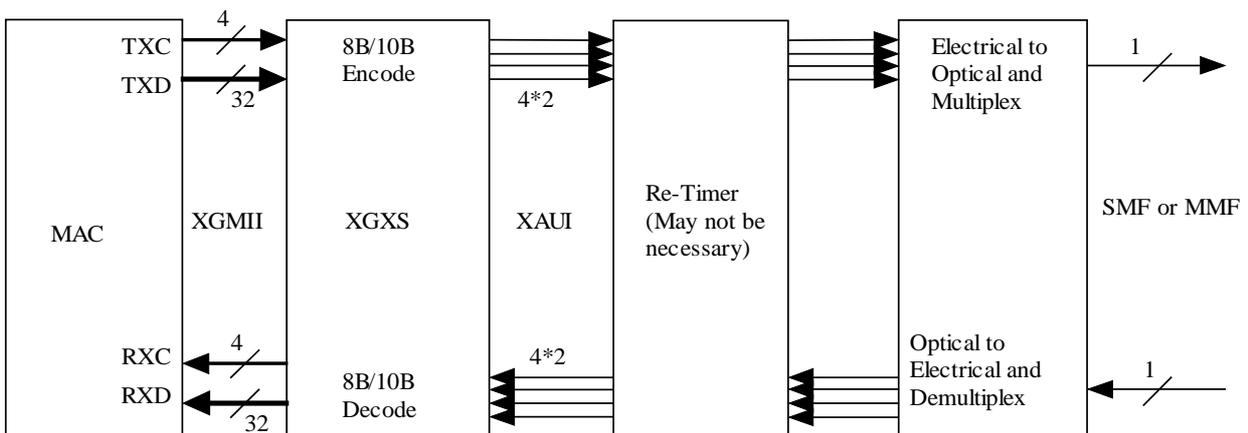


Fig. 2. Implementation example.

## **Physical Media Device Functions**

The PMD transmit function converts 4 electronic bit streams (denoted as tx\_lane[0:3]) as requested by the PMD service interface into four separate optical signal streams (denoted as TP1[0:3]). The four optical streams are converted, through WDM, to a single stream delivered to the Medium Dependent Interface (MDI).

The PMD receive function de-multiplexes the received optical signal into four separate optical streams denoted as TP4[0:3] and it converts these optical streams to electrical signals, denoted as rx\_lane[0:3].

The signal detect function reports to the PMD service interface the presence of optical signals on all four lanes. The received signal needs to be greater than -30 dBm, which is greater than the receiver sensitivity and compliant with 10GBASE-WWDM signal input specification.

## **GIGABIT ETHERNET DEMONSTRATION**

ASTRON has built one Gigabit Ethernet data link over 2 kilometres to demonstrate the transmission of astronomical data with Gigabit Ethernet technology over a relatively long distance. Customized GbE physical interface cards with SC connectors, feature an optical link distance up to 2km, performs optical-to-electrical and electrical-to-optical conversion and takes care of clock/data recovery, transmit clock frequency multiplication, de-serialization and serialization. With LAN WDM PHY 10GbE technology, the 1 GbE can be easily upgraded to a 10GbE system. With such a LAN WDM PHY 10GbE solution for the LOFAR short-range network, there are more advantages to meet the requirements. XAUI to XAUI implementation simplifies the system and reduces the costs. The well-known coding scheme (8B/10B) enables the design and upgrades network from GbE to 10GbE network easily reusing ASTRON's experience with Gigabit Ethernet technology. The 4 lanes at 3.125 Gbps can be utilized efficiently to match the data rates of LOFAR stations. The 300m MMF and 10km SMF capabilities provide a unite design option for the LOFAR short-range network with easy maintenance and network management. Products from several vendors are ready to meet such a solution, and the required interface inter-operations capabilities have already been demonstrated. The rising speeds in combination with the increase in the number of applicable wavelengths provide the required scalability for future expansion of LOFAR and different applications.

## **CONCLUSIONS**

We have shown that emerging 10GbE technology has sufficient throughput and flexibility to make it applicable for the short-range data transport network of LOFAR. The high volume main stream PC market will drive the price of 10GbE technology even low enough to make the short-range network fibre cost dominated. Using the 10 GbE interfaces as repeaters every 10 km, they may even be used in the initial phase of the long-range data transport network of LOFAR.

## **REFERENCES**

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