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Generic Ethernet Passive Optical Network Platform for Advanced Protocol Development

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Abstract: - This paper describes a generic Ethernet Passive Optical Network platform, which is developed in the IST project E-next. The purpose of the platform is to allow future experimentation with dynamic bandwidth allocation algorithms, seamless handover between wireless access points, multicast transmissions, etc. within a Passive Optical Network. A general description of the Ethernet Passive Optical Network technology is presented and detailed information about the platform is supplied. Furthermore, experimentation possibilities for the platform are proposed.

Key-Words: - EPON, MPCP, Dynamic Bandwidth Allocation, FPGA

1 Introduction

Passive Optical Networks (PON) are receiving increased attention as a solution to provide fibre based broadband access. Ethernet PONs (EPON) are optimised for Ethernet transport, and standardization is carried out in IEEE [1] by the “Ethernet in the first mile” workgroup. A PON is a point-to-multipoint (P2MP) optical network as shown in Fig. 1. The basic building blocks are the Optical Line Terminal (OLT) and the Optical Network Unit (ONU). The OLT is connected with up to 64 ONUs by optical fibre and a passive optical splitter. Upstream and downstream transmissions can take place at the same time as each direction has different wavelengths.

Traffic in the downstream direction is broadcast to all ONUs, whereas it is a bit more complicated in the upstream direction, where several approaches can be used to avoid collisions. Wavelength-division multiplexing is currently considered cost prohibitive since each ONU requires a wavelength-specific transceiver and the OLT needs a tunable receiver or a number of receivers for all wavelengths. The more cost-effective solution, time-division multiplexing (TDM), is thus the approach taken in EPONs. Fig. 2 shows the system architecture of an EPON using TDM in which each ONU is given a time slot for upstream transmission.

The fact that the optical splitter is a passive component that does not need power is a key factor in the cost effective EPON, as there is no need for active control in the field between the central office and the user. Compared with point-to-point links, the P2MP structure also minimizes a practical problem of handling potentially thousands of incoming fibres at the central office by reducing this number by a factor of 64.

1.1 Multi-Point Control Protocol

To control the P2MP fibre network, EPON uses the Multi-Point Control Protocol (MPCP). The MPCP arbitration mechanism developed by the IEEE 802.3ah Task Force supports dynamic allocation of non-overlapping upstream transmission windows (time slots) by the OLT. MPCP is not concerned

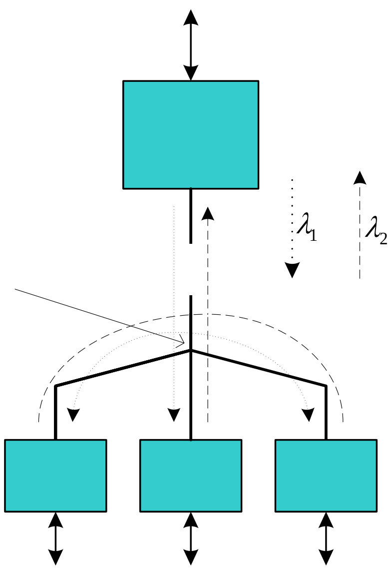

Fig. 1. PON architecture.

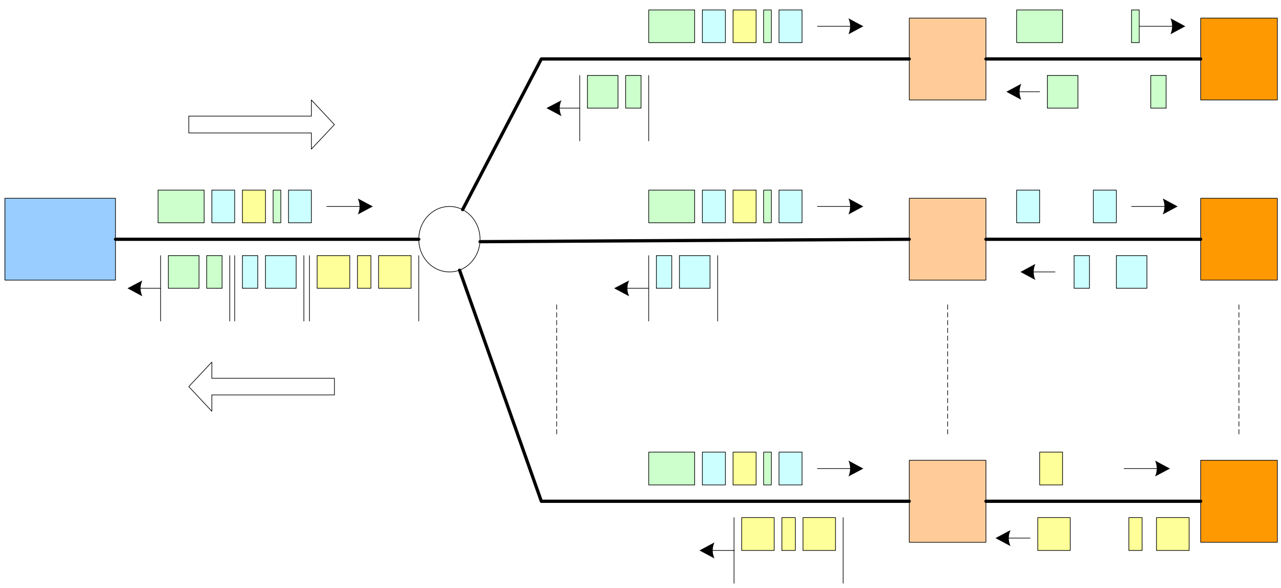

Fig. 2. System architecture of EPON employing time-division multiplexing.

with a particular algorithm, but can facilitate any bandwidth allocation scheme. Three types of messages are available for auto-discovery (REGISTER_REQUEST, REGISTER, REGISTER_ACK), which is the process of adding new ONUs to the EPON, and two messages are used for the two-way messaging (REPORT and GATE) defined to arbitrate between the upstream transmissions of different ONUs. Each ONU buffers incoming Ethernet frames ready for transmission in a number of queues (possibly ordered according to QoS) and uses a REPORT message to report the amount of data to the OLT.

In order to optimize the bandwidth usage, the MPCP monitors the round-trip times (the time it takes from the OLT sends a GATE message until a REPORT message is received from a specific ONU), which allows minimization of the space between upstream slots. This process is called ranging.

1.2 Organization and objective

The European IST project E-Next is an FP6 Network of Excellence that focuses on Internet protocols and services. The general objective of E-Next is to reinforce European scientific and technological excellence in the networking area through a progressive and lasting integration of research capacities existing in the European Research Area.

Commercial EPON equipment is available today, but it is not possible to change protocols and algorithms in these products. So as means to demonstrate and verify the theoretical results obtained, a Generic Ethernet Passive Optical Network Platform is developed within the E-Next consortium. There are other examples of EPON testbeds, e.g. [10] in which the hardware and functionality of a sole ONU platform is described. On this ONU testbed, user data is handled by an FPGA and MPCP protocol computation is performed in an ARM processor. As the next section shows, the EPON platform described in this paper is

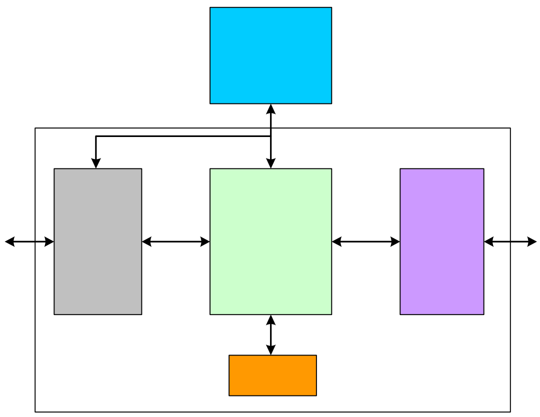

Fig. 3. Hardware on OLT and ONU modules.

fully implemented with both OLT and ONUs and MPCP is moved to the FPGA, which allows a simpler hardware design.

The goal is to demonstrate advanced protocols in the fields of dynamic upstream bandwidth assignment, wireless access, and multicast transmissions at a later point. The remaining parts of this paper present the PON platform in more detail, and describe the applications planned.

2 Platform Architecture

The EPON platform consists of one OLT and up to

64 ONUs and is fully operational with data rates of up to 1.25Gbit/s downstream and 155Mbit/s upstream. The OLT and ONU PCBs have many similarities, and a common overview of the hardware is shown in Fig. 3.
The Xilinx FPGA is the central component of the design. Here, the MPCP protocol is implemented and all data flows through the FPGA. If extra storage is needed (if for example implementing a system with prioritized queues) an SRAM module of 16Mbit is accessible. The burst-mode nature of the upstream data makes the use of traditional clock and data recovery (CDR) components from point-to-point applications unsuitable in this direction. Such components rely on phase-locked loop (PLL) circuits, which require a large preamble to lock the PLL circuit to the incoming data. Since the large preamble is needed every time a new ONU is assigned bandwidth, such a design would be ineffective. The upstream CDR takes place in the FPGA on the OLT, which enables instant recovery of the data and the large preamble overhead is avoided. The downstream data is continuous and standard CDR components are used. The asymmetric architecture differs from the IEEE 802.3ah objective of 1.25Gbit/s symmetric transmissions, but imposes no problems in a test bed intended for protocol tests.
The optical components (still referring to Fig. 3) on both OLT and ONU naturally have complimentary transmit/receive wavelengths.
Connection to a PC, LAN, wireless access point or the like is made possible through a 4 port MAC interface that allows individual data rates of 10/100/1000Mbit/s.
Finally, an interface to a "Linux-In-A-Box" (LIAB) is present, which is a control module with a small Pentium processor running Linux [3]. With this interface it is possible to access the FPGA and the MAC controller. If experimenting with different algorithms for dynamic bandwidth assignment, it is possible to run a higher level algorithm in the LIAB (for example written in C) and then set relevant registers in the FPGA, which could be read by MPCP and thereby assign bandwidth to the ONUs. Hence, it is not necessarily a pure VHDL project to work with the platform.

The remainder of this section supplies detailed information on the hardware platforms for OLT and ONUs respectively. The delivered FPGA designs are created in VHDL and accommodate a basic implementation of the EPON. The dynamic bandwidth allocation (DBA) algorithm initially implemented in the design is quite basic, as it simply distributes available timeslots evenly to the ONUs.
Common for OLT and ONU VHDL designs is that the user is free to add functionality and alter existing modules in order to evaluate DBA algorithms, perform wireless protocol tests, etc.

2.1 Functional components in the OLT

Fig. 4 shows the functional blocks in the OLT design. The DBA and MPCP blocks handle the assignment of timeslots and generation of control messages. It is in these two blocks experimentation

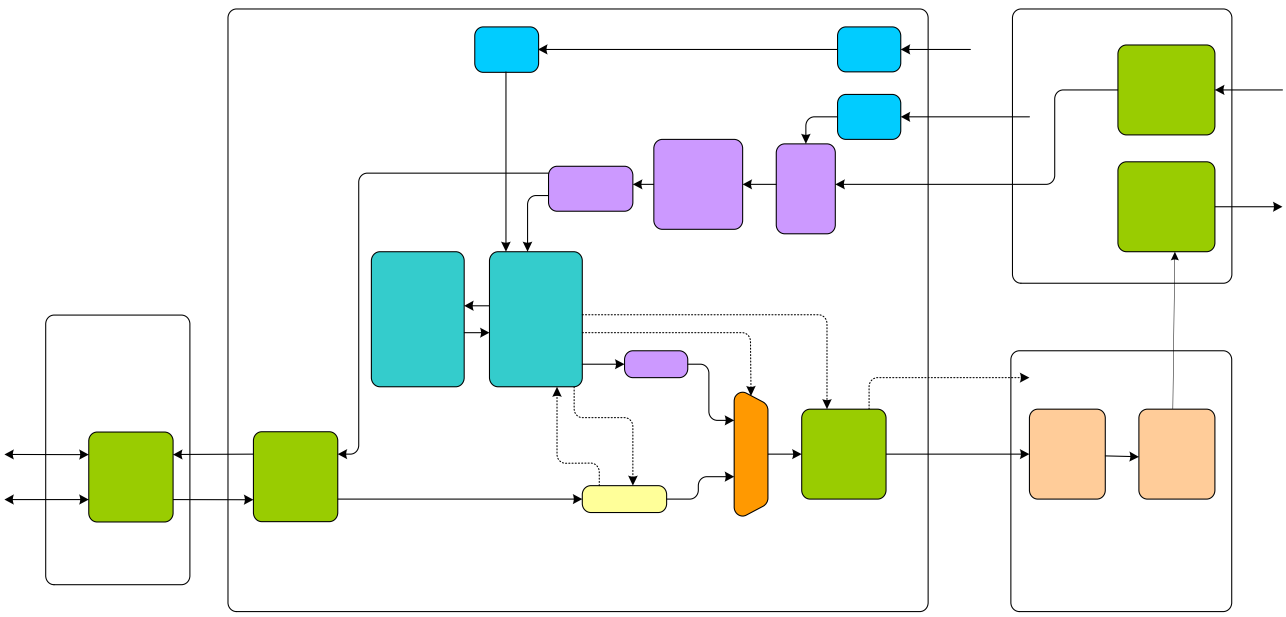

Fig. 4. Logical overview of the OLT components. LIAB, SRAM and minor interfaces are not shown.

with other and more advanced DBA algorithms can be performed – the rest of the design can be used unchanged if desired.

Below, the components of the system are described.

Ethernet MAC

A 4 port 10/100/1000 Mbit/s Ethernet interface. This interface is the obvious choice for supplying data to the EPON.

Optical transceiver

Data for the optical device is handled serially. In the downstream direction (when the optical component is transmitting), a serializer is inserted in the datapath. This means that data can be delivered in parallel from the FPGA and the high downstream data rate is obtained. The serializer also introduces 8b/10b encoding of the data, which is necessary in the optical transmission. In the upstream direction, data is delivered serially directly from the optical device to the FPGA, which allows for a very efficient CDR. This design requires that 8b/10b decoding takes place in the FPGA.

CDR

Clock and Data Recovery is carried out in the FPGA by using a technique that reads the value of the incoming bits on 4 different clock phases. By comparing the data read on the 4 different phases in the event of a data transition, it can be determined which clock phase is the most reliable. With this technique CDR is performed instantly.

FIFO and MUX

A small buffer is needed in the downstream direction in order to insert control packets without loosing data. The multiplexer shifts between the user data and control messages (after framing).

Packet filter

It is necessary to recognize the REPORT messages from the ONUs and hand them to the MPCP protocol. User data is led to Ethernet interface.

Timing components

The OLT holds the Global Time of MPCP. The Global Time is a 32bit counter, which is incremented for every 16ns (62.5MHz).

2.2 Functional components in the ONU

Fig. 5 shows the functional building blocks of the ONU design. As it can be seen there are many similarities to the OLT design and again the user is free to use some or all of the FPGA components. Opposed to the OLT, the ONU has serializing/de-serializing components in both upstream and downstream direction. This means that CDR and 8b/10b decoding does not take place in the FPGA. Instead, a few other components are introduced:

Priority FIFOs

The design is QoS capable, as user traffic in the upstream direction is classified and can be assigned different priorities. QoS is enabled by having three prioritized queues for the upstream data.

Asynchronous FIFO

The clock rate is lowered in the FPGA in the downstream direction by doubling the data width in a asynchronous FIFO.

Packet filter

The packet filter is slightly different compared to the one in the OLT, as it not only has to recognize control messages – it also has to filter out the packets that are not intended for the ONU.

2.3 Status

At the time of writing the hardware platform is in the preliminary test phase in which the different components interoperability is verified. The MPCP

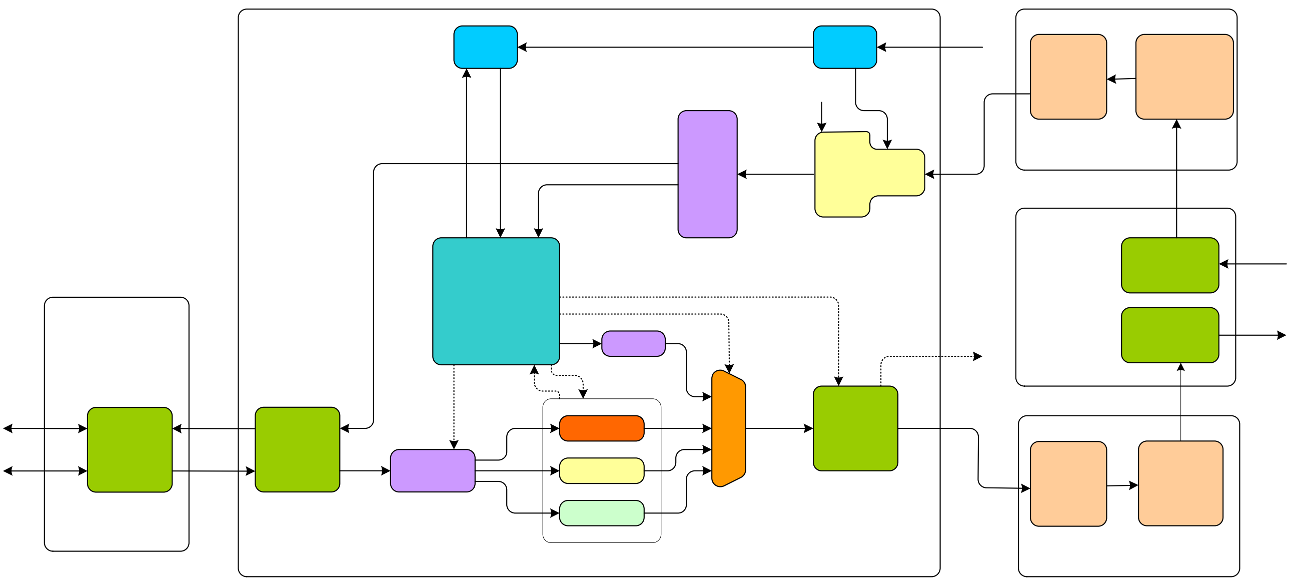

Fig. 5. Logical overview of the ONU components.

protocol is implemented in VHDL and the various modules of which it consists was simulated independently. A simple DBA algorithm is created and used for initial testing.
Next step includes a large scale test of the entire MPCP protocol and tests of the full system, consisting of one OLT and three ONUs.

3 Dynamic Bandwidth Allocation

The technology of Ethernet Passive Optical Networks is relatively new, but already a large number of algorithms exist that deal with bandwidth allocation. The following section will describe the different categories of algorithms, which all can be used by MPCP to assign bandwidth.
DBA algorithms for EPONs can be divided into three categories as described in the taxonomy by McGarry, Maier and Reisslein [2]. As illustrated in Fig. 6, the main difference is between statistical multiplexing and QoS assurance, where the latter comprises both absolute assurance and relative assurance.

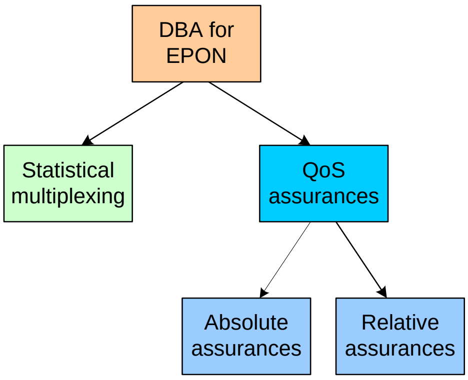

Fig. 6. Taxonomy of DBA algorithms

3.1 Statistical Multiplexing

The simplest form of bandwidth assignment is statistical multiplexing in which each ONU is assigned transmission windows based on the quantity of traffic they have. This is usually done in a round robin fashion, but to prevent heavy loaded ONUs from monopolizing the bandwidth, finite sized transmission windows can be applied. The granted upstream bandwidth is based on the amount of backlogged data in the ONU at the time of reporting. Data arriving after the request message is sent must therefore wait for the next grant. To prevent undesirable delay in traffic, the grant for the ONU can be adjusted by a specific amount or a predetermined factor. An example of a statistical multiplexing algorithm is Interleaved Polling with Adaptive Cycle Time (IPACT) [5].

3.2 QoS Assurance

In systems employing QoS, it is necessary to add

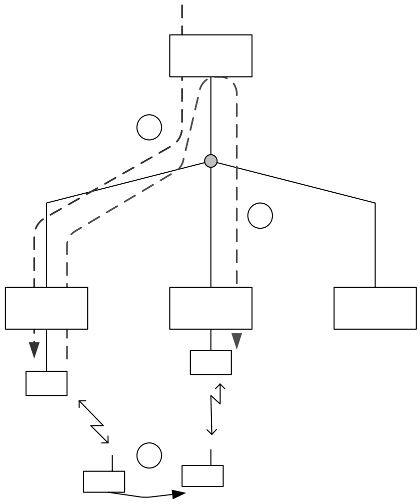

Fig 7. Handover in combined network.

some form of priority queues in the ONUs. Different classes of traffic can originate from one end user or several end users with different Service Level Agreements (SLA).
Absolute QoS assurance algorithms allow the ONUs to have different classes of traffic, and each ONU is then granted an amount of bandwidth or served with best effort depending on its SLA. The individual ONU determines how to use the granted bandwidth and possible unused timeslots (including unutilized parts of timeslots) are shared among ONUs without bandwidth guarantee and heavy loaded ONUs. The advantage of absolute QoS assurance is the deterministic bandwidth guarantee for ONUs with SLA, but it comes at the risk of starving ONUs without a SLA. Examples of algorithms giving absolute QoS assurance are Bandwidth Guaranteed Polling [6] and Deterministic Effective Bandwidth [7].
Relative QoS Assurance divides traffic in the ONU into categories (e.g., high, medium, low) and buffers it accordingly. The QoS based traffic from ONUs to OLT can be controlled entirely by the OLT, in which case high priority data from all ONUs is served first before medium priority traffic is transmitted. The strict enforcement of queue priority might result in starvation of low priority traffic. Instead of the OLT handling all scheduling, each ONU can be assigned bandwidth in proportion to its SLA, thus saving overhead in the messaging between ONU and OLT. Examples of algorithms giving relative QoS assurance are DBA for Multimedia [8] and DBA for QoS [9].

4 Test scenarios for EPON platform

This section is a study of scenarios for testing advanced networking methods on the EPON platform. The generic nature of the test bed allows for a wide range of setups to be implemented and tested.

4.1 DBA Algorithms

Implementation and test of dynamic bandwidth allocation algorithms from the different categories described in the previous section is the most obvious use of the EPON platform. It will allow algorithms to be tested with various real life traffic conditions and could be used to monitor different parameters impact on the system, e.g. QoS. The practical implementation of the multipoint control protocol could also yield interesting results with regards to clock and data recovery, ranging, discovery handshake etc.

4.2 EPON and Wireless combined

To allow the implementation of a wireless access network as defined in [4] on the user edges of an EPON structure with smooth and seamless mobility constraints, a set of problems and needs arises. A possible setup is illustrated in Fig. 7 and consists of a mobile station (STA) moving from one access point (AP) to another, each connected to different ONUs. On the EPON development platform, each mobile node will be able to move through the access points without losing the upper-layer connections and with a small (if not zero) probability of packet-loss. It is possible to take advantage of the EPON peculiarities, such as its tree topology, and allow centralized control of the node transactions, but then handover overhead and delay must be taken into account. Another factor to study and evaluate is the cost of a given solution, in terms of complexity and resource usage.

4.3 Multicast over EPON

Multicast from OLT to the ONUs can be done very efficient due to the point-to-multipoint nature of EPON. A mapping of the multicast from Layer 3 (as defined by the OSI network model, IP in most cases) to Ethernet (Layer 2 in the OSI model) must be performed at an appropriate place in the data path. A multicast method must also be implemented in the EPON to allow all ONUs to accept transmission from the OLT.

5 Conclusion

This paper has introduced the generic EPON evaluation platform under development in the E-next Network of Excellence. The FPGA based design with gigabit optical interface and Ethernet allows a multitude of future test setups. An introduction to the problems involved with point-to-multipoint was given as well as a general description of the multipoint control protocol and dynamic bandwidth allocation algorithms. Wireless handover in the PON and Multicast over EPON are also introduced as future applications of the optical networking platform.

6 Acknowledgement

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