

A Low Power 40 Gbit/s Cascaded Extension to Bit-Interleaving Optical Networks Enabling Next-Generation Metro/Access Connectivity

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Optical networks in use today were not designed to accommodate the needs of new technologies such as cloud services and the Internet of Things. Features as flexible bandwidth allocation and low packet-delay variation, which are of crucial importance, are still missing in current metro/access networks. In this paper the solution known as CBI-PON is highlighted. CBI-PON is a cascaded extension of the BiPON protocol offering these features, while lowering the network's power consumption. A 40 Gbit/s implementation of the electrical part is presented, showing 80× (Repeater) and 6× (End-ONT) power consumption reduction compared to currently available commercial equipment.

Introduction

The demand for higher bandwidths has been steadily rising over the last few years [1]. To satisfy this demand, a divergent collection of access technologies has been developed. Particularly interesting are the Passive Optical Networks (PONs), since they are generally considered as a cost-effective and energy efficient option.

Furthermore, upcoming technologies such as the Internet-of-Things and cloud services pose new challenges such as a need for highly flexible dynamic bandwidth allocation and low packet-delay variation. On top of these new challenges, the environmental impact of communication networks is becoming more and more significant: in 2012 an estimated 1.8 % of the global power consumption was attributed to communication networks [2]. Therefore, next-generation networks should try to reduce their power consumption.

In this paper, the Cascaded Bit-Interleaving PON (CBI-PON) is introduced as a solution to all these challenges. First, the Bit-Interleaving PON (BiPON) is introduced, followed by its extension CBI-PON. Subsequently, the CABINET implementation is presented. Finally, the predicted power consumption figures illustrate the potential of the concept.

Bit-Interleaving PON Protocol

In 2010 the Bit-Interleaving PON Protocol was introduced [3, 4]. Traditional PONs use a packet-based TDM: bits intended for a single Optical Network Unit (ONU) are sent consecutively and are grouped in packets, as shown in Figure 1a. This has some important implications on the receiver side. In short, the receiver front-end must operate at a high frequency and must recover all bits, which is a power hungry operation. The MAC

processor then continues to process all bits, including those addressed to other ONUs. This energy efficiency was mitigated by introducing a paradigm-shift and moving to a bit-based TDM: bits are sent one at a time, with bits for other ONUs in between. A clarifying schematic representation is given in Figure 1b.

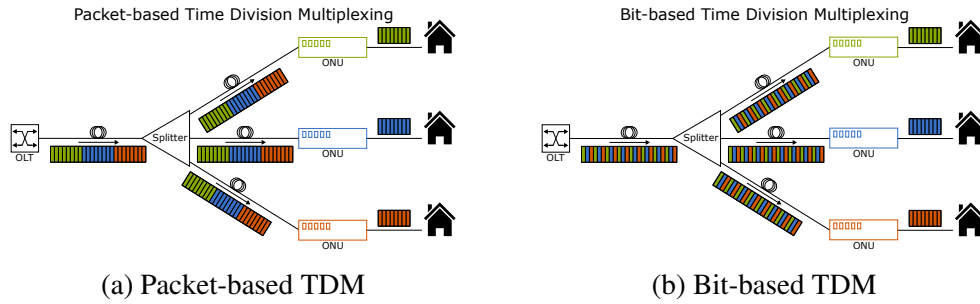


Figure 1: Time-Division Multiplexing

Furthermore, bits are sent in the form of a BiPON Frame, which contains a frame header. This header allows receiver configuration on a frame-per-frame basis, which enables a highly flexible dynamic bandwidth allocation scheme. For a more elaborate description of the protocol the reader is referred to [3, 4]. The BiPON concept was demonstrated in a 10 Gbit/s implementation with power consumption measurements showing reduction factors from $35\times$ up to $180\times$ depending on the specific configuration.

Cascaded BiPON

In an effort to further decrease communication networks' power consumption, the Cascaded BiPON (CBI-PON) concept was developed. A Cascaded BiPON is a multi-level PON network where each level consists of a self-contained BiPON. A 3-level implementation is shown in Figure 2, where the 3 levels (L1, L2, L3) are clearly indicated. With the exception of the lowest level (L3), each level consists of two types of CBI Devices: CBI Repeaters and CBI End-ONTs.

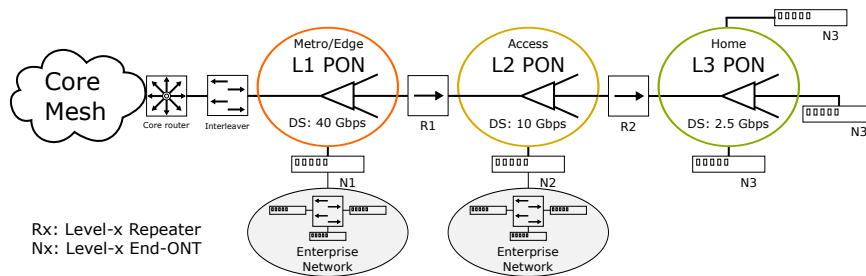


Figure 2: Cascaded Bit-Interleaving PON

The sole purpose of CBI Repeaters is to repeat CBI Frames to lower level BiPONs, which explains why they are not present on the lowest level. To this end, only the headers of

the incoming CBI Frames are processed by the CBI Repeaters. According to the configuration of the CBI Repeater and the header data, the appropriate part of the payload is repeated to the lower level BiPON. The processing complexity of the CBI Repeaters is deliberately kept to a minimum to reduce the power consumption of these devices.

CBI End-ONTs act as the leaf nodes of the BiPON on each level. Based on the information parsed from the frame header, all necessary processing is performed on the payload and the output data is sent to the FPGA which provides a standard Ethernet interface to the end user.

CABINET Implementation

The CABINET Application-Specific Integrated Circuit (ASIC) was developed to demonstrate the concept of the CBI-PON and its power consumption reduction potential. The CABINET chip is a multi-mode, multi-rate device: it can act both in Repeater mode as in EndONT mode, and it supports input line rates of 40 Gbit/s, 10 Gbit/s and 2.5 Gbit/s. This allows the CABINET chip to be used to implement any CBI Device in the presented 3-level CBI-PON, reducing cost of deployment for the network operator. A system overview of the CABINET ASIC is shown in Figure 3. It consists of an analog front-end that sub-samples the incoming data, recovers the clock and retimes the data. Subsequently, this data is processed by the MAC pre-processor. The physical implementation is shown in Figure 4a and the testboard is shown in Figure 4b.

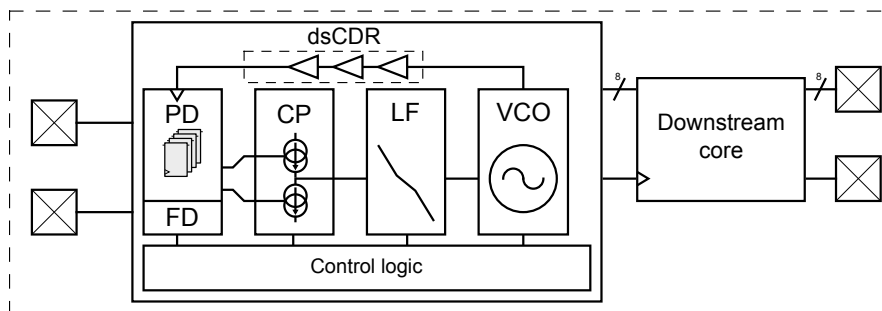
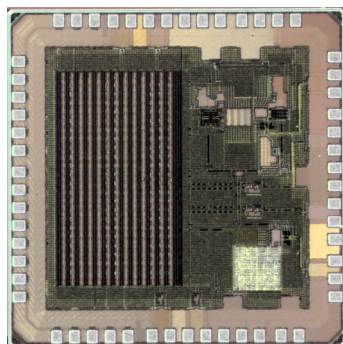
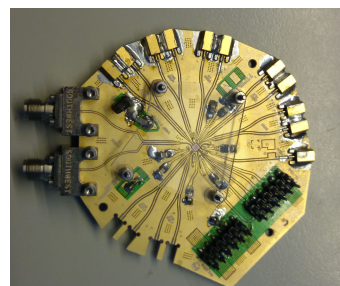


Figure 3: CABINET System Overview



(a) CABINET ASIC



(b) CABINET Testboard

Figure 4: CABINET Implementation

Power Consumption Reduction

The first prototype of the CABINET ASIC had some issues, causing some modes to only function partly. Combining the simulated power consumption and the measured power consumption of the functional parts, the total power consumption was estimated. These extrapolated results are presented in Table 1.

Table 1: Extrapolated CABINET power consumption

CBI Repeater			CBI End-ONT		
	Simulated	Extrapolated		Simulated	Extrapolated
L1	126 mW	187.63 mW	L1	106 mW	162.55 mW
L2	86.5 mW	120.48 mW	L2	66.5 mW	94.55 mW
L3	-	-	L3	50.88 mW	60.51 mW

Within the GreenTouch project, a reference architecture was defined to compare power figures. The access network is defined as a 40 Gbit/s ring of Remote Nodes with an aggregation switch combining 32 2.5 Gbit/s PONs with an average of 73.36 ONUs per PON. This aggregation switch (201 mW/ONU) is equivalent to 32 L1 Repeaters (2.56 mW/ONU), resulting in an $80\times$ power reduction.

The leaves of the access network are ONUs (1.481 W/ONU) containing a small internal PON to support 2 Ethernet ports. An L3 Repeater and 2 L3 End-ONTs would be equivalent, but since there is no L3 Repeater implemented, the power number of the L2 Repeater will be used. This configuration is estimated to consume 241.5 mW/ONU, which translates to a more than $6\times$ power reduction.

Conclusion

In this paper, the Cascaded Bit-Interleaving PON was presented as a way to mitigate the challenges that are appearing for next-generation metro/access networks. To demonstrate the potential of this solution, the CABINET was developed: a 40 Gbit/s ASIC that can implement both CBI Repeaters as CBI EndONTs. Compared to commercial equipment, the estimated power consumption of the CABINET shows reduction factors of $80\times$ (Repeater) and $6\times$ (EndONT).

References

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