Novel Low Cost PON Protection via Harvested Power

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Abstract: PON protection is costly due to the necessary redundant equipment. We describe a method utilising harvested optical power and show test results using commercial equipment, which prove protection could be provided at very low cost.

1. Introduction and Motivation

Time Division Multiplexing Access Passive Optical Networks (TDMA-PON) are the access technology of choice for residential fibre deployments. In the UK and other markets PONs are also being deployed for small and medium sized business enterprises. Protection and resilience will grow in importance for these business customers and could be an area where an operator can differentiate their networks. Several methods of providing resilience have been proposed[1]and standardized[2]. However, there are no commercial deployments of these protection methods mainly due to the extra cost of the redundant equipment that is needed (e.g. Fig. 1b). This paper presents a Type B protection method (i.e. for the OLT and the feeder fiber) that reduces the amount of redundant equipment required, so reducing the cost. Similar to traditional Type B protection this method also needs to use 2xN optical splitters.

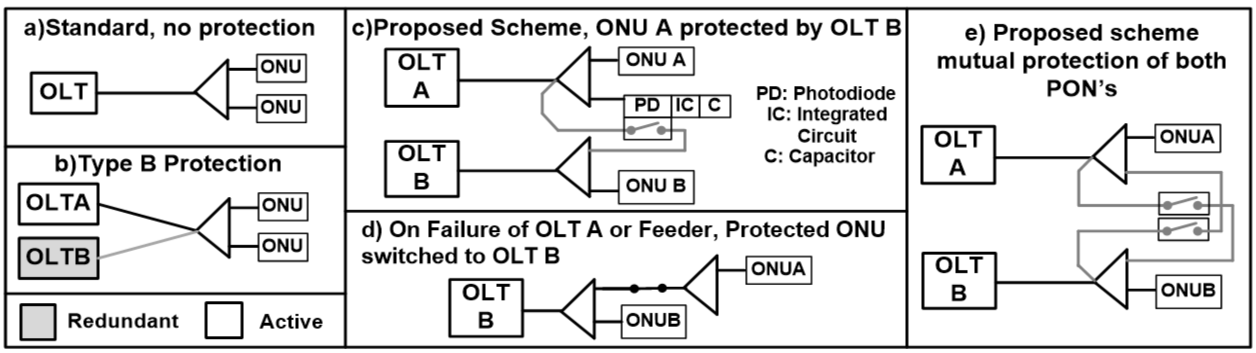

Figure 1 a) Unprotected PON; b) Standardized Type B configuration; c) Proposed new scheme single protection during working condition; d) Proposed new scheme single protection during failure condition; e) Mutual protection

Typically, several splitters are co-located inside a splitter node, which offers an opportunity to provide a resilient path inter-connecting two PONs as shown in Fig. 1c, where ONUs in PON A are simultaneously connected to PON B downstream from its splitter through an on/off switch. This scheme allows selected customers to be protected by an adjacent working PON by the simple act of pre-registering their serial numbers and other necessary parameters[2]. Obviously, the services profiles of the ONUs need to account for this failure condition where OLT B bears the burden of supporting a larger number of ONUs. This may not be too onerous as only a few selected ONUs (e.g. businesses) may be allowed to re-connect and recover their service traffic.

Shown in Fig. 1c, the key components are a Control Block with a PD, an IC, and a large capacitor, and an on/off switch, which does not require any external power supply and operates autonomously. Remote powering of equipment in the Optical Distribution Network (ODN) from a source in the central office has been proposed before for applications ranging from a telephone ringer[3], Internet of Things[4] and Raman powered intelligent splitters[5]. In this work, we propose to harvest the PON downstream optical power to power the switch and monitor the PON status. A splitter port in each PON is used to monitor and harvest power in the working PON and to connect the cascaded protected splitter through the on/off switch (Fig. 1d). Upon a failure in the working PON status, the switch will connect the ONUs to the secondary OLT through a cascaded splitter architecture. The method allows ONUs to automatically return to their working OLT once the fault condition is rectified (revertive operation). As the OLT A starts transmitting again, the Control Block will force the switch to open, thus causing ONU A to disconnect from PON B and re-connect to PON A (more detailed explanation in the next section).

2. Harvesting Power on a PON & PON Design Considerations

In a lab experiment we used an Integrated Circuit (IC) from Analog Devices[6] as described in[4]. This is a low power, synchronous, boost dc-dc regulator to harvest optical power into a capacitor. We used a non-latching optical

Micro Electro Mechanical (MEM) switch from DiCon Fiber optics with low power consumption (max. 20µW) and an insertion loss of <0.5dB. The MEMs switch is controlled and powered from the IC by using the IC's Low Light Condition (LLC) output via a pull up resistor to Vout. This method was preferred to using a microcontroller, as it reduces power consumption and improves reliability. The whole circuit including switch is small enough to fit in a splice tray located with the two primary splitters as shown in Fig. 3.

In normal operation the capacitor is charging, and the LLC output voltage is high at 3.5V and the switch is open. On the loss of downstream optical power the IC sets the LLC output voltage low at 0.15V, closing the switch. On restoration of the light from the OLT, the photodiode detects downstream power, setting the LLC output to high again, opening the switch and reverting back to normal operation.

The LLC threshold is set at -21dBm with a 5dB hysteresis. These values are fixed on the IC due to it being designed for harvesting sunlight via a photovoltaic cell. Ideally, the threshold would be reduced beyond the ONU's sensitivity at around -30dBm, which is the ONU minimum received power, and the hysteresis also lowered.

The capacitor (0.5F) holds enough charge (>3.1V) for approx. 14 hours to allow the circuit to be switched back in less than 10sec, after which the capacitor will need to be charged back up to a minimum of 3.1V to allow the LLC to operate. The capacitor size forces a trade-off between the time allowed to correct the fault and allow a relative fast reverting action, and the time it will take to charge and activate the revertive action. It is worth noting that during the time it takes the capacitor to charge (if the fault has not been rectified quickly enough), the protected ONUs will still be served from the protection OLT.

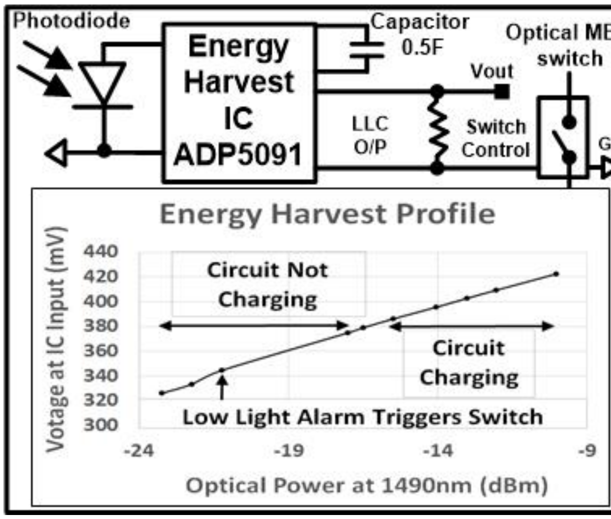

Figure 2. Circuit Diagram & measured harvest power profile

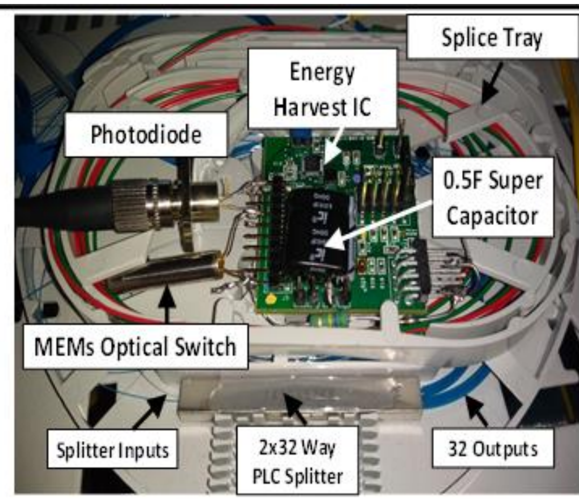

Figure 3. Circuit in Splice tray with 2x32 splitter

The energy harvest IC's minimum input is 380mV. The photodiode in conductive mode produces 385mV at the dc-dc input of the IC at -15.5dBm optical power, as shown in Fig.2. If the MEMs switch is operated at 21dB loss (isolation) when off, then the extra load is sufficient to increase the required optical power to -11.5dBm to maintain charging. In a PON with a 32-way splitter this would allow approx. 10km of fiber, if we assume the OLT transmitted power is +8dBm, which is 2dB above the minimum average transmitted power in the newly standardized D class GPON optics[7]. This is not ideal, but other PON design compromises could be made that are outside the scope of this work. On the other hand, the protection method could be improved by using a latching optical switch to reduce power consumption, re-designing the harvest IC to operate at lower voltages and by selecting a photodiode to be more efficient at 1490nm.

The ONUs that are switched are now in a cascaded architecture (Fig 1d). So the OLT transceiver needs to account for the extra loss, from the second splitter, switch and drop fibres. In a 32 way splitter design the Class D[7] optics with a 35dB power budget would allow this operation and permit ~9km of fibre.

3. System Experiment and Results

An experiment was set up as a proof of concept, to test the service restoration and to measure the data outage during protection switching. The experiment was set up to be representative of a deployed real design as shown in Fig. 5 using commercial PON equipment with no modification. The results are shown in Fig. 6 and Fig. 7.

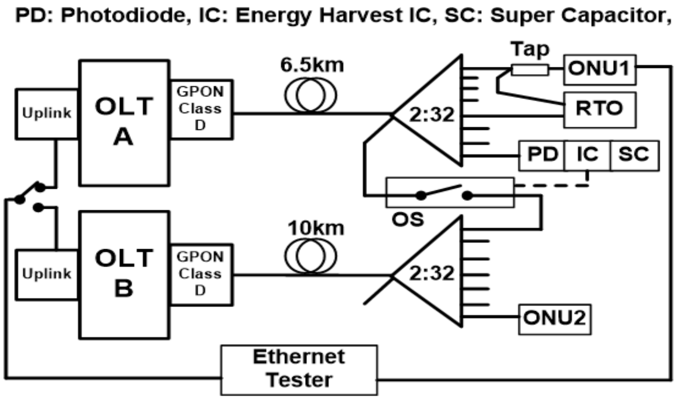

Figure 5. Experiment setup diagram

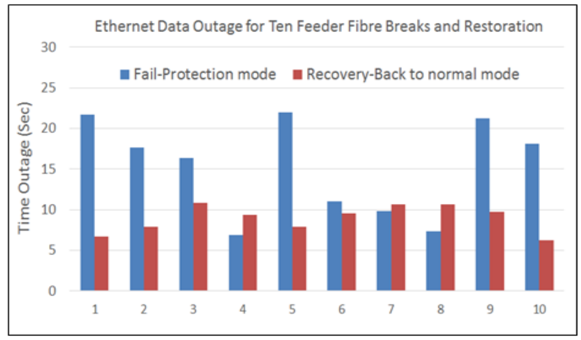

Figure 6 Ethernet outage times for fail and recovery.

The Protected PON delivered -11.2dBm of power to the harvesting photodiode at the output of the splitter. During fail status, the total ODN loss between the OLT B and the ONU1 over a cascaded splitter arrangement and switch was 36.1dB due to six connectors in the link. The MEMs switch contributed 0.48dB loss when in the ON state and 21dB in OFF state as measured. After bringing ONU1 and ONU2 up to working condition, with OLT A and OLT B respectively, the PON fiber at the OLT A was disconnected to simulate a failure condition. Once the traffic service is restored through the protection PON, the fiber was re-connected to OLT A to clear the fault and automatically revert the traffic through the working OLT A. This operation was repeated several times and the results are shown in Fig.6. The blue bars depict the times until the service traffic is restored on the protection OLT after failure and the red bars depict the outage times when the protection switching is reverted to the working OLT. In protection mode the restoration time was measured up to 22sec. and the outage time when reverting after the fault was fixed (from OLT B to A), was measured up to 10.8sec. These results are in comparison to the Type B protection reported[8] which had a 9.5sec and 8.8sec switching time respectively. No loss of data or errors were measured on ONU 2 during either operation. The slower time in switching to the protection mode is in part due to a 10µF input capacitor required at the input to the IC and the load resistance of the DC-DC converter giving a minimum of 5s before the IC can detect a drop in the optical power. This could be improved by trading charging efficiency for switching speed. Fig. 7 shows the RTO traces where it can be seen how ONU 1 is reconnected to OLT B after failure of OLT A (left), and how ONU1 is re-connected back to OLT A after the fault is cleared.

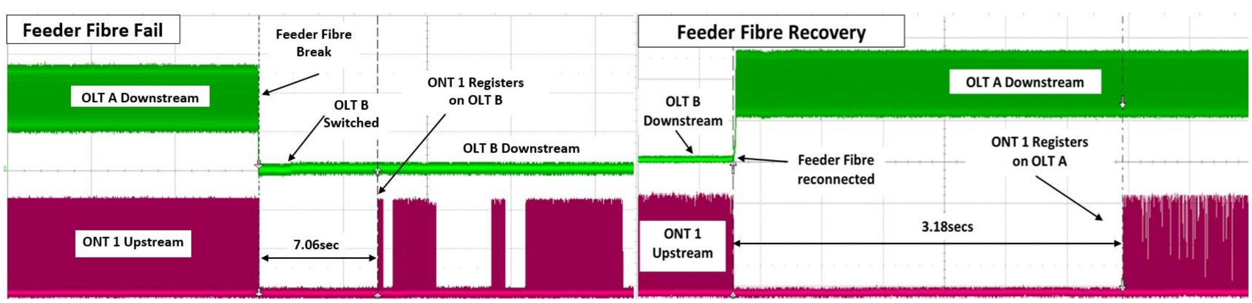

Figure 7. RTO Measurement of loss and recovery after the feeder is pulled from OLT A (left) and reinserted (right).

4. Conclusion

A practical method to provide protection on a PON has been proven and switching times have been measured using available, non-customized, commercial equipment. The test results could be improved after some development; for example, customizing the IC for PON applications to improve the speed of switching.

References

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