Optimization of existing access networks with low-cost multilevel modulation formats

Optimization of Existing Access Networks with Low-Cost Multilevel Modulation Formats

R. van der Linden,[1,2] N.C. Tran,[2] E. Tangdiongga,[1] and A.M.J. Koonen[1]

[1] COBRA Research Institute, Eindhoven University of Technology, The Netherlands
[2] Genexis B.V., The Netherlands

PON networks are designed around a minimum received power level. The actual use of power budgets in a PON typically varies widely. Utilizing multilevel modulation for ONUs that have high power margins can increase network capacity utilization without investing in expensive optics. In this paper we present statistics from a commercial GPON network and demonstrate that a capacity increase is possible for a majority of the users. Even users with a low power margin can benefit from multilevel modulation, if smart distribution of timeslots among users is utilized.

Introduction

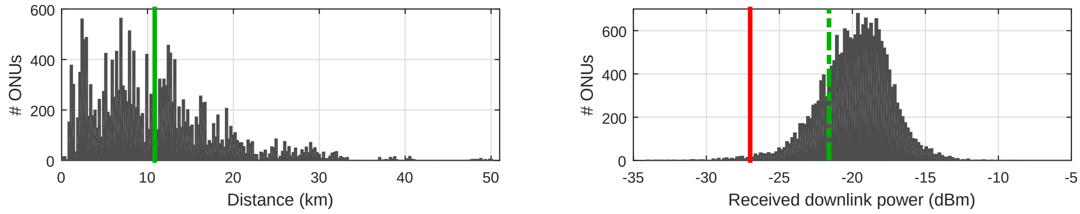
Passive optical networks (PON) serve a large diversity of users, neighbourhoods, and regions. This leads to diversity in network topologies, varying in speed, splitting ratio, and reach. Only one predefined modulation format, determined by the worst-case operational conditions, is used throughout the network. As a result, optical network units (ONUs) that are in better operational conditions, e.g., lower losses, cannot utilize their advantage. That is, a low-loss, short-range ONU will deliver the same performance as a high-loss, long-range ONU. Industry sees the need for more flexibility in the network [1]. We propose using a flexible modulation scheme, where in parts of the network on-off keying (OOK) is used, but in parts where the conditions are better 4-level pulse amplitude modulation (PAM) is used. 4-PAM allows to transfer twice the data rate of OOK at the same symbol rate.

A straightforward implementation of flexible 4-PAM in a PON would be to allocate 4-PAM to ONUs that support this and keep OOK for the other ONUs. Therefore some users will see an increase in supported data rate, while others will not. Similar to the situation in copper access networks, where a user with a shorter copper line will experience a faster connection. An alternative implementation takes advantage of the time-division multiplexing (TDM) protocol in PONs. In this implementation 4-PAM ONUs are allocated less timeslots, thereby freeing-up timeslots for the OOK ONUs. This increases the net capacity of the PON as a whole.

This paper explores the feasibility of sharing the available aggregated data rate with ONUs that do not support 4-PAM, through TDM. Upstream transmission is left for a future study.

Pulse Amplitude Modulation

Using multilevel modulation formats decreases the eye opening. The power penalty, expressed in dB, of M-PAM relative to OOK at the same symbol rate is $P_p = 10\log_{10}(M-1)$. This formula is only valid under the assumption of additive white Gaussian noise and does



(a) (b)

Figure 1: Exemplary statistics of a dataset of the GPON deployments of INEA. (a) ONU position w.r.t. the CO operated by INEA-PL. The vertical solid line depicts the average distance of 10.8 km. (b) Statistics of ONU received optical power. Vertical lines show the sensitivity for OOK (red, solid) and 4-PAM (green, dot dash).

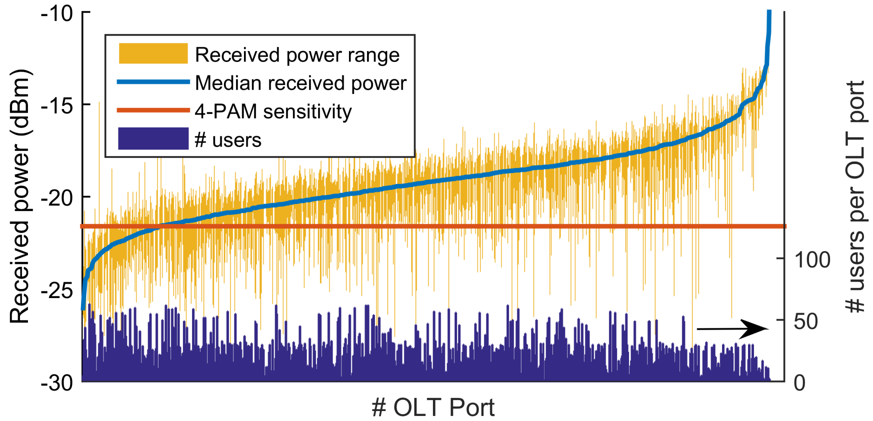
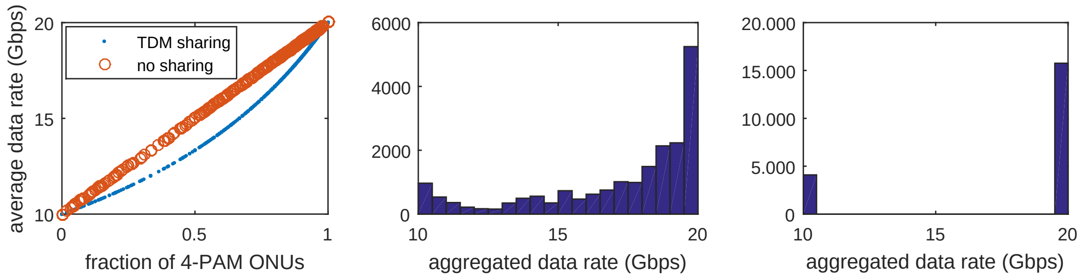


Figure 2: Statistics of a dataset of the GPON deployments of INEA on a per OLT port basis, showing: The power range, consisting of the second-most to second-least of ONU optical received power per OLT port; the median received optical power; the number of ONUs per OLT port

not take into account the additional deteriorated sensitivity due to e.g. noise on the electrical driving signal, relative intensity noise (RIN), timing jitter, and chromatic dispersion [2]. Therefore an additional small power penalty is to be expected on top of this lower limit. Measurements on a setup with 4-PAM format, time-interleaved with OOK, show that the optical power penalty of 4-PAM relative to OOK for transmission over 20 km fiber at the FEC (forward error correction) target BER 10^{-3} is 5.4 dB [3]. This value will be used throughout this paper.

Network Statistics: Received power

The standardization of the different PONs (BPON, GPON, XG-PON, and NG-PON2) allows for 15 dB of differential received optical power within each class of optics [4]. This does not make any statement on the actual differential power budgets encountered in the field. Fig. 1a and Fig. 1b show a histogram of the network distances and optical received powers respectively. This data originates from a dataset of approximately 20,000 ONUs from the GPON deployments of INEA, Poland. As observed, there is a large spread in the fiber lengths and the received powers by the various ONUs, making use of the possible differential optical path loss. Even more, only 1.6% of the ONUs is within 1 dB of the prevalent received power sensitivity limit of -27 dBm (class B+ optics) for this network. The majority of the ONUs have more signal power available.
Fig. 2 shows the range of ONU received powers per OLT port. The median and second-



(a) (b) (c)

Figure 3: a) Attainable average data rate for a given fraction of ONUs that support 4-PAM in the INEA network b) Histogram of speed ONUs see in the entire network if TDM sharing is utilized to its fullest extend. c) Histogram of speed ONUs see in the entire network if no TDM sharing is used.

most to second-least optical received power range for ONUs at a certain OLT port are shown. Additionally the number of ONUs at a certain OLT port are shown. This figure shows that for more than 90% of the OLT ports more ONUs do support 4-PAM, than that there are ONUs that do not. Furthermore, for 97% of the OLT ports at least one ONU supports 4-PAM, allowing for some, albeit small, form of capacity increase.

The statistics in this network are based on a GPON network. In line with the experiment in [3], we focus on a PON with standard data rates of 10 Gbps. This network addresses the need for higher data rates and differs from the GPON network. The optical losses are equivalent to a GPON network, keeping the above network statistics valid.

Network Statistics: Data rate

A distinctive feature of PONs is that multiple ONUs are connected to the same OLT port. The optical received powers of various ONUs on a single OLT port may vary. Due to the TDM protocol in power splitter based PONs, the OLT has control over the fraction of available timeslots that is allocated to a certain ONU. This allows to increase the fairness in a flexible modulation based PON. ONUs that support 4-PAM can be allocated a smaller fraction of the available timeslots, thereby freeing-up timeslots for OOK only ONUs. This increased fairness does come at the cost of a smaller increase in network throughput due to flexible modulation compared to a case where no fairness is increased. As OOK ONUs are allocated more timeslots, this means a larger portion of the time is spent transmitting at a slower data rate, as illustrated by Fig. 3a. This figure shows the total throughput attainable at the various OLT ports in the examined network, as a function of the fraction of ONUs on that specific OLT port that support 4-PAM. It can be seen that the average data rate is slower for every fraction of supported 4-PAM ONUs, except the demarcation cases of no supported ONUs and all supported ONUs. Once again, it does mean that every user on this OLT port gets this exact average data rate, where in a non-shared situation the average is made up of a binary sitation, where an ONU either sees 20 Gbps or 10 Gbps.

Comparing these statistics from Fig. 2 and 3a with the power penalty induced by the use of 4-PAM, and taking the varying number of users per OLT port into account, the aggregated data rate seen by each user can be obtained. Fig. 3b shows a histogram of the resulting data rates. For reference purposes the histogram of data rates seen by users in a non-TDM sharing scenario is shown in Fig. 3c. Emphasizing that with TDM sharing the number of users that see an increased bandwidth grows, albeit with a lower increase.

In an attempt to summarize the aggregated data rates seen by the entire network, a cu-

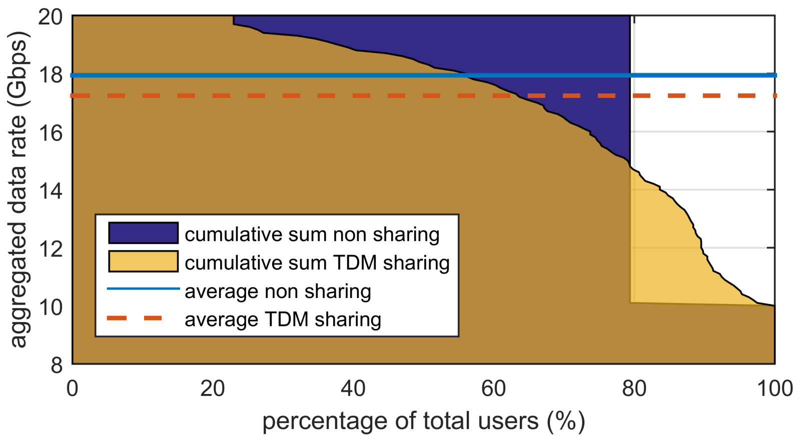


Figure 4: Cumulative sum of the aggregated data rates. Shown is the percentage of users that experiences the aggregated data rate on the y-axis or higher.

mulative sum of the aggregated data rates is shown in Fig. 4. This figure shows which percentage of users sees a certain aggregated data rate or higher. For the non TDM sharing scenario it shows the binary situation the network. 79% experiences a doubling of the data rate to 20 Gbps, while the other 21% sees a data rate of 10 Gbps. The resulting average data rate is 17.9 Gbps. For a TDM shared flexible network, 23% of the ONUs sees an aggregated data rate of 20 Gbps. 50% of the network sees an aggregated data rate of 18.3 Gbps or higher, 80% sees an aggregated data rate of 14.7 Gbps or higher, and 90% sees an aggregated data rate of 11.8 Gbps or higher. The average data rate is 17.2 Gbps in this case.

Conclusions

The use of flexible modulation increases the capacity and flexibility in the network. If no TDM sharing is utilized across an OLT port, 79% of the network can use 4-PAM, and subsequently sees an aggregated data rate of 20 Gbps, while 21% of the network keeps using OOK, therefore sees an aggregated data rate of 10 Gbps. The average aggregated data rate of the entire network therefore becomes 17.9 Gbps.
If TDM sharing is used, results become more nuanced. A larger part of the network now sees some benefit from flexible 4-PAM, however, for many users the increase is smaller than in a non-TDM sharing case. The average aggregated data rate of the entire networks drops to 17.2 Gbps, although the distribution of these speeds is more fair.

Acknowledgements

We would like to acknowledge network operator INEA for providing the GPON network statistics. This research is made possible by the Dutch Technology foundation STW through the grant 13530.

References

[1] F. Effenberger et al., "Beyond NG-PON2: A more flexible future," Communicate 71, (2013)
[2] K. Szczerba et al., "4-PAM for high-speed short-range optical communications," J. Lightwave Technol., **4**, p. 885-894 (2012)
[3] R. van der Linden et al., "Utilizing Unused Power Budget to Increase Network Capacity in Practical PON Deployments by Introducing Flexible Modulation," in Proceeding European Conf. on Opt. Comm, 2015, P.7.12
[4] ITU-T G.989.2, "40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification," (2014)