

WDM-PON für Zugangsnetze der nächsten Generation

WDM-PON for next generation optical access

Stephan Pachnicke¹, Michael Eiselt¹, Helmut Griesser², Klaus-Grobe², Jörg-Peter Elbers²

¹ADVA AG Optical Networking, Maerzenquelle 1-3, 98617 Meiningen, Germany

Tel. +49-3693-450-573, Fax +49-3693-450-22573, E-Mail: spachnicke@advaoptical.com

²ADVA AG Optical Networking, Fraunhoferstr. 9a, 82152 Martinsried / Munich, Germany

Kurzfassung

In unserem Beitrag untersuchen wir passive optische Zugangsnetze der nächsten Generation im Wellenlängenmultiplexbetrieb (WDM-PON). Diese müssen Schritt halten mit dem stetig wachsenden Bandbreitenbedarf bei Privat- und Geschäftskunden sowie bei der Anbindung von Mobilfunk-Basisstationen. Für den Privatkunden werden in der näheren Zukunft Zugangsdatenraten von 1 Gb/s pro Nutzer prognostiziert. Für Geschäftskunden und Anwendungen im Mobilfunkbereich werden sogar noch höhere Datenraten von 10 Gb/s und mehr benötigt. Im Folgenden werden unterschiedliche Systemdesigns vorgestellt und Herausforderungen und Lösungsmöglichkeiten auf Komponenten- bzw. Subsystemebene erörtert. Weiterhin werden Kosten und Energieverbrauch für ausgewählte Szenarien untersucht. Außerdem werden aktuelle Ergebnisse aus der Standardisierung präsentiert und Auswirkungen auf das Systemdesign diskutiert.

Abstract

We investigate wavelength division multiplex passive optical networks (WDM-PON) for next generation optical access. These have to cope with continuously increasing bandwidth demands from private and business customers as well as from mobile backhaul applications. In residential access in the near future data rates of more than 1 Gb/s per user are envisioned. For business customers and mobile backhaul 10 Gb/s and more will be needed shortly. In this article system designs will be discussed and challenges and solutions on the component and (sub-) system level will be presented. Furthermore, cost considerations and energy consumption will be investigated. Also recent results from standardization bodies and the impact on the system design will be shown.

1 Introduction

Telecommunication has become a central element of our life. Especially in the last 20 years disruptive changes have taken place with the emergence of the Internet and ubiquitous availability of mobile telecommunications in many areas around the globe. The rapid development of the Internet and of broadband services (e.g. video-on-demand) can also be seen by an exponential growth of the data traffic being transported in access networks (**Fig. 1**). Currently, the annual growth rate of the data volume is in the range of 30 - 60%. It is not expected that this rapid growth will flatten in the next couple of years [1][2].

An important step for enabling access to broadband contents has been the introduction of digital subscriber lines (DSL). These currently allow data rates of up to 50 Mb/s (based on VDSL2) utilizing standard

twisted-pair phone lines. To cope with the expected bandwidth growth within the next 5 to 10 years and to offer line rates of 1 Gb/s or higher, however, entirely new concepts will be needed in the near future.

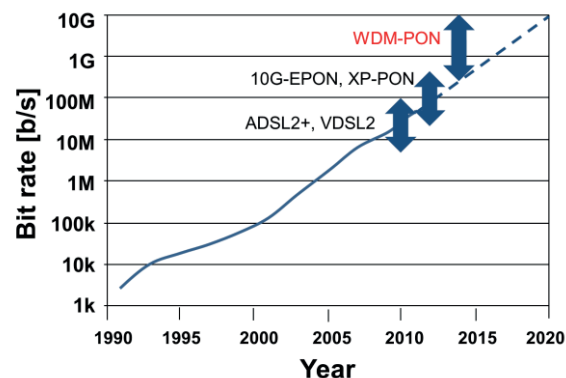


Fig. 1. Development of access data rates since 1990 and forecast up to 2020 (based on [3])

2 Passive optical networks

Only fiber-based solutions (fiber-to-the-home, FTTH, fiber-to-the-building, FTTB) will be able to provide sustainable data rates of 1 Gb/s and higher to the end user [4]. An overview of different concepts for passive and active optical networks (PON, AON) is shown in **Fig. 2**. The main differences between the concepts become apparent when looking at the number of fibers, which need to be connected to the central office (CO) and the maximum (uncontended) bit rate for the end user. Furthermore, costs, energy consumption, footprint in the CO and scalability to even higher data rates are important aspects.

From **Fig. 2** it can be derived that three main PON variants can be distinguished (there may also be combinations of these variants). Each variant has its specific advantages and disadvantages. In the case of a direct point-to-point connection one bi-directional fiber is needed per customer. In the CO this may lead to space problems as each fiber has to be connected to a transceiver. Furthermore, the effort for rolling out the fiber plant is significant. In the other two network designs the CO is connected to a passive remote node by a single fiber. The node is realized in the case of TDMA-PON (TDMA: time-division-multiple-access) as a passive splitter, which equally divides the input power between the output ports. The customer premises equipment (CPE) of each user has to be able to process the full data rate, and the peak data rate is

shared by all customers. This concept may be challenging to realize for higher sustained data rates due to minimum requirements on the receiver sensitivity and limitations due to accumulated chromatic dispersion (CD) along the transmission line.

In the WDM-PON (WDM: wavelength division multiplex) variant the remote node is realized as a wavelength selective multiplexer (e.g. a passive arrayed waveguide grating, AWG), which routes a certain wavelength to each customer. The AWG is typically realized in a cyclic manner allowing to route one specific downstream wavelength to and one specific upstream from the end user. WDM-PON combines the advantages of AON and TDMA-PON to have only one fiber at the CO and to provide at the same time a high (uncontended) data rate to the customer. Furthermore, WDM-PON meets higher security concerns of many business customers by terminating a dedicated wavelength at each customer and not broadcasting information to everybody as e.g. in the TDMA-PON case.

3 Challenges

There are a number of challenges, which need to be solved before WDM-PON systems will be deployed in high volume in the field:

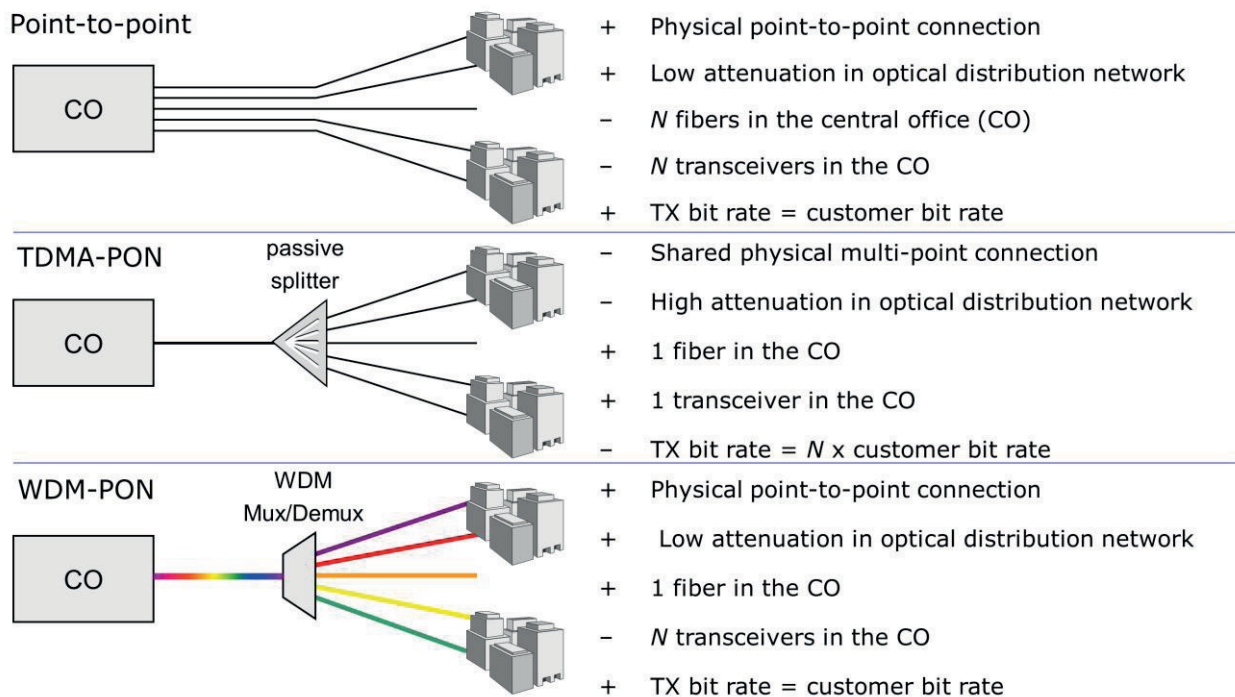


Fig. 2. Comparison of different PON architectures

- Compact (preferably photonic-integrated), cost- and energy-efficient modules for the CO and CPE must be developed, which are designed for mass-production.
- A concept is needed for the aggregation of the data streams of the individual customers. This should also be easily scalable to higher data rates and support multiple operators.
- Simple end-to-end operation, administration and maintenance (OAM) is needed.

4 Development of integrated-optic transceivers for the central office

For the successful introduction of WDM-PON systems on the mass market it is mandatory that integrated, cost- and energy-efficient transceiver modules are available for the central office (i.e. optical-line terminal, OLT) [5]. The EU project PIANO+ IMPACT [6] aims at integrating 40 lasers (or 40 photo-diodes for the receiver) together with the multiplexers or demultiplexers (**Fig. 3**) in CFP-sized modules. To further reduce costs multi-channel RF-driver amplifiers shall also be embedded into the module. Additional savings can be gained by using a centralized wavelength locker for all lasers of the OLT instead of one for each wavelength. The fiber management is simplified significantly by integrating the multiplexers and demultiplexers into the transceiver module. In this way only a single fiber needs to be connected to the OLT, and no ribbons for connecting a high number of fibers are necessary. To employ a single fiber for both directions (to/from the customer, single fiber working) up- and downstream signals are distinguished by different wavelength bands (L-band for downstream and C-band for upstream). In the first generation the maximum number of users per OLT (or fiber) will be 40 making use of a 100 GHz channel grid. By utilizing a 50 GHz grid the number can be doubled in a second

step.

The desired wavelength plan is a result of recent standardization activities within the ITU-T study group 15. Recommendation G.698.3 [7] (ex G.sdapp) provides optical parameter values for physical layer interfaces of dense wavelength division multiplexed (DWDM) systems primarily intended for metro applications. It, however, also comprises WDM-PON applications with a single bidirectional fiber. The recommendation describes DWDM systems with channel spacing of 100 GHz and a bit rate of a signal channel of up to 1.25 Gb/s (equivalent to 1 Gb/s Ethernet, GbE).

For the separation of the different DWDM channels a single cyclic arrayed waveguide grating (AWG) can be used. A characteristic of such an AWG is the periodicity of the frequencies routed from the common port to a given output port (also called free spectral range, FSR). The FSR assumed in ITU-T G.698.3 is 5.4254 THz measured at the channels with nominal frequencies 193.9 THz and 188.4746 THz. The FSR furthermore is a function of the index contrast ratio of the material used in the construction of the AWG. The above value is based on a 1.5% index contrast ratio. The use of a single AWG for separating the WDM channels in both wavelength bands furthermore leads to different channel spacings in both bands (97.154 GHz in the L-band and 100 GHz in the C-band). In total 48 channels in each band have been specified in ITU-T G.698.3. Out of these a subset of 40 has been selected for use in our WDM-PON system (beginning at 192.0 THz for the C-band and 186.6288 THz for the L-band).

5 Development of a low-cost transceiver for the end-user

Another key component of the WDM-PON system is the transceiver unit for the end user (customer premises equipment, CPE, also termed optical network

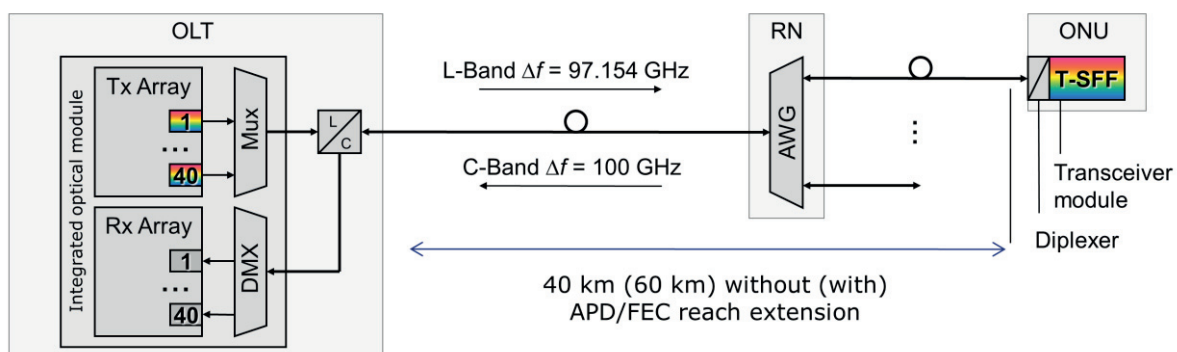


Fig. 3. Schematic of a WDM-PON system

unit, ONU). The development of a (low-cost) mass-manufacturable CPE module is the central part of the PIANO+ TUCAN project [8]. To be able to produce the CPE unit cost-efficiently it is desirable that the same module can be deployed at every customer. Furthermore, the module should have low energy consumption.

Both goals can be achieved by a new (wavelength) tunable optical transmitter assembly, which can be produced cost efficiently. A major part of the energy consumption of a laser is caused by an integrated thermo-electric cooler (TEC). This is why a tunable laser without a TEC is desirable. A prerequisite for this is to actively compensate for the frequency drifts and mode jumps of the laser (e.g. by electric tuning of the frequency) [9] and the use of a high-temperature material system (e.g. aluminum quarternary) along with a tuning algorithm maximizing the mode hop free range [10]. There are two approaches for compensating this wavelength drift: using a wavelength locker to obtain a closed-loop feedback signal or using an open-loop approach by monitoring the temperature and changing the laser currents appropriately. A promising approach is to combine both methods [11]. Further reduction of the costs can be achieved by omitting the wavelength locker on each laser and deployment of a centralized wavelength locker (e.g. etalon-based) in the OLT. Via an embedded communication channel the CPE receives a feedback signal from the OLT, containing the deviation from the target wavelength (Fig. 4).

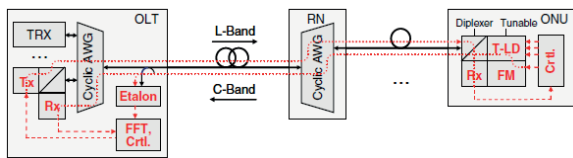


Fig. 4. Control loop for wavelength locking [11]

It is possible to use a shared wavelength locker for all

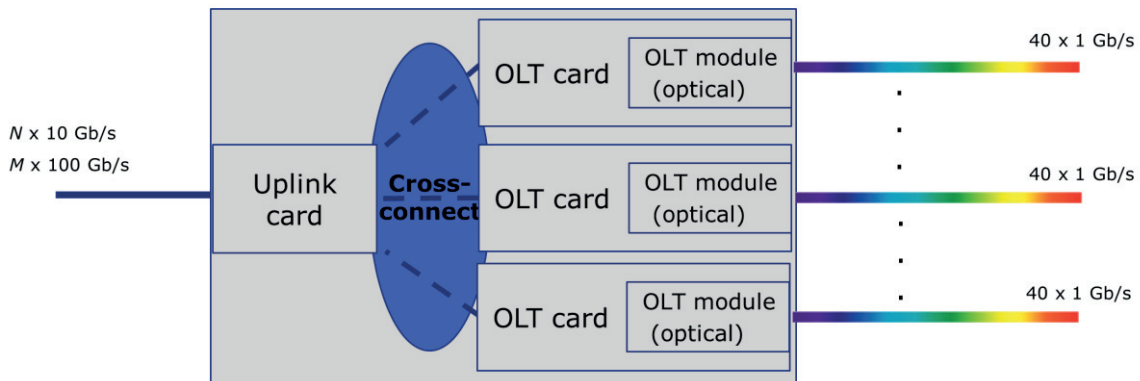


Fig. 6. Schematic of a Tb/s aggregation platform for WDM-PON

WDM channels simultaneously [11]. To distinguish the different channels at the centralized wavelength locker, a pilot tone-based method may be used. Amplitudes or frequencies of the carriers are modulated with a tone in the kHz range with different tone frequencies for each laser. If the maximum slope of the (periodic) etalon transfer function is aligned with the target wavelength grid, the pilot tone power can be used as an error signal. This error signal can be simultaneously calculated for all channels by means of an FFT. Recently it has been shown that this method allows control of the laser frequency with a high accuracy and for various types of tunable lasers [9] [11]. Using an active frequency control of the tunable laser also avoids time consuming calibration of each component and enhances the cost reduction of the ONU. Finally, additional savings can be gained by increasing the photonic integration level and placing all necessary components (laser, modulator, photo diode and C/L band splitter) on a single photonic chip (Fig. 5).

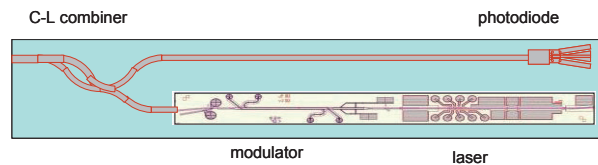


Fig. 5. Transceiver photonic-integrated circuit containing laser, modulator, photo diode and splitter (courtesy of Oclaro, Inc.)

6 Development of a Tb/s aggregation platform

To connect several hundreds or even thousands of customers to a central office an aggregation platform is needed with a total capacity, which can easily exceed 1 Tb/s (Fig. 6). Important aspects, which need to be considered, are the use of statistical multiplexing, efficient multicasting capability, a high reliability and the support of several service providers (to enable un-

bundling). Furthermore, cross-connect functions on OSI layers 1 and 2 and OAM functionality (e.g. connectivity fault management, performance management and link management) must be focused on.

Beyond aggregation functionality for the residential customers, business customers and especially mobile-backhaul have different requirements.

In the case of residential customers multiple services may originate at each optical network unit (ONU). These may be e.g. voice, internet or video services. To differentiate between them virtual local area network (VLAN) tags can be used. For each service a special VLAN tag is assigned. IEEE 802.1q defines the use of a 32-bit field for this purpose. VLANs may also be double-tagged; meaning that two VLAN fields can be employed (also called Q-in-Q). This allows a simplified service differentiation (use of a tag per service / per customer). Another way of using tags is to identify different operators. If, however, services, customers and different operators need to be distinguished MPLS or provider backbone bridges ('MAC-in-MAC') need to be used because only two VLAN fields may be cascaded according to the IEEE standard.

For mobile backhauling applications synchronization features are mandatory [13][14]. In current 3G networks the reference clock for base stations is usually distributed via the global positioning system (GPS). For next generation mobile networks (e.g. long-term evolution, LTE) the reference clock will be distributed via the packet-switched backhaul network. This will require physical synchronization support (e.g. Sync Ethernet) or packet-based synchronization (e.g. IEEE 1588v2) to enable precise timing. In LTE services the air interface needs a synchronization accuracy of 2.5 μs. This already leads to a network infrastructure packet timing requirement in the sub-microsecond regime. Longer term, the timing accuracy is expected to trend down into the low hundreds of nanoseconds as air interfaces evolve [15] and new applications like location based services are turned on. In this context WDM-PON has the advantage that different channels are multiplexed optically and in this way packet delay variations are minimized (compared

to e.g. electrical multiplexing such as TDMA). An important feature of WDM-PON is also the possibility of infrastructure sharing for mobile and fixed backhauling (Fig. 7). This has the advantage that fiber must be deployed only once and may be used for different services yielding cost benefits. If different mobile operators share the same site (for their base-band units), they may be distinguished in backhauling similar to the service differentiator described above by the use of Ethernet VLANs or by different WDM channels.

7 Cost and energy consumption

Cost and energy consumption are important factors for the deployment of WDM-PON systems in large quantities. A summary of the estimated power consumptions of the ONU and OLT is listed in the following Tables 1 and 2 [16].

The power consumption figures are estimates based on current technology. With next generation technologies these numbers will get smaller, and we expect a target of 1 W for the tunable ONU and 0.5 W for the OLT (per channel).

Table 1. Estimated ONU power consumption

Component	Estimated Power Consumption [mW]
Tunable laser, driver, heater	700
APD, TIA, LA	300
ONU MAC	300
Total power	1300

Table 2. Estimated OLT power consumption

Component	Estimated Power Consumption [mW]
Laser (arrayed, semi-cooled)	400
APD (arrayed), TIA, LA	200
Port aggregation	500
MAC, tuning	200
Total power per channel	1300

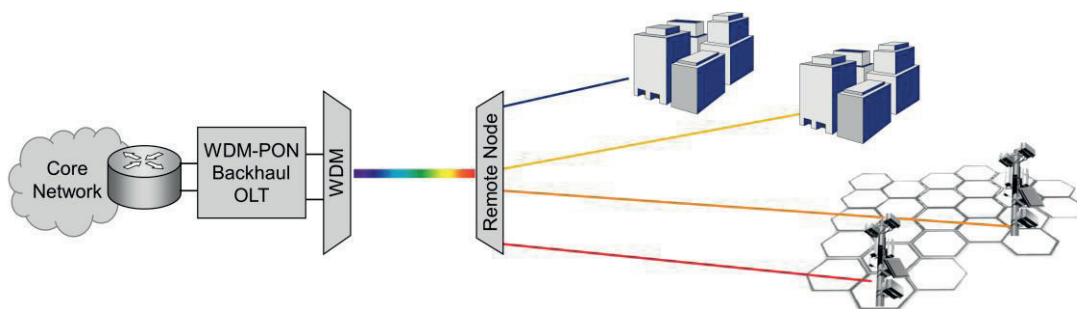


Fig. 7. Convergence of fixed and mobile access

The midterm cost goal for the ONUs (manufactured in very large quantities) is a decrease of a factor of 10 compared to current technology. A similar cost figure (on a per channel basis) is aimed at for the OLT.

8 Conclusion

We have shown a study on next generation access based on wavelength-division multiplexing passive optical networks (WDM-PON). The presented research activities aim at paving the way for a mass rollout of WDM-PON systems. By increasing the amount of photonic integration substantial cost-reductions in comparison to today's components and subsystems are expected. On the customer site new tunable lasers without TEC and wavelength locker will lead to a much lower price as well as better energy efficiency. Finally, a new aggregation platform will allow smooth integration of different services and operators.

Acknowledgement

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