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Invited Paper

A physical layer perspective on access network sharing

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ABSTRACT

Unlike in copper or wireless networks, there is no sharing of resources in fiber access networks yet, other than bit stream access or cable sharing, in which the fibers of a cable are let to one or multiple operators. Sharing optical resources on a single fiber among multiple operators or different services has not yet been applied. While this would allow for a better exploitation of installed infrastructures, there are operational issues which still need to be resolved, before this sharing model can be implemented in networks.

Operating multiple optical systems and services over a common fiber plant, autonomously and independently from each other, can result in mutual distortions on the physical layer. These distortions will degrade the performance of the involved systems, unless precautions are taken in the infrastructure hardware to eliminate or to reduce them to an acceptable level. Moreover, the infrastructure needs to be designed such as to support different system technologies and to ensure a guaranteed quality of the end-to-end connections.

In this paper, suitable means are proposed to be introduced in fiber access infrastructures that will allow for shared utilization of the fibers while safeguarding the operational needs and business interests of the involved parties.

1. Introduction

Communication networks in the access and metro-access space provide a variety of services to customers in a telecom-type architecture, connecting homes, businesses or radio base stations to a central location which in turn is connected to the metro network. Other networks in this space interconnect nodes of non-telecom type customers, such as enterprises or data centers, in a non-hierarchical architecture. Deployment and maintenance of the passive infrastructure in these network segments are associated with very high expenses. So in case of new services to be provided, new connections to be established or new operators wanting to enter the market, network sharing can help minimize these costs.

Network sharing models are frequently discussed in terms of the following layers and business actors, listed here for optical networks:

- Service Layer (Service Provider: SP), providing access to applications, such as Internet, streaming video, voice services for e.g. residential and business users.
- Active Layer (Network Provider: NP), comprising the transmission equipment, i.e. optical systems and electrical switches, combined with suitable management systems.
- Passive Infrastructure Layer (Infrastructure Provider: IP), comprising cabinets, ducts, cables, fibers and other passive components along the fiber links.

This simple structure can be further differentiated for describing more accurately the various possible sharing models and for better capturing the operational and economic implications [1–3].

2. Use cases and drivers for fiber sharing in access

Multiplexing different services on OSI Layer 2 or Layer 3 before transmitting them, known as Bitstream Access (BA), is a popular approach to sharing networks, due to its ease of implementation and operation. Alternatively, a fiber can be connected exclusively to an individual NP or SP. This dark fiber service (DF) is available in some metro and access networks around the world [4]. These two variants of network sharing are conveniently supported by today's technology, not requiring major changes to the equipment. However, from a service and business perspective, they are imposing limitations on bandwidth, flexibility and service evolution (BA), or they are exploiting network resources inefficiently (DF).

Here we will consider fiber sharing (FS) among multiple NPs or SPs by transmitting their traffic in different optical channels on the same fiber links. This approach is currently not applied in networks as it has not been supported by commercial systems or by installed infrastructures so far.

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There are a number of potential benefits from FS over BA which will eventually outweigh the added cost associated with its initial implementation, and which will open new opportunities for operating and using a network. Fibers can be shared e.g. by:

- multiple competing NP or SP addressing the same group of customers, but wanting to stay independent from a third party's network hardware; users can dynamically churn between them
- services with different types of traffic (see below) offered in parallel by an operator to the customers
- services of different market sectors (wireless backhaul or fronthaul, utility networks, enterprise networks, data center interconnects), having different operational needs and special requirements on security and availability
- other non-telecom-type services, such as machine-to-machine-type (Internet of Things, IoT), having specific needs on traffic dynamics and latency.

Aside from these service, business and operations related motivations, there are also technical factors that in future will call for keeping different services separate in different optical channels instead of multiplexing them all into one common signal stream. It is anticipated that some services will be provided more efficiently, if their technical needs were accommodated by e.g. suitable modulation formats or protocols which, however, are not compatible with each other, thus taking advantage of dedicated optical channels:

- high frequency analogue signals transmitted over optics (like Cable Television (CaTV) overlay in Gigabit Passive Optical Network (GPON)) will find an application in 5G fronthaul for remote radio heads (RRH) with many antenna elements [5]
- dedicated framing and encapsulation methods for digital backhauling that better match the signal structures of wireless transmission, as compared to existing solutions
- high capacity streaming and download/upload services benefitting from transmitting very large data blocks (e.g. content distribution networks)
- optical connections for traffic with exceptionally low latency requirements (e.g. IoT services in 5G networks)
- offloading local traffic onto dedicated optical sub-networks, thus not burdening the access-to-core connections by this local traffic
- enabling for spontaneous and "connectionless" small data traffic communication in IoT-type applications [5].

In the following sections, some physical layer aspects of fiber sharing in access will be discussed in more detail and possible hardware solutions for managing shared networks will be outlined.

3. Fundamental aspects of fiber sharing in access

The fibers of the optical distribution network (ODN) in Passive Optical Networks (PON), connecting the Optical Line Terminal (OLT) with the Optical Network Units (ONU), can be shared by employing Dense Wavelength Division Multiplexing (DWDM) type multiplexing technologies e.g. on a 50 or 100 GHz grid. Coarse Wavelength Division Multiplexing (CWDM) is not considered here, as it is not scalable to high channel numbers.

With the recently released document G.989.2, specifying the physical layer of Next Generation PON 2 (NG-PON2) networks [6], a framework for implementing DWDM-type solutions in an access network has been provided for the first time. Similar architectures have been elaborated in European research projects, such as DISCUS [7], though for much higher channel numbers ($\geq$32 channels, as opposed to 4–8 channels in NG-PON2) and longer distances (100 km, as opposed to 40 km). As usual in optical access networks – for saving cost and for easing implementation and maintenance of the ODN – the optical transmission in these Time/Wavelength Division Multiplexing (TWDM) networks is mostly bidirectional over a single fiber strand on separate wavelengths in downstream (DS) and upstream (US) direction, respectively. When the network extends over long distances, i.e. into the metro space, then also dual fiber links per connection are an option, with unidirectional transmission on each of them. For the sake of simplicity, in this paper only single fiber links will be described and each DS/US channel pair will be denoted by only a single wavelength.

The different wavelength channels can be used for transmitting a mix of traffic from different operators, for different services, for different customers or for non-telecom-type applications, as outlined in the previous section. All these service and traffic types shall generically be called 'clients' in this paper. The capacity of each wavelength channel can be further shared among multiple ONUs by employing sub-wavelength multiplexing, such as Time Division Multiplexing/Time Division Multiple Access (TDM/TDMA) or other suitable modulation techniques, thus establishing optical point-to-multipoint (ptmp) links, here in a TWDM-PON configuration. Alternatively, the wavelength channels can remain unshared, being modulated in any format and be assigned to a single ONU, thus establishing optical point-to-point (ptp) links in a DWDM-PON configuration.

In Fig. 1 two possible scenarios are shown for sharing an ODN by 4 clients via DWDM, in a TWDM-PON or DWDM-PON configuration or a mix of both. In a first scenario all OLTs are collocated, e.g. in a Central Office (CO), sharing the entire ODN including the feeder fiber (top). In a second scenario the OLTs are located in different places and have access only to the common distribution and drop section of the ODN via disjoint feeder fibers that are connected to the first power splitter in the field (bottom). (Note: combining the different wavelengths at the first power splitter (star coupler) is advantageous over using an additional wavelength multiplexer, as it leaves the ODN wavelength agnostic and reuses an already existing splitter, hence saving additional components and losses.)

The channels are established either by different independent transmission systems (possible in both scenarios) or by a common system (possible only in the collocation scenario). In either case, the ONUs are equipped with fixed or tuneable wavelength transceivers, or even with multi-port transceivers for multiple channels in parallel, depending on the use cases listed in the previous section. Here, the ODN is assumed to be transparent, i.e. not wavelength selective or routing.

In contrast to the ODN in Fig. 1, the fiber connections to the users – or more generally, to the end nodes – could as well be ptp-fiber links from the CO to the Customer Premise (CP). This ptp-type ODN is sometimes considered advantageous over ptmp ODNs, because it is agnostic to the specific transmission system. However, in such ptp networks with many fiber links, DWDM-type sharing on each fiber would then obviously require a very large number of colored optical interfaces and WDM (de)-multiplexers at the OLTs which is economically not viable. With a ptmp-type ODN the hardware effort is reduced and DWDM sharing is more easily accomplished.

It is advisable to set up the ODN as generically shown in Fig. 2. The feeder and distribution section can be of any type (ptp or ptmp) and may contain system specific elements such as splitters or wavelength routing (de)multiplexers. The drop section beyond the Fiber Flexibility Point (FFP) in Fig. 2 is always of ptp-type. The FFP is the last point in the network, where system specific components like power splitters or wavelength selective elements can be used. The end nodes are connected at this point to the desired feeder network via a fiber patch panel or a fiber switch.