Mitigation of Crosstalk in Passive Optical Network

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Abstract— **In order to accommodate the needs of very high-speed broadband access, the most attractive solution is passive optical network. A passive optical network (PONs) is a potential dominant technology on the field of access networking. Passive optical network (PON) is one of the important access network technologies to provide end users the cost effective broadband services. Passive components improve the network performance. But interference occurs during access of network. It degrades the network performance. Here we will analyse the sources of interference i.e. crosstalk and studied various methods to improve the network performance in terms of crosstalk.**

Keywords— **PON, Optical Distribution Network, Optical Line Terminal (OLT), Optical Network Unit (ONU), Crosstalk.**

I. INTRODUCTION

Since the internet and broad-band access network were introduced during the last decade, emerging applications, such as video on demand (VOD), digital cinema, telepresence, and high-quality audio transmission, demand high-throughput optical access networks with stringent quality of service (QoS) requirements. However, the infrastructure of current access networks suffers from limited bandwidth, high network management cost, low assembly flexibility and bad network security, which obstructs the network from delivering integrated services to users. Owing to the maturity of optical components and electronic circuits, optical fiber links have become practical for access networks [1].

Advances in electro-optic technologies have made fiber optical communication a promising networking choice to meet the increasing demands of high-performance computing communication applications for high channel bandwidth and low communication latency. Fiber optic communications offer a combination of high bandwidth, low error probability, and gigabit transmission capacity. They have been extensively used in wide-area networks [2].

Further, Passive Optical Networks (PONs) are seen as the most promising technology to cost-effectively explore the fiber potential and deliver high-bandwidth volumes. The passive optical network (PON) is just one of several access technologies used by service providers, but it enjoys a dominant position in the access market. The Passive Optical Network (PON) is a network, which carries data in the optical domain between the OLT and the ONU or ONT1 and the transport path of the optical signal is passive. This implies that the optical network devices (between the transmitter and receiver) are non-powered, i.e. no electrical devices are used.

The basic PON principle is summed up by the following phrase: "The basic principle of PON is to share the central Optical Line Termination (OLT) and the feeder fiber over as many Optical Network Units (ONUs) as is practical given cost effective optics". The PON concept specifies an Optical Distribution Network (ODN), where traffic is transported optically between an OLT and several ONUs, as illustrated in Figure: 1. three different PON schemes have been defined. These have slightly different service requirements depending on the ending point of the fiber. Fiber-To-The-Curb (FTTC) concept provides the end-users with asymmetric and symmetric broadband access as well as Plain Old Telephony Service (POTS) and Integrated Services Digital Network (ISDN) access together with Digital Subscriber Line (DSL) services. Fiber-To-The-Building (FTTB) concept for Multi-Dwelling Units (MDUs) provides POTS and ISDN together with the asymmetric and symmetric broadband access. FTTB for businesses provides also private line services. The third scheme, Fiber-To-The-Home (FTTH) provides asymmetric and symmetric broadband access together with POTS and ISDN for homes directly connected to the fiber [3].

The advantages of using PONs in subscriber access networks are numerous:

1. PONs allow for long reach between central offices and customer premises.
2. PONs minimizes fiber deployment in both the local exchange office and the local loop.
3. PONs provides higher bandwidth due to deeper fiber penetration, offering gigabit per second solutions.

4. Operating in the downstream as a broadcast network, PONs allows for video broadcasting as either IP video or analog video using a separate wavelength overlay.

5. PONs eliminate the necessity to install active multiplexers at splitting locations, thus relieving network operators of the gruesome task of maintaining active curbside units and providing power to them. Instead of active devices in these locations, PONs use small passive optical splitters, located in splice trays and deployed as part of the optical fiber cable plant.

6. Being optically transparent end to end, PONs allows upgrades to higher bit rates or additional wavelengths [4].

Fig. 1 General PON architecture and terminology [3]

The paper is organized as follows. In Section I we discussed that Passive optical network is the most promising technology to access network. In Section II, we discuss the proposed Pon architecture. In Section III we studied about crosstalk which degrade the network performance. Section IV reports the analysis of the different techniques to improve the network performance in terms of crosstalk.

II. PASSIVE OPTICAL NETWORK ARCHITECTURE

Passive optical networks (PONs) have emerged as an attractive and promising approach to deliver broadband services to a large number of subscribers. In a typical PON, services are originated from the optical line terminal (OLT) at a head end or central office (CO) and carried along an optical fiber feeder for about 10–15 km, before the optical power is split into multiple output distribution fibers, via an optical power splitter located at the remote node (RN). Each distribution fiber, usually less than 5 km in length, then forwards the services toward the destined optical network unit (ONU), where the optical signal is terminated before being further distributed to all the subscribers attached to this ONU via other media, such as copper wire, etc. With such high fiber penetration into the access arena, the system cost of PONs has to be kept low in order to make them economically viable and

competitive. PON features its passive remote node, which greatly relaxes the cost of managing optical elements in outside fiber plants [5].

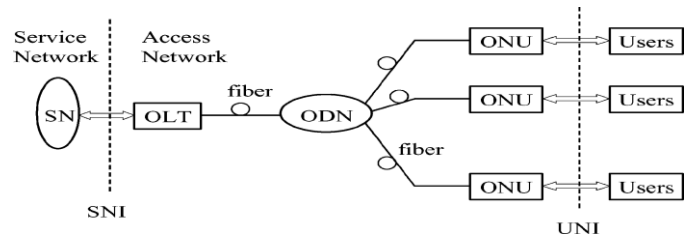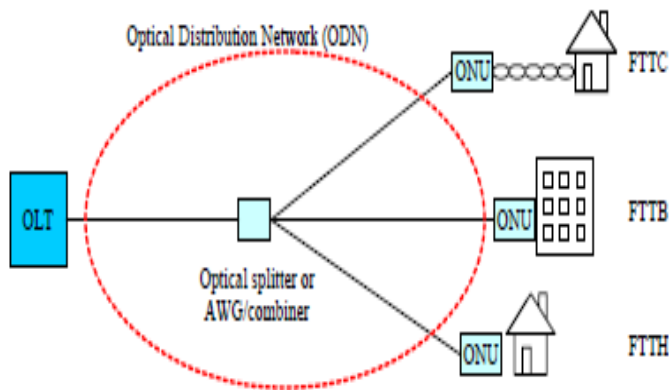Fig. 2 Passive optical network Architecture [6]

Besides, both the RN and the ONUs have to be kept simple and low-cost. [5].

III. CROSSTALK ANALYSIS

Crosstalk is the general term given to the effect of other signals on the desired signal. Cross-talk is the capacitive and inductive coupling of signals from one signal line to another. The electrical signals in a wire pair generate a small electromagnetic field which surrounds the wire pair and induces an electrical signal into nearby wire pairs. This inductive and capacitive coupling (known as crosstalk) is often the largest noise impairment in a twisted pair and can substantially reduce DSL performance [7].

Crosstalk may be many types like near end crosstalk and far end crosstalk, and interchannel and intrachannel crosstalk. These type of crosstalk may arise from cascaded a wavelength demultiplexer with wavelength multiplexer and due to imperfect isolation of one switch port from other. The inter-channel crosstalk originates from the upstream and downstream data transmission and is due to non ideal WDM couplers/splitters and optical switches that are needed for wavelength multiplexing/demultiplexing. These types of crosstalk analysed as follow:

A. *Near-end crosstalk and Far-end crosstalk*

I. Near-end crosstalk (NEXT)

It is defined as the crosstalk between a receiving path and a transmitting path of DSL transceivers at the same end of two different subscriber loops within the same twisted-pair cable (see Fig. 3).

NEXT is a major impairment for systems that share the same frequency band for upstream and downstream transmission. Transmission systems can avoid self-NEXT by using different frequency bands for upstream and downstream transmission, but they still have to cope with NEXT from other services as well as far-end crosstalk (FEXT) [7].

II. Far-end crosstalk (FEXT)

It is the noise detected by the receiver located at the far end of the cable from the transmitter that is the noise source (see Fig. 3). FEXT is less severe than NEXT because the FEXT noise is attenuated by the propagation through the full length of the cable. Crosstalk can be the largest noise impairment in a

twisted pair and often substantially reduces transmission performance of DSL systems [7].
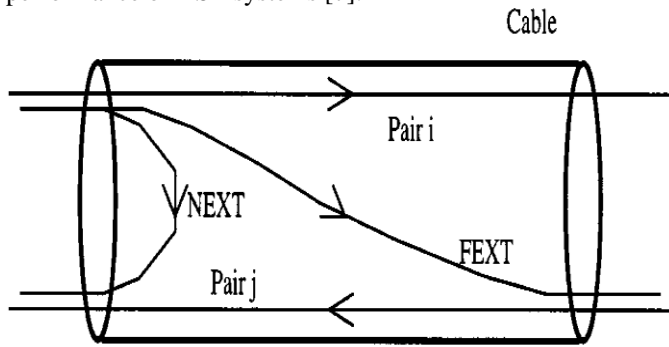

Fig. 3 Example of the generation of crosstalk in a cable [7].

B. *Interchannel and Intrachannel crosstalk*

I. Interchannel Crosstalk

When the crosstalk signal is at a wavelength sufficiently different from the desired signal's wavelength that the difference is larger than the receiver's electrical bandwidth. This form of crosstalk is called interchannel crosstalk. Interchannel crosstalk can also occur through more indirect interactions, for example, if one channel affects the gain seen by another channel, as with nonlinearities [8].
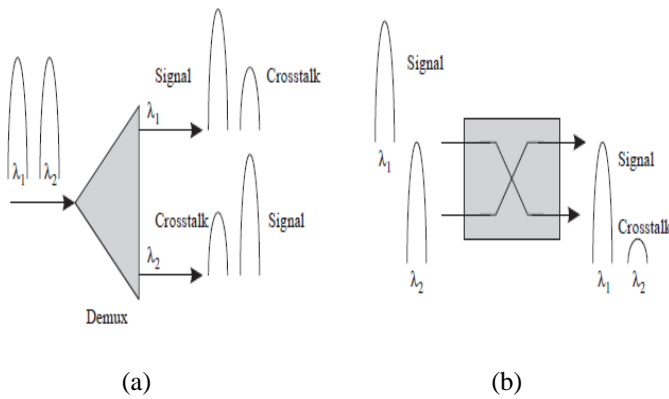

Fig. 4 Sources of intrachannel crosstalk. (a) A cascaded wavelength demultiplexer and a multiplexer, and (b) an optical switch [8].

II. Intrachannel Crosstalk

When the crosstalk signal is at the same wavelength as that of the desired signal or sufficiently close to it that the difference in wavelengths is within the receiver's electrical bandwidth. This form of crosstalk is called intrachannel crosstalk. Intrachannel crosstalk effects can be much more severe than interchannel crosstalk [8].
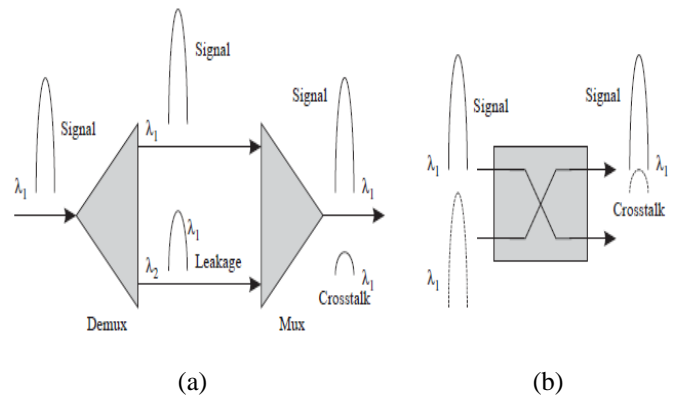

Fig. 5 Sources of intrachannel crosstalk. (a) A cascaded wavelength demultiplexer and a multiplexer, and (b) an optical switch [8].

IV. CROSSTALK SUPPRESSION TECHNIQUES

These types of crosstalk cause the degradation of signal to noise ratio, quality of factor and to an increase a bit error probability. Thus network performance will degrade.Crosstalk suppression becomes particularly important in networks, where a signal propagates through many nodes and accumulates crosstalk from different elements at each node. Various techniques have been studied to improve the system performance. Near end crosstalk and far end crosstalk has been studied. Digital subscriber lines (DSLs) are fundamentally limited by crosstalk. The case where all crosstalk is from the same type of DSL has been studied over the years and accurate models have been standardized. The original method for summing mixed crosstalk was to simply add all the powers of each of the 1% worst cases of the different services in the mix, and this is called the naïve crosstalk summation method here. Several alternative summation methods that predict less crosstalk than the naive method have been proposed [7]. Crosstalk from other channels can be cancelled in a linear fashion by weighting and summing the photocurrents of the desired channel and several adjacent interfering channels. Alternatively, in nonlinear crosstalk cancellation, decisions are made on the interfering signals, and these decisions are weighted and summed with the photocurrent of the desired channel [9].

Four different OXC topologies have been studied. Their crosstalk sources have been identified and their total crosstalk is calculated based on analytical equations. It is studied that crosstalk can be removed by using filter before and after the switch and wavelength converter is used. A big difference between coherent crosstalk and noncoherent crosstalk has been observed. To reduce the coherent crosstalk, phase scramblers could be used [10].

Reflection and Rayleigh backscattering-induced interferometric crosstalk in a link employing a reflective semiconductor optical amplifier (RSOA) may cause significant power penalty and, thus, limit the performance of the system. We investigate interferometric crosstalk suppression in a centralized light generation wavelength division multiplexing-passive optical network (WDM-PON) by single-tone phase modulation either by utilizing the

nonlinear behavior of the RSOA at the optical network unit (ONU) or by applying an external phase modulator at the source side. 6- and 7-dB reduction in power penalty for reflection-induced crosstalk is achieved, respectively. For Rayleigh backscattering-induced crosstalk power penalty is improved with 3 and 4.5 dB, respectively [11]. It is proposed that the Rayleigh backscattering will cause serious power penalty in the link deploying an RSOA. An easy-to-implement and effective method using RSOA bias dithering reduced RBS-induced crosstalk power penalty with 3dB. This power penalty can be improved further by applying phase modulation or phase scrambler at the laser (requires extra hardware), since a broader spectrum can be achieved [12].

Crosstalk reduction by phase scrambling, including transmission, is presented. It is experimentally demonstrated that phase scrambling substantially reduces interferometric crosstalk, enhancing the system tolerance to crosstalk. For instance, crosstalk values of 16-dB results in power penalty less than 2 dB after transmission over 200-km SSM fibre. Phase scrambling mitigates the limitations imposed by interferometric crosstalk at the expense of network reach. Power penalty further can be improved [13].

A novel scheme is proposed to suppress Rayleigh noise in carrier-distributed wavelength-division-multiplexed passive optical networks, by using differential phase-shift keying (DPSK) as the upstream modulation format. Due to the narrow spectrum of the distributed carrier, the Rayleigh noise towards the optical line terminal (OLT) also has narrow spectrum and can be effectively suppressed by the notch filter-like destructive port of the delay-interferometer at the OLT, which is used to demodulate the upstream DPSK signal simultaneously. Experimental demonstration of the 10-Gb/s upstream signal is achieved with less than 0.2-dB power penalty induced by Rayleigh noise after the transmission of 20-km single-mode fiber [14].

To circumvent the challenging issue of Rayleigh noise reduction in wavelength-division-multiplexed passive optical network (WDM-PON), we provide an insight into the source of Rayleigh noise, and confirm that the suppression of carrier Rayleigh backscattering (RB) should be the primary target in the design of Rayleigh noise-resilient upstream receiver module for a transmission reach up to 60 km. Then a novel scheme to effectively suppress the carrier RB in carrier-distributed WDM-PONs is proposed and demonstrated. By simply replacing the upstream modulation format of conventional on-off keying (OOK) with differential phase-shift keying (DPSK), the system tolerance to carrier RB is substantially enhanced by 19 dB, as the carrier RB can be considerably rejected by the notch filter-like destructive port of the delay-interferometer (DI) at the optical line terminal (OLT), which is used simultaneously to demodulate the upstream DPSK signal. Experimental demonstration of 10-Gb/s upstream signal is achieved with less than 2.5-dB power penalty induced by Rayleigh noise after the transmission in

60-km single mode fiber, without using any amplifier in outside plant [15].

V. CONCLUSIONS

In this paper, we summarized Passive Optical Networks and explain the architecture of passive optical network. We examined the types of crosstalk and survey the different techniques to improve the crosstalk. In such a way, network performance will improve.

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