Analysis of Interactions between Node Induced Crosstalk and Fiber Nonlinearities in Optical Metropolitan Area Networks

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Abstract

The problems that occur at the nodes of a metropolitan area network (MAN) can interact with optical fiber nonlinearities. In this paper, impacts of such interactions, in particular the one between crosstalks occurring at the optical add/drop multiplexers (OADMs) of metropolitan network nodes and optical fiber nonlinearities, on transmission performances of optical fiber systems are investigated. The optical fiber systems are a non-zero dispersion shifted fiber (NZDF) system and a standard single mode fiber (SMF) system where dispersion compensating fiber (DCF) is used for dispersion management, shortly a SMF+DCF system. Significant impairments on transmission performances are observed in simulations. The results show that such interactions should be carefully considered during the design of metropolitan WDM networks.

1. Introduction

The bandwidth requirement increases as the variety of services increases in communication networks. This makes wavelength division multiplexing (WDM) a key technology for current and future public networks. In the last decade, usage of WDM in metropolitan area networks (MANs) is widespreading [1-4]. Various traffic types, protocols and technologies traditionally distributed to access networks, CATV networks and local area networks (LANs) are tending to be carried over a single metropolitan infrastructure.

Since metropolitan networks include cascaded add-drop multiplexers and/or cross-connected nodes, they are sensitive to the problems occurring in network devices. These problems can also interact with the nonlinear phenomena in optical fibers. The aim of this paper is to investigate the results of such interactions, in particular the one between the crosstalk occurring in network nodes with fiber nonlinearities under a 10 Gbps transmission rate.

The in-band crosstalks can occur in input and output ports of optical add-drop multiplexer (OADM) nodes of a metropolitan network due to the problems in optical network devices. The impact of in-band crosstalks on the transmitted signal can increase with effects of optical fiber nonlinearities. This phenomenon was initially analyzed in long haul WDM systems [5]. In this paper, the interaction of the in-band crosstalk with fiber nonlinearities in regional metropolitan networks is analyzed for two different transmission systems. The first system is a non-zero dispersion shifted fiber (NZDSF) system and the second one is a standard single mode fiber (SMF) system using dispersion compensating fiber (DCF) between the nodes along the optical path of the signal for dispersion management, which will be shortly called as SMF+DCF system throughout the paper.

2. The Simulation Model

One or two metropolitan levels may exist in a public network. A two-level metropolitan structure contains a regional ring as well as access rings. The regional metropolitan ring has a perimeter of 200-300 kilometers while access rings are used for distances of 10 to 100 kilometers.

In this paper, we focus on a regional ring with a perimeter of 250 km. All nodes on both the regional ring and access rings are assumed to be OADMs that are equally spaced from each other along the rings.

The multiwavelength data coming to the input port of the node i on the metropolitan ring is demultiplexed to all wavelength channels by the WDM demultiplexer and the ingoing data from the channel λ_i is dropped with the help of add-drop switch. Using the same switch, the outgoing data is also sent via the channel λ_i. After the add-drop switch, all channels are multiplexed by a WDM multiplexer. The multiplexed data passes through an optical amplifier block. The amplifier gain is assumed to compensate for both optical fiber and node losses. The multiwavelength data exiting the node i is transmitted to the following node j. Data add-drop procedure is performed via the channel λ_j at this node. In simulations, only one wavelength channel is assumed to be added/dropped in each node. Simulations are focused on an optical path where the signal passes through eight cascaded nodes.

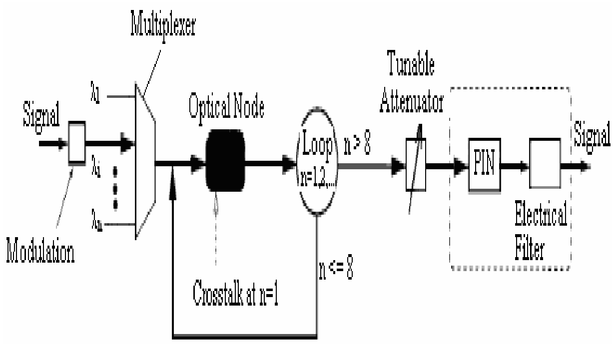

Fig. 1. The simulation model

The simulation model is shown in Fig. 1. The optical wavelength that is focused on in the simulation model is 1550 nm. The crosstalk is assumed to occur at a frequency that is shifted by Δν Hz from the signal carrier frequency. In practice, this frequency shift is due to the laser wavelength instability and/or limitations of filters. In simulations, ASE noise is not considered and the signal power level is taken as 10 dBm in order to observe nonlinear effects. The crosstalk is assumed to occur at the first node and propagate to the eighth node with the signal. The crosstalk level is taken as 25 dB lower than the signal power level. To simulate the worst case, the polarization states of the crosstalk and the signal are assumed to be identical.

Table 1. Fiber parameters used in simulations

		Fiber Type		
		NZDSF	SMF	DCF
Parameter	D (ps/nm.km)	2	18	78
	α (dB/km)	0.25	0.21	0.50
	γ ($W^{-1}.km^{-1}$)	2.3	1.5	4.9
	A_{eff} (μm^2)	50	80	30

Fiber parameters used in simulations, i.e. the dispersion coefficient D, the attenuation constant α, the nonlinearity coefficient γ and the effective area A_{eff}, are given in Table 1.

In this simulation model, only one wavelength channel, i.e. λ_j, is focused on in order to investigate the interaction of the crosstalk with fiber nonlinearities. However, the transmission system has a multiwavelength structure. Therefore, besides the phenomenon investigated in the paper, other phenomena like cross phase modulation (XPM) and four wave mixing (FWM) may also exist. However, considering the sufficiently spaced channels in the NZDSF system and the high chromatic dispersion of the SMF+DCF system, the impact of such phenomena on the interaction investigated in the paper will be negligibly small.

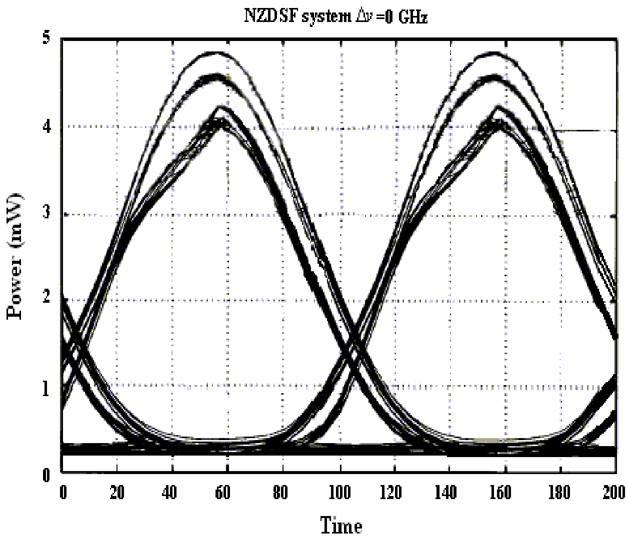

Fig. 2. The eye diagram of the best case in NZDSF system

3. Simulation Results

In Figs. 2 and 3, the best case (Δν = 0 GHz) and the worst case (Δν = 7.5 GHz) eye diagrams of the NZDSF system observed at the last node, i.e. the eighth node, receiving the signal are shown respectively. In these simulations, it is assumed that 10 dBm input power at the node i has been amplified to its initial value at the input of the each node along the optical path. Comparing the two eye diagrams, a significant deterioration of transmission characteristics can be easily seen in Fig. 3.

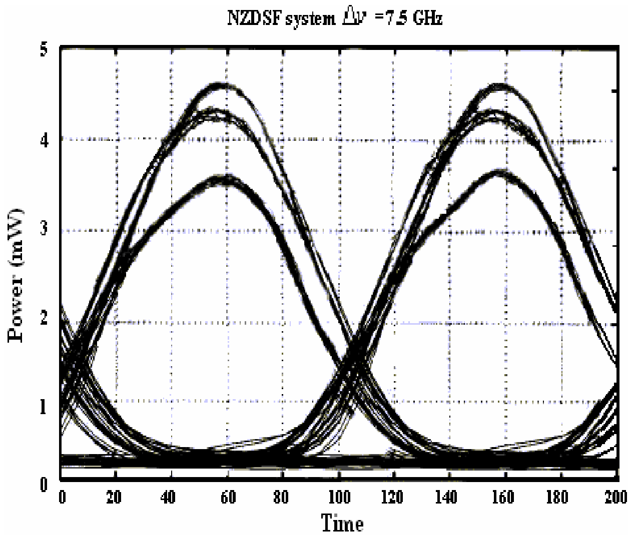

Fig. 3. The eye diagram of the worst case in NZDSF system

In Figs. 4 and 5, the best case (Δν = 0 GHz) and the worst case (Δν = 5.8 GHz) eye diagrams of the SMF+DCF system observed at the last node, i.e. the eighth node, receiving the signal are shown respectively. The deterioration in the transmission performance of the SMF+DCF system is similar to that of the NZDSF system.

The results obtained from eye diagrams shown in Figs.2-5 show that interaction of the node induced crosstalk with optical fiber nonlinearities causes limitations on the optical transmission of regional metropolitan networks.

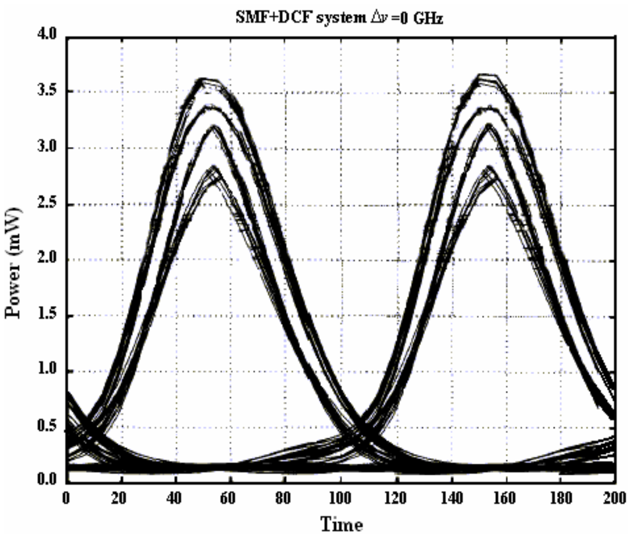

Fig. 4. The eye diagram of the best case in SMF+DCF system

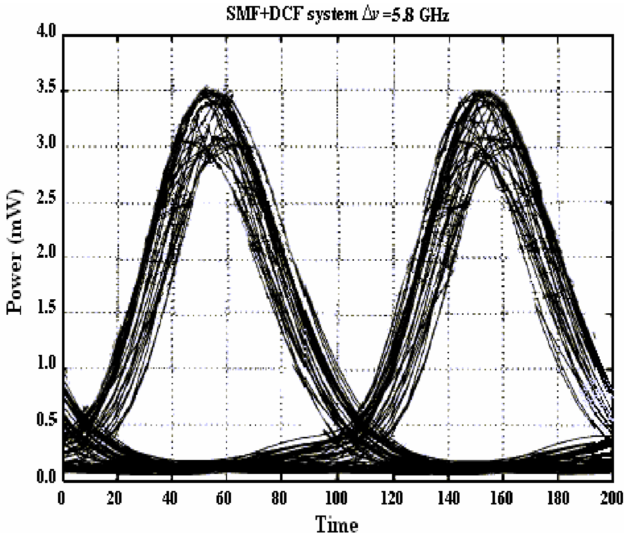

Fig. 5. The eye diagram of the worst case in SMF+DCF system

The variation of the power penalty with Δν frequency difference between the signal and the crosstalk is shown in Fig. 6. In NZDSF system, the power penalty is negligible for Δν = 0 GHz. The power penalty increases with increasing values of Δν and approaches to a level of 2 dB for Δν = 7.5 GHz. After that, the power penalty decreases as the value of Δν increases. Similar to that of NZDSF system, the power penalty is negligible for Δν = 0 GHz in SMF+DCF system. The power penalty increases with increasing values of Δν and approaches to a level of 1.3 dB for Δν = 5.8 GHz. After that, the power penalty decreases as the value of Δν increases.

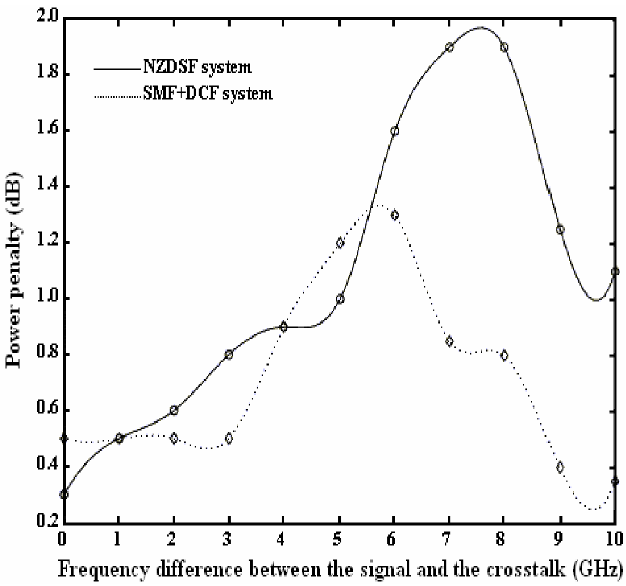

Fig. 6. Power penalty variation with Δν frequency difference between the signal and the crosstalk

The results obtained from Fig. 6 show that the interaction of the crosstalk with optical fiber nonlinearities does not have significant effects on the transmission performance at low Δν values. However, as the value of Δν increases, the interaction raises the power penalty. The degradation of the power penalty after Δν values of 7.5 GHz for the NZDSF system and 5.8 GHz for the SMF+DCF system can be explained with the existence of the modulation instability (MI). MI depends on the fiber nonlinearity coefficient (γ), and the signal power. These two parameters determine the MI gain peak frequency. At this frequency, the effect of MI gain on the transmission system is maximum. The MI gain peak frequency is 20 GHz in the NZDSF system. However the receiver filter, whose bandwidth is 7.5 GHz, suppresses the impact of MI gain beyond 7.5 GHz. The MI gain peak frequency is 6 GHz for the SMF+DCF system. This value is within the bandwidth of the receiver filter and it is very close to Δν value at which the maximum power penalty occurs. However, maximum power penalty in the SMF+DCF system is 0.6 dB lower than that of the NZDSF system. This is due to values of the fiber nonlinearity coefficient γ in SMF and NZDSF, i.e. γ value of SMF is lower than that of NZDSF.

The power penalty variation with the distance between any two adjacent nodes is shown in Fig. 7. In this simulation, the optical path of the signal is assumed to be composed of eight equally spaced nodes. The worst cases of both systems, i.e. Δν = 7.5 GHz for the NZDSF system and Δν = 5.8 GHz for the SMF+DCF system, are considered. It is clear that the length of the total optical path increases with the increasing distance between adjacent nodes. In the NZDSF system, a significant and continuous power penalty increase is observed. However, a relatively low power penalty, whose maximum value is 1.2 dB, is obtained in the SMF+DCF system. The difference between power penalties of both systems increases obviously for distances exceeding 30 kilometers. This is due to the combined effect of self phase modulation (SPM) and group velocity dispersion (GVD) occurring in optical fiber systems, which becomes a major factor determining the transmission performance with the increasing value of the total optical path length.

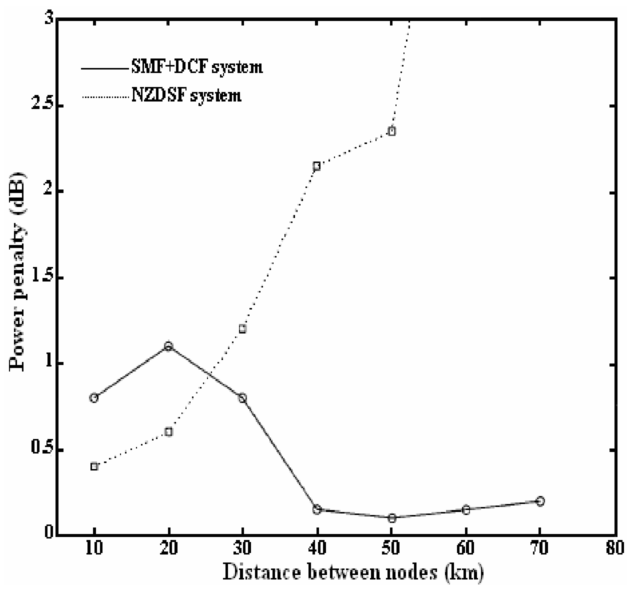

Fig. 7. Power penalty variation with the distance between nodes

The variation of the power penalty with varying number of nodes on a regional path having a length of 250 km is shown in Fig 8. In the NZDSF system, the power penalty increases until 10 nodes. Then it slightly decreases and saturates at approximately 1.4 dB for the number of nodes greater than 14. However, in the SMF+DCF system, the power penalty generally increases with increasing number of nodes. The larger number of nodes in the 250 km regional path means smaller distances between adjacent nodes providing higher average signal power during propagation that results in enhancement of the interaction between the crosstalk and optical fiber nonlinearities.

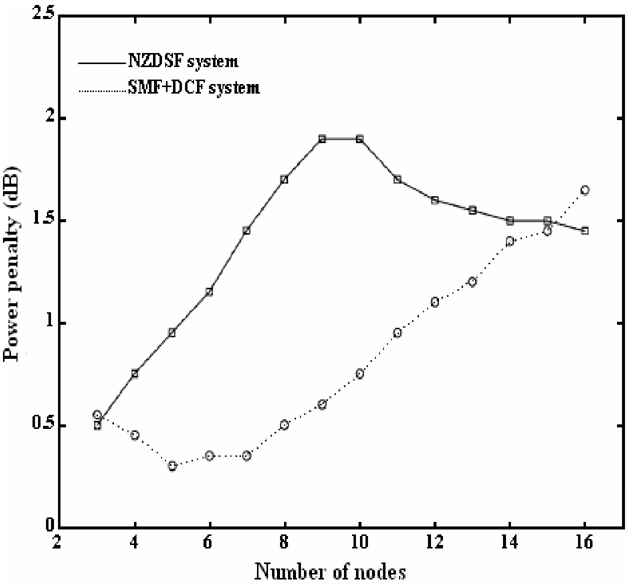

Fig. 8. Power penalty variation with the number of nodes

4. Conclusions

In this paper, the impact of the interaction between the crosstalk existing in OADMs of metropolitan network nodes and optical fiber nonlinearities on transmission performances of NZDSF and SMF+DCF systems is investigated.

The significant transmission performance impairments observed in simulations emphasize the importance of the crosstalk/fiber nonlinearity interaction for design and implementation of metropolitan networks. It should be noted that the ASE noise is neglected in simulations. However in practice, the impact of the ASE noise must be considered as well as the interaction reported in this paper. Therefore, the crosstalk/fiber nonlinearity interaction will cause additional limitations on optical transmission in practical systems. Moreover, variations in the optical signal to noise ratio (OSNR) and the input power will affect the eye diagrams. Finally, in practical systems, the crosstalk may exist in not only a specific node as investigated in the paper but all nodes along the optical path of the signal, which results in more complicated interactions and performance limitations.

5. References

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