Power Divergence Due to Wavelength Rerouting in Long Haul Circulating Loop Experiments

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Abstract

The power divergence and the resulting transmission penalty due to wavelength rerouting is measured in long-haul transmission for different power adjustment steps in an applied constant gain circulating loop experiment.

Introduction

Photonic switching elements in transparent networks, such as reconfigurable optical add drop multiplexers (ROADMs), provide a platform to support greater network flexibility through wavelength rerouting. This capability enables or enhances architectures and protocols for future scalable, bandwidth efficient transparent networks such as generalized multi-protocol label switching (GMPLS) and optical flow switching (OFS). Experimental studies of wavelength reconfiguration have been largely limited to short reach and un-amplified systems [1] or demonstrations of specialized amplification designs or technologies [2]. Nevertheless, one expects that transparent long haul networks will exhibit the scale and transparency to benefit from wavelength reconfiguration. However, circulating loops commonly used in laboratory experiments to study long distance transmission are not well suited for the study of channel power dynamics due to wavelength reconfiguration. Due to gain saturation, amplifiers in reconfigurable networks are typically operated under constant gain control. Such constant gain control can become unstable in circulating loops because the output signal is returned to the input. Following a recent method used to study transient power divergence [3], stable constant gain operation is achieved in a circulating loop by adjusting the target output powers of amplifiers in constant power mode in order to maintain constant gain in the presence of reconfiguration. Furthermore, the port settings of a wavelength selective switch (WSS) used in the loop are modified in order to realize different channel configurations, unlike the transient case in which upstream channels are cut. The effectiveness of this method in circulating loop experiments is validated and the steady-state transmission penalties accumulated during long haul transmission are measured as the system is tuned through discrete operations such as adjusting the amplifier tilt and output power or adjusting the power leveling using the WSS attenuators. Examples of power divergence and associated transmission penalties due to wavelength reconfiguration are investigated for configurations varied between full loading, uniform spectral distribution and banded groups.

Power control in transparent networks is typically characterized by a combination of fast amplifier control and slower fine tuning of channel power, ripple and tilt. We assume that wavelength reconfiguration requires release of the existing connection and establishment of the new connection to an error free state each without introducing bit errors on other wavelengths. Therefore, in addition to the signaling required to coordinate the reconfiguration, the reconfiguration time will depend on the physical layer tuning of control elements. Here we examine the required tuning to move from different wavelength configurations in three steps: (1: CG) opening and closing WSS ports while each amplifier maintains constant gain, (2: PT) correcting the tilt and total output power error of the amplifier (by tuning the constant gain target), and (3: FO) adjusting the WSS per channel attenuation settings to bring the system to its optimal setting. The extent to which these controls must be adjusted will stretch the reconfiguration time from seconds to minutes or longer, impacting the potential for fast reconfiguration.

Experiment

A ROADM circulating loop is constructed with a wavelength selective switch (WSS) at the input and nominally 80, 80, 90, and 70 km SSMF fiber spans. Forty 100 GHz spaced channels are 10.7 Gb/s NRZ-OOK modulated with a 2^{31}-1 pseudo-random bit pattern [4]. Two stage erbium doped fiber amplifiers were used in the loading path, receive path, WSS output and the output of each span. The dispersion map uses -/+500 ps/nm pre-/post-compensation and 32 ps/nm residual dispersion per span. Each gain flattened amplifier is equipped with a mid-stage variable optical attenuator to adjust the gain tilt and a dispersion compensating module. The total power and optical spectrum is monitored at the input and output of each amplifier stage in the loop.

In these experiments the system is first setup with all 40 channels propagating over the maximum transmission distance. The amplifiers and WSS are optimized for this configuration, to serve as an initial reference point. The system is then reconfigured by modifying the WSS switch positions to a configuration consisting of five channels spread across the

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spectrum and then again to successive five-channel banded configurations each consisting of four channels adjacent to one of the channels from the spread configuration (Fig. 1). In this way we sample the system settings for fully loaded, uniformly spread, and banded wavelength configurations. For each banded configuration, the power divergence and transmission penalty on the central channel is measured at each step of the system tuning from CG to PT to FO. For each step, the gain of the amplifiers is maintained to within +/- 0.3 dB for each stage.

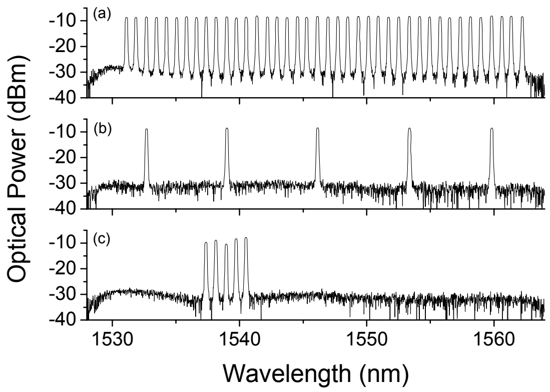

Fig. 1. Fully optimized spectra at loop output after 1 round trip for (a) 40 channel, (b) 5 channel spread, and (c) 1538 nm 5 channel banded configurations.

Fig. 2 shows the optical signal to noise ratio (OSNR) margin (delivered OSNR – required OSNR for a bit error ratio, BER = 10^{-3}) after 5 round trips (1600 km) for the central channel of each band as the system is tuned from the spread configuration to the respective banded configuration. Note that this corresponds to a reconfiguration of 4 out of 5 channels for which the measured channel is not reconfigured. A launch power of +6 dBm/channel is used for these measurements. The two channels at either end of the spread spectrum experience an improved margin, whereas the margin is reduced by up to 5.5 dB for the other channels. Nevertheless, a margin > 3 dB is maintained for reconfiguration over 1600 km due to the high launch power enabled by the pre-compensated dispersion map. For the channel at 1532 nm, which increases in power, the maximum transmission distance of 2560 km is reduced to 2240 km because of an increased non-linear penalty. Fig. 3 shows power spectra at the loop output for the banded configuration centered on the 1538 nm channel. For 6 dBm/channel span launch power, the constant gain channel power is 10 dB below the fully optimized (FO) power after 5 round trips. Similar measurements using a launch power of 0 dBm show a power drop of 6 dB after 4 round trips. The observed power deviation is due to differences in the WSS attenuator settings for the different configurations, which results from a combination of changes in the amount of stimulated Raman scattering and the gain ripple variations for the different amplifier channel loadings. Other gain nonlinearities such as spectral hole burning [3] may also contribute. The optimized WSS attenuator settings vary up to 2.5 dB across all configurations.

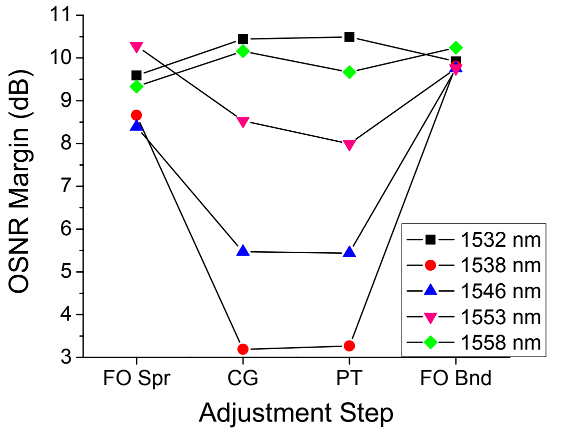

Fig. 2. Measured transmission margins after 5 round trips for reconfiguration from a spread (spr) to banded (bnd) configuration; FO=fully optimized, CG=Constant gain applied, PT=power and tilt adj.

Wavelength reconfiguration has been studied in a circulating loop experiment using step-wise system adjustments with constant gain realized by explicitly setting the amplifier power levels. Reconfiguration among spectrally distributed and banded configurations without channel power tuning is shown to result in large power deviations and a corresponding margin reduction.

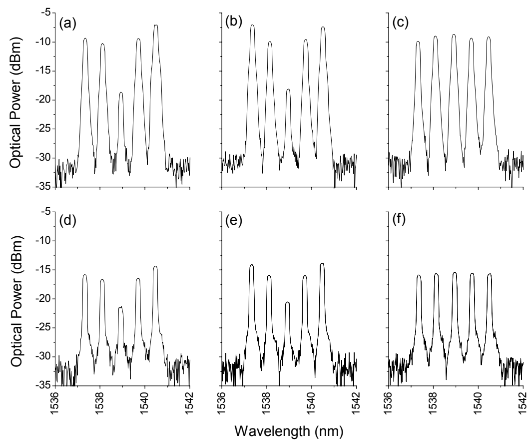

Fig. 3. Optical spectra for banded configuration around 1538 nm: (a)-(c)CG, PT, FO for 6 dBm launch power; (d)-(f)CG, PT, FO for 0 dBm launch power.

References

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