Dispersion-Managed Fiber (DMF): Experimental & Economic Evaluation

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Abstract: *We report an experimental comparison of 40 Gbit/s transmission over DMF and G.652 fibers and find a 30% reach advantage for DMF. Cost modelling for a generic German backbone network quantifies DMF economic advantage.*

Introduction

Commercial availability of very high capacity IP routers employing 40 Gbit/s interfaces accelerated the final preparations of 40 Gbit/s transmission systems for deployment in backbone networks. A number of field trials and press releases have been reported recently [1] showing the mature state of 40 Gbit/s technology. At the same time, there has been increasing interest in Raman assisted transmission [2] as an efficient technique to boost optical signal to noise ratio (OSNR). Record results at 40 Gbit/s with Raman amplification were achieved with DMF [3], a solution that provides better transmission properties versus single fibers. DMF consists of dispersion slope matched +D and –D fibers arranged in a symmetrical configuration with –D fiber placed in the center of the span. This fiber arrangement offers the same +D fiber type at the amplifier huts thus simplifying the operations. The symmetric span configuration also optimizes Raman effective noise figure [4-5]. DMF precise dispersion compensation over the transmission band, low polarization mode dispersion (PMD) and low dispersion sensitivity to temperature [6], reducing the need for per channel and any active compensation [7]. Economic modeling shows that in the large 40 Gb/s networks (link length ~2000 km) DMF can reduce network cost by 50% [8]. In this work we focus on evaluation of DMF in a smaller size German backbone network.

Experimental Evaluation

To evaluate transmission performance of DMF, measurements for three 40-Gbit/s RZ-ASK signals (centre wavelength: 1550.92 nm, channel spacing: 100 GHz, duty cycle: 50%) were carried out in a recirculating loop test-bed. The measured back-to-back receiver sensitivity of this system was -31 dBm for a bit-error-ratio (BER) of 10^{-9}. The performance of DMF (see Fig. 1 a) was compared to a traditionally designed optical transmission section that consists of standard single-mode fiber (G.652-compliant fiber), dispersion compensating fiber (DCF) and an additional amplifier in front of the DCF (see Fig. 1 b).

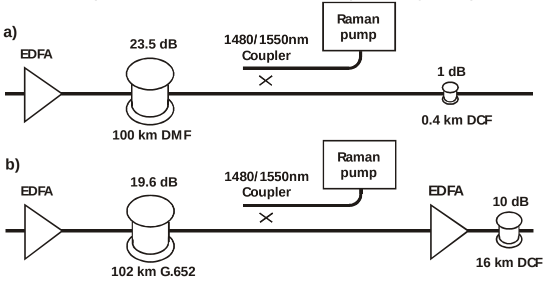

Figure 1: Investigated transmission sections:
a) DMF-section b) G.652 section

DMF parameters are given elsewhere [7]. Two scenarios were considered for both transmission fibers: a) pure EDFA amplification (noise figure 4.5 dB) and b) a hybrid scheme (5 dB EDFA gain) using additional Raman amplification.

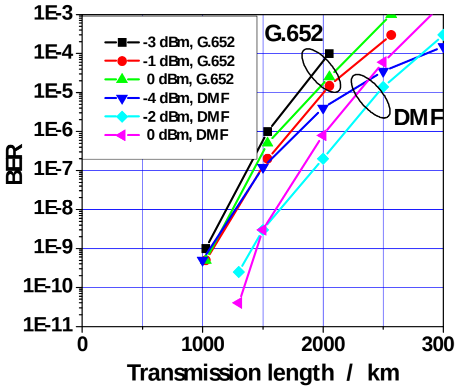

Figure 2: BER as a function of distance for G.652 and DMF-sections with Raman assisted transmission at different launch powers per channel

The loop experiments were carried out for 100 % inline compensation of chromatic dispersion at the measured wavelength of 1550.92 nm, which was reached for the DMF-section by inserting an additional 0.4-km piece of DCF. In the case of EDFA only transmission (results are not shown here) nearly similar performance was achieved for both fibers. It is known from undersea transmission experiments that +D/-D DMF span configuration (different from +D/-D/+D used in our experiment) is optimal for this case. Figure 2 shows measured BER versus transmission distance for different launch powers per channel for the Raman assisted transmission. For optimum launch powers, the cascaded DMF-sections give an additional reach of ~30% (at BER = 10^{-9}) as compared to the cascaded G.652-sections. Another interpretation of these results is that DMF provides higher margin at the same distance (from Figure 2 ΔQ~1.5 dB at 1400 km).

Economic Evaluation

Now we will explore how network capital expenditure (CAPEX) will differ for DMF and G.652 in a typical European national network, e.g. the generic German backbone network [11] consisting of 17 nodes, 26 links and 4447 route kilometers; the longest path is slightly less than 1000 km. Total traffic demand (voice, data and IP) of 4.4 Tbit/s was assumed for the year 2006.

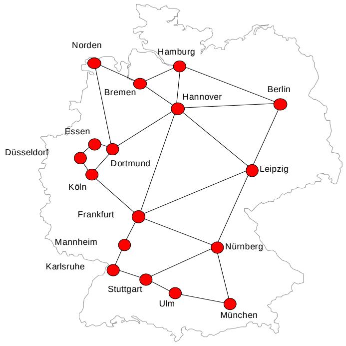

Figure 3: Topology of the generic German backbone

WDM systems with 100 km spans over G.652 and DMF had transparent reaches of 1100 km and 1400 km respectively, and capacity of 48x40 Gbit/s. Operating expenditures (OPEX) were not considered in this study. The details of the cost model have been described elsewhere [9]. Nodes with degree 2 are equipped with transparent optical add/drop multiplexer (OADM). Nodes with degree >2 have opaque design with O-E-O regeneration and traffic rerouting. We also considered the transparent case where traffic is routed without O-E-O regeneration. For both cases, a 1+1 protection scheme was assumed. We used current prices for network elements from system vendors; however cable prices were not included in these calculations in order to focus on equipment savings. The cost of dual-stage amplifiers was assumed to be 14% higher than that of single-stage.

Table 1 shows the normalized costs of different network components with Opaque and Transparent node designs.

Total CAPEX*	Opaque			Transparent		
	G.652	DMF	Δ	G.652	DMF	Δ
Transponders	1535.4	1533.0	0.2%	322.4	320.0	0.7%
Terminals	300.0	300.0	0.0%	300.0	300.0	0.0%
OADMs	36.0	36.0	0.0%	36.0	36.0	0.0%
Amplifiers and DCMs	38.0	26.6	30.0%	38.0	26.6	30.0%
TOTAL	**1909.4**	**1895.6**	**0.7%**	**696.4**	**682.6**	**2.0%**

*** Normalized to Transponder cost**

Table 1: CAPEX for network components

The CAPEX totals illustrate that the transparent architecture potentially realizes large savings which are due to the reduction of transponders. Given that the longest path in the network is less than 1000 km, the full potential for CAPEX savings due to the longer reach of DMF is not realized in either opaque or transparent networks. DMF enables simplified amplifiers and eliminates DCMs resulting in a cost reduction of 30% which is realized for every lit fiber. Another possibility to utilize the improved performance over DMF is to increase the span length between amplifiers rather than system reach. Our calculations indicate [10] that in the German network DMF could have 20 km longer span length yielding total CAPEX savings of 1% in an opaque architecture**.** Fewer amplifiers in the network will result in lower OPEX and the possibility to skip some amplifier huts.

Summary

We have evaluated the transmission performance of DMF and compared it with that of G.652 under the same conditions. We concluded that ~30% longer total reach could be achieved with 100 km spans. Due to the relatively small size of the generic German network, DMF will not significantly reduce the number of transponders. However, it enables a 30% reduction in the cost of amplification and dispersion compensation. Additional DMF advantages could be utilized by extending the span length between amplifiers.

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