Optimisation of All-Optical Network Testbed

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ABSTRACT

The capacity and high flexibility potentials of transparent optical networks have already been realized in practice. By keeping the signal in the optical domain, the optical network is limited by performance degrading physical effects. Link budget design has to take into account both noise and distortion related impairments.

A simulation environment is used to analyse wavelength division multiplexing (WDM) transmission links for establishing an all-optical network (AON) testbed for carrying out research and development activities. The primary focus of numerical modelling was the characterisation of signal degradation levels, link power budget and end-to-end physical connection for a typical metro environment. The simulation outcome was applied to support the selection of optical components (laser, Mux/Demux, receiver, EDFA, fibre type, attenuators etc.) as well as overall performance of WDM system characterised by bit-error rate (BER). Finally, results of numerical analyses are used to assess the feasibility of connecting two optical research facilities within a 30 km distance.

KEY WORDS
Wavelength division multiplexing (WDM), physical layer, numerical optimisation, quality of service (QoS), signal impairments, bit-error rate (BER).

1. INTRODUCTION

Deployment of wavelength division multiplexing (WDM) technology enabled capacity and flexibility potentials of transparent optical networks to be realised in practice. In transparent optical networks, signals are mainly kept in the optical domain while passing through switching, attenuation, multiplexing, demultiplexing, routing and optical amplification stages. Due to minimised opto-electronic conversion in such networks, all-optical network (AON) is a prime example of cost-efficient way of managing bits [1]. However, while transparent AONs offer numerous advantages, they are also subject to some constraints. The most important is maintaining the high quality of transmitted signals to guarantee the overall quality of service (QoS) for network users, i.e. guarantee a low bit error ratio (BER). Consequently, the design and optimisation of all-optical networks have to take into account both noise (amplified spontaneous emission, receiver noise, laser noise, interferometric crosstalk etc.) and distortion (chromatic dispersion, polarisation mode dispersion, non-linearity, crosstalk etc.) related impairments [2].

A research project involving the investigation of the feasibility of an all-optical, end-to-end metro WDM network testbed is presented in this paper. The simulation environment is used to analyse the WDM physical layer transmission links for the testbed. The primary focus of numerical modelling was the characterisation of signal degradation levels, link budget and end-to-end physical connection in typical metro environment. The simulation outcome and optimisation were applied to support the selection of key optical components (laser, Mux/Demux, receiver, optical amplifier, fibre type, attenuator etc.) as well as overall performance of WDM system characterised by bit-error rate (BER). Finally, results of numerical analyses are used to assess the feasibility of connecting two optical research facilities within a 30 km distance.

This paper is organised into sections. The design specification of the testbed is listed based on required overall functionality (Section 2), numerical simulation and optimisation of system parameters and component parameters (Section 3). In the last part of this paper, we analyse the numerical results, discuss their applicability and make conclusions regarding the potential real network application (Section 4). Future prospective work is also outlined.

2. SYSTEM SPECIFICATION

The testbed planning required the all-optical network (AON) functionality to be implemented involving key building blocks for an all-optical end-to-end WDM network [3], [4]. These key building blocks include photonic cross-connect (PXC) [5], optical add/drop module (OADM), multiplexer (MUX), de-multiplexer (DeMUX), transmitter, receiver, and optical amplifier [6]. The testbed network requirements are as follows:

- Transmission distance: 10 – 100 km, typical for metro WDM application,
- 4 bi-directional channels at 2.5 Gbps/channel,
- 200 GHz channel spacing,
- AON functionality in place (signal transmission, transport, photonic switching with add/drop channel, end-to-end transmissions, amplification, system control and signal reception),
- No signal regeneration along the transmission stage,
- Overall system performance: $BER \leq 10^{-12}$, i.e. $Q \geq 7.5$ dB.

Figure 1 shows the testbed layout. It has 4 optical channels in addition to a pair of add/drop channels. At transmitter, 4 channels of pseudo random binary sequences (PRBS) are generated and modulated to 4 channels of lasers, then the modulated optical signals pass through a photonic cross-connect (PXC) with a pair of add/drop channels. The variable optical attenuators (VOA) equalize the optical power of the 4 channels after the PXC. Then these optical signals are multiplexed and coupled into a standard single-mode fibre (with loss of 0.2 dB/km [7]). At the receiving end, the signals pass through another node (with DeMUX and PXC) and are equalized again before the receivers.

In the transmission stage, optical signals inevitably suffer from impairments that lead to system performance degradation. There are two groups of signal impairments: noise- and distortion-based. The noise includes Amplifier Spontaneous Emission (ASE), receiver noise (shot-, thermal-, excess-, etc.), laser noise, etc. The primary sources of distortion are fibre and component chromatic dispersion (CD), polarisation mode dispersion (PMD), non-linearities such as self-phase modulation (SPM), cross-phase modulation (XPM), four wave mixing (FWM), laser frequency chirp, filter concatenation, crosstalk etc. These noise and distortion affects on system performance, including causes, behaviors and remedies, have been extensively studied in the literature [8] and [9]. Such affects of signal impairments (both noise and distortion) for the 2.5 Gbps/channel, 200 GHz channel spacing WDM networks (4 channels) are quite small and could be negligible [8] and [9]. The simulation results also validate the above conclusion.

Therefore, the primary source of optical signal degradation is the attenuation from fibre and component loss. Such attenuation can be overcome by using optical amplifiers e.g. erbium doped fibre amplifier (EDFA). However, optical amplifiers also introduce noise (ASE, etc.), add complexity in overall link budget and increase the overall network cost. The numerical optimisation of proposed testbed system answer the question regarding the trade-off between the amplification of the optical transmission signal and introduced ASE noise and cost.

The primary roles of numerical simulation are as follows:

- Optimising the receiver sensitivity to select appropriate receivers,
- Finding the reachable distance without amplification to determine whether or not the use of optical amplifiers is necessary,
- Assess the feasibility of connecting two optical research facilities within a 30 km distance,
- Optimising the extinction ratio (ER) for the external modulators (EXM) to help selecting appropriate realistic transmit sources.

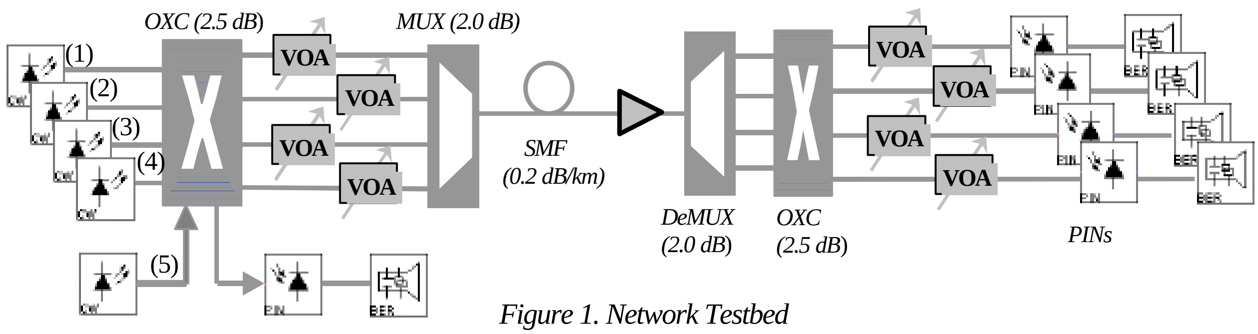

Figure 1. Network Testbed

3. NUMERICAL OPTIMIZATION AND DISCUSSION

To accomplish the tasks of the testbed mentioned above, three groups of simulations are set up as follows:

1) To obtain the optimised value of the receiver sensitivity, the relationships between system performance and receiver sensitivity are numerically analysed. In this group of simulations there are 4 cases: using directly modulated lasers (DML) and external modulators (EXM) as transmit sources, with and without EDFA respectively.

2) The transmission distances under the given typical parameters of the low-cost commercially available components are optimized. The critical transmission distances while keeping acceptable overall system performance are determined. In this group of simulations two cases, using DML and EXM as the sources respectively, without optical amplifier are investigated. The simulation results are used to help determining whether or not the use of optical amplification is necessary, and for assessing the feasibility of connecting the two optical research facilities within a 30 km distance.

3) The affects of extinction ratio (ER) on overall system performance are analysed and optimised ER value is drawn out.

All simulation results are obtained from the tool VPItransmissionMaker™. In Figure 1, channel 3 is the cut-through channel (dropped) and its Q-factor is not simulated. The Q-factors of all other 4 channels are to be analyzed.

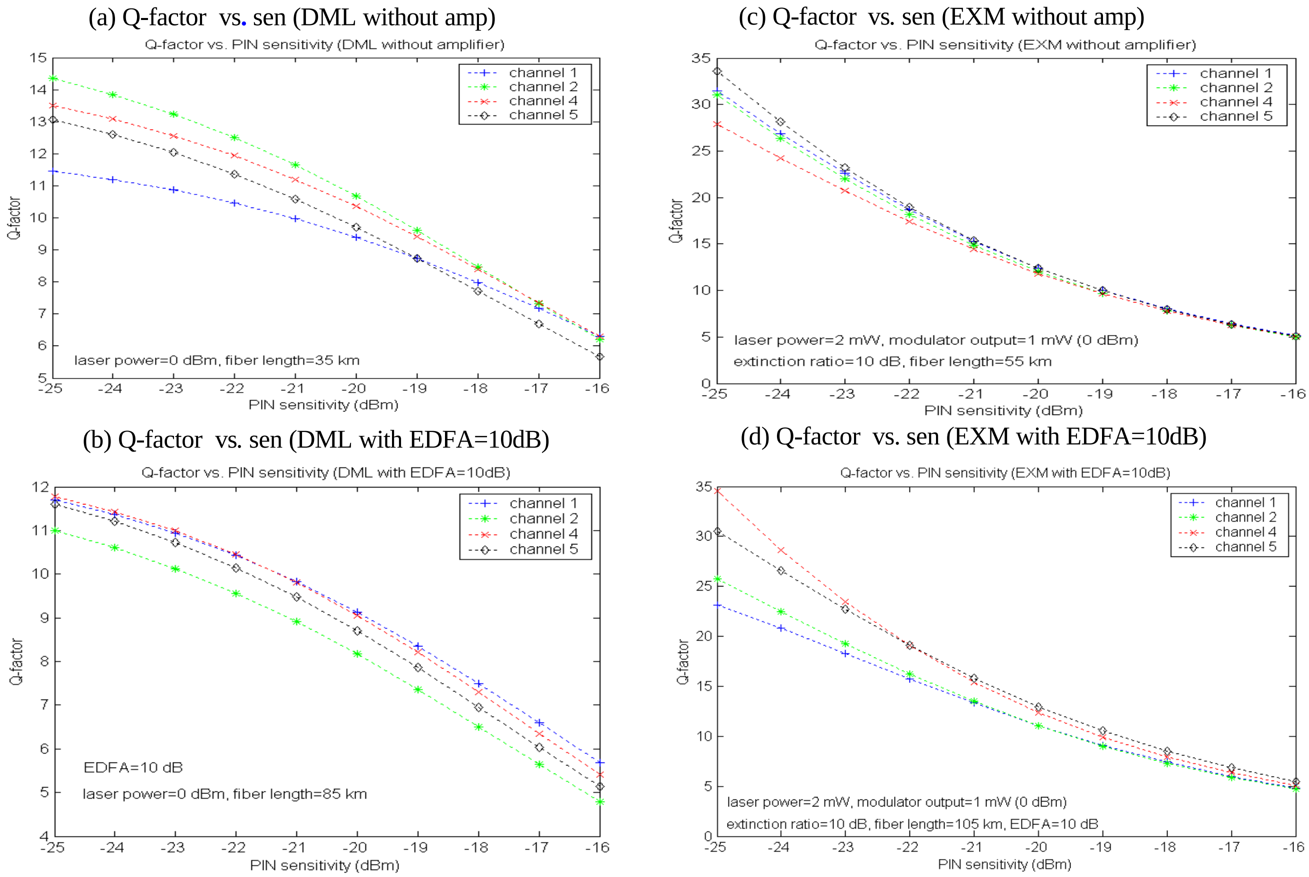

Figure 2. Optimise the receiver sensitivity for receivers

3.1 Receiver

In this group of simulations the appropriate receiver sensitivity is selected for the given distance (35km) and required system performance ($Q \geq 7.5$dB). Figure 2 shows the relationship between Q-factors and receiver sensitivities using DML and EXM (with and without amplifiers respectively) as transmit sources.

Figure 2(a) shows that when a DML is used as transmit source and with receiver sensitivity of –18 dB, fibre length of 35 km, the Q-factor is about 8 dB (worst channel). Case (b) uses a DML with an EDFA (10 dB gain) and better performance is expected because of the optical amplification. Case (c) uses an EXM and generally an external modulator has better performance than a directly modulated laser, thus (c) has better behaviour than (a). Finally (d) uses an EXM and an EDFA (10dB gain) so that it has the best system performance. Therefore among the 4 cases in this group of simulations, (a) is the worst case. The simulation results in Figure 2 also validate the above analyses. If we can find a receiver sensitivity that is good enough for case (a) then it should be OK for all the other cases. Therefore from the results we know that receivers with sensitivity higher than –17 dB are good enough for connecting the two optical research facilities within a 30 km distance.

With a 10 dB gain EDFA, in cases (b) and (d), the transmission distance is expected to be extended by 50km based on a fibre loss of 0.2 dB/km [7]. But the simulations show that with an EDFA (10 dB gain) and a 50 km longer fibre length, the Q-factor is slightly lower than the original cases (a) and (c) respectively. The primary reason is due to the ASE noise introduced by optical amplifier.

3.2 Critical transmission distance

Figure 3 shows that the critical transmission distance (maximum fibre length) for the worst channel is ~32 km for a DML and ~52 km for an EXM respectively, while satisfying the system performance requirement ($Q \geq 7.5$ dB). Both cases are under the following conditions: receiver sensitivity of –17 dB; both the DML laser output and external modulator output power are 0 dBm; the insertion loss for the switch is 2.5 dB and 2.0 dB for MUX/DeMUX; the fibre loss is 0.2 dB/km. These simulation results are consistent with the theoretical power budget estimations.

From Figure 3 we can also see that the two optical research facilities within a 30 km distance could be connected by using selected commercially available, cost-efficient components and without using optical amplifiers.

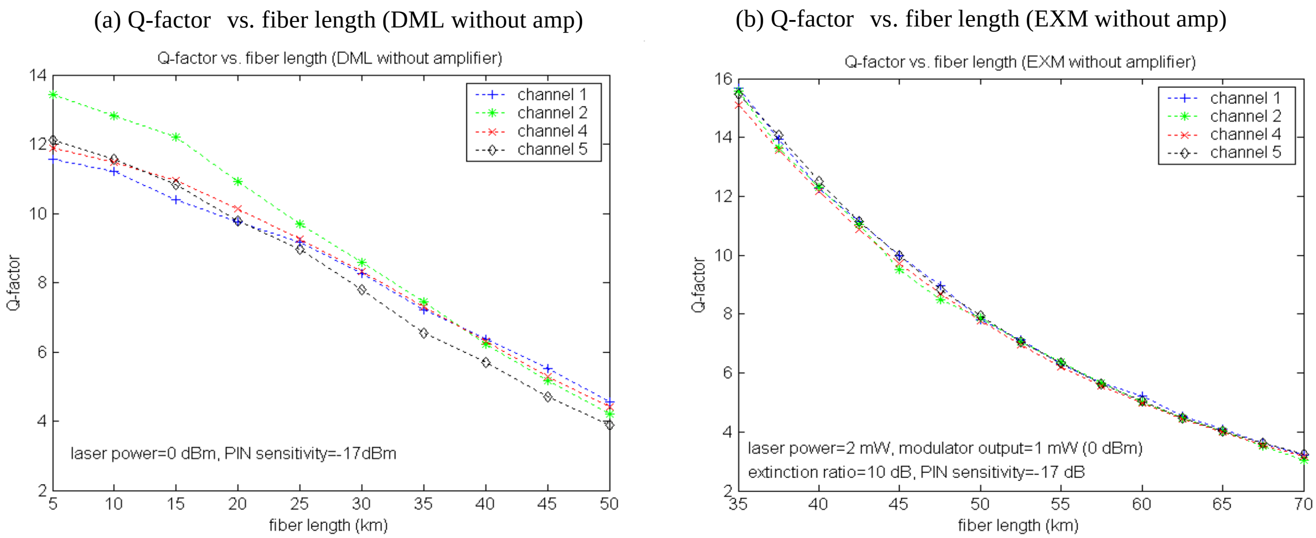

Figure 3. Critical transmission distance: Q-factor vs. fiber length

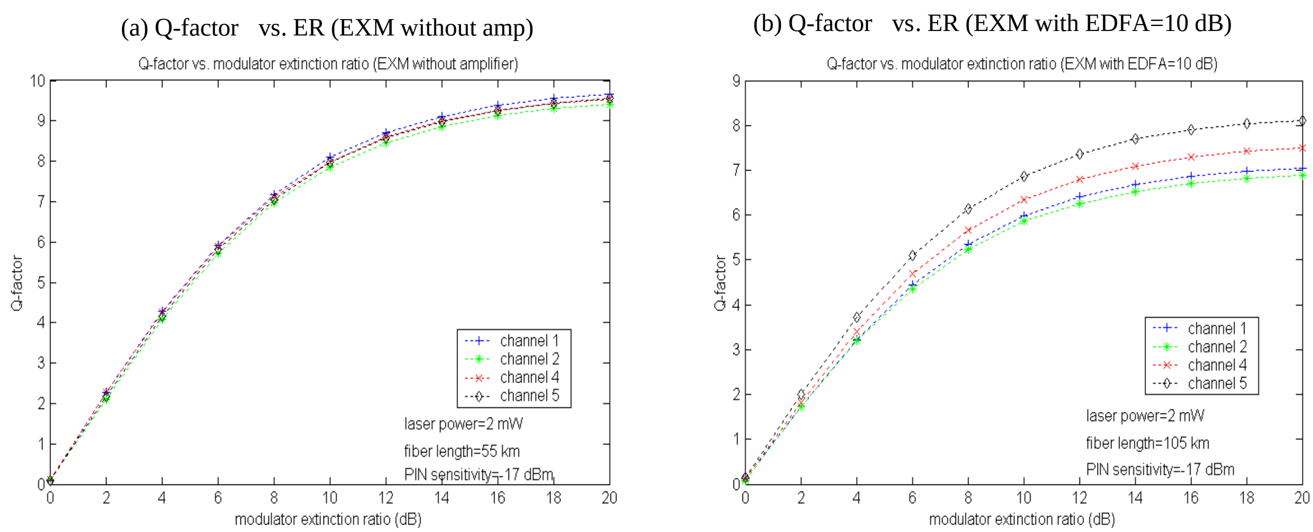

Figure 4. Relationship between Q-factor and ER (EXM)

3.3 Extinction ratio of external modulators

The affects of extinction ratio on the system performance are investigated. From Figure 4 we find the system performance is improved (Q-factors increase) along with the increase of the extinction ratio (ER) of external modulators. In both cases (a) and (b) the Q-factors increase almost linearly when the ER ≤ 10 dB. However, when the ER exceeds a certain value (12 dB) the Q-factors increase very slowly. That means the system performance cannot be improved by increasing the ER unlimitedly. Therefore, considering the cost for increasing the ER, we find that an ER of 10 dB is the optimised value for our particular application.

Similar to Figures 2(b) and (d), in Figure 4(b) with a 10 dB gain EDFA the transmission distance is expected to be extended by 50 km based on a fibre loss of 0.2 dB/km [7] while getting the same Q-factor. But the simulation result in Figure 4(b) shows that with a 50 km longer fibre length the Q factor is slightly lower than the original case in Figure 4(a). The primary reason is due to the ASE noise introduced by the EDFA.

4. CONCLUSIONS

An all-optical research network testbed for carrying out research and development activities is proposed and some key signal impairments are analysed. The numerical optimisation of the key parameters of the realistic devices are also obtained and used for helping select commercial network components. From the simulation results, the optimised receiver sensitivity is –17 dB for the required overall system performance (Q≥7.5 dB). The optimised extinction ratio for external modulators is 10 dB; increasing the ER above this value cannot improve the system performance efficiently. The reachable transmission distances without optical amplification are ~32 km for directly modulated lasers and ~52 km for external modulators respectively. Thus it is possible to connect the two optical research facilities within a 30 km distance without optical amplification.

Future prospective work might consist of upgrading the testbed with increasing the channel data rate to 10 and 40 Gbps, adding more channels, and reducing channel spacing (e.g. 100 GHz). Furthermore, after the verification and validation of the testbed, a set of experiments and research activities will be scheduled using the testbed.

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