Dynamically Allocated Wavelength WDM Network Demonstrator

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Abstract

In this communication we describe the demonstrator implementation of the optical network DAWN (Dynamically Allocated Wavelength WDM Network). We discuss the implementation of the nodes, the network behaviour and the overall implementation of the network demonstrator. The MAC (Multiple Access Control) protocol of the network is analysed.

I. INTRODUCTION

Optical Wavelength Division Multiplexing (WDM) technology has emerged as the dominant technique used in the realisation of all-optical networks. In wavelength agile networks, by assigning wavelengths to the network transmitters and receivers, it is possible to embed a virtual topology in a physical network [1]. This requires the use of tuneable components (tuneable transmitters and/or receivers) featuring short tuning times as well as to co-ordinate the use of a limited number of wavelengths.

The demonstrator that is described here is part of the DAWN (Dynamically Allocated Wavelength WDM Network), a project funded by FCT program PRAXIS XXI. The DAWN architecture is based on the use of a reflective semiconductor optical amplifier (RSOA). The main components of the transmitter of each node is the RSOA and a tuneable optical filter. Each node receives a signal comprising a comb of reference wavelengths and selects one of the wavelengths by appropriately setting the optical filter. The received signal travels along the RSOA where it is amplified, modulated and reflected back to the network. Besides providing gain, this simple scheme has the advantage of facilitating wavelength monitoring and control at the controlling node. The control information necessary to achieve coordination between the nodes is subcarrier multiplexed and superimposed on the baseband payload.

In this project as important as the study of the physical network level is the study of the logical level, emphasising the interdependence between them. In order to validate these studies, we implemented a demonstrator comprising of a small-scale experiment, consisting of four nodes (Figure 1). For the purpose of future network studies, the demonstrator can be extended by adding virtual nodes. The extension of the demonstrator by virtual nodes is of crucial importance for the assessment of work that will be developed at the logical level of the network: study of logical topologies that are best adapted for WDM networks for given traffic scenarios, development of a network media access protocol able to coordinate the transmission among the different nodes, and the implementation of optimal message routing algorithms suitable for WDM networks.

II. DEMONSTRATOR DEFINITION

The DAWN demonstrator is shown in Figure 1 and consists of 3 user nodes and a controlling node

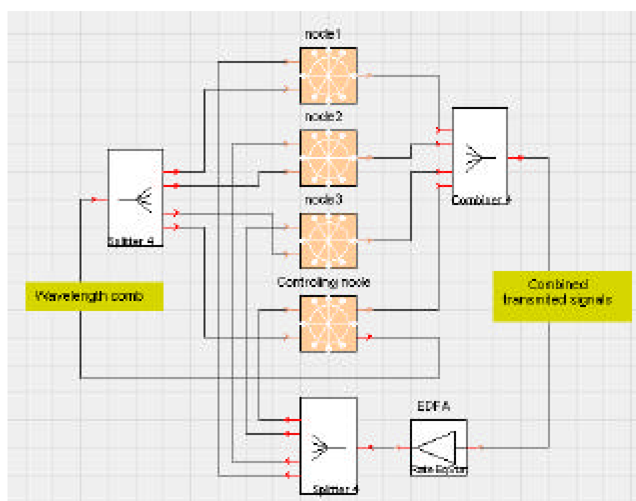

Fig. 1- Demonstrator simulation model, built on the Virtual Photonics PTDS Simulator©.

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Each user node is identified by a subcarrier frequency. Taking into account harmonic and intermodulation distortions, were chosen 1.7, 1.8 and 1.9 GHz as appropriate values for the subcarrier frequencies.
Each node has a fixed wavelength receiver and a wavelength tuneable transmitter that sends messages on a specific wavelength in the 1500 nm window. Each message contains a baseband data packet and one SCM (Subcarrier Multiplexing) control packet. The data occupies the baseband up to f_D=1 GHz. The data rate of the control channels are kept relatively low, typically in the 5-15 Mb/s range.
Wavelength channels were chosen according the to the ITU grid in the ranges of the available laser sources, considering a separation of 200 GHz to ensure good isolation between channels. For the demonstrator, the chosen wavelengths were 1547.5, 1549.2 and 1550.9 nm.

III. CONTROLLING NODE

The controlling node, shown in Figure 2, consists of two sections. Wavelength Comb Generator and Control Processing Section.
The Wavelength Comb Generator creates a comb of stable wavelengths, recurring to an array of three DFB lasers. Wavelength stability is a key issue of WDM systems, however, in the proposed network this problem is simplified since the comb of wavelengths is generated in a central point which simplifies wavelength control and monitoring.

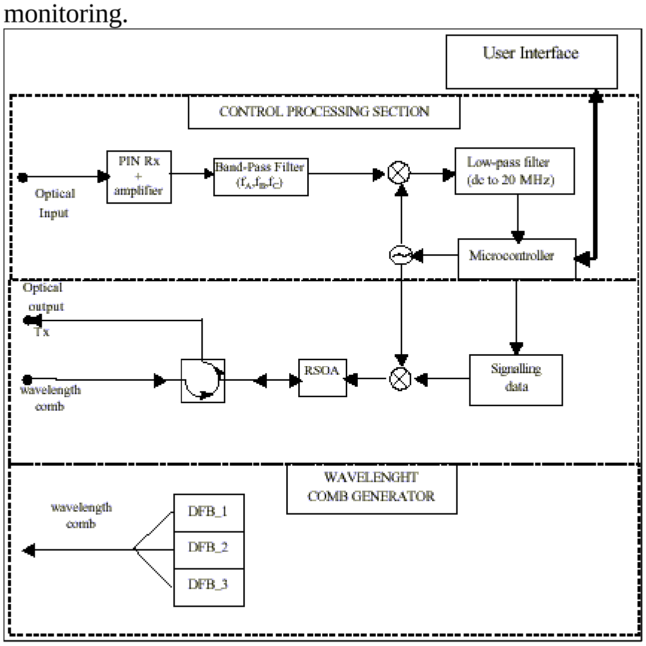

Fig. 2 – Controlling node schematic.

The other function of the controlling node is to process the signalling information arriving from the nodes of the network and to send it to all nodes of the network. The receiver section consists of a PIN based receiver with a bandwidth up to 1.7 GHz. The absence of an optical filter before the receiver allows the receiver to receive signals from all nodes. Since in the demonstrator there are only three wavelengths, the PIN does not operate under saturation, however in a network with more nodes this would not apply and another implementation would be necessary. After optical detection, the arriving signal is filtered by a band pass filter. By using a tuneable local oscillator the controlling node sweeps all the f_is (i = A,B,C), reading and processing their control data. The frequency synthesis unit is based on the PLL LMX2336 and the VCO PVS-1790. Besides the refered tasks, the controlling node needs to deliver to all nodes control data. By generating control baseband serial data in the microcontroller, modulating it with the tuneable oscillator, the information can be delivered. After this operation the signalling data is located in the appropriated f_is (i = A,B,C) and ready to be sent to the nodes. Since each user node uses a receiver with a fixed wavelength, an elegant way to make the control information arrive to all nodes is to modulate a RSOA with the control data. In this way all the control data appears in all wavelengths and is broadcasted to the network. In order to perform the control and monitoring of the network the controlling node has to maintain tables with the status of the wavelengths of the network, and the status of the nodes of the network.

IV. USER NODE

A. General overview

Figure 3 illustrates the design of an user node. At the transmitter section, a parallel 8-bit control header is converted to serial data by a digital control circuit implemented using a microcontroller. From the control header 3 bits are reserved for the identification of the node to be contacted, 3 bits for the identification of the receive node and the remaining are not used. The control bit stream modulates a subcarrier frequency. Then, the data after being filtered by a square root raised cosine filter [2] is added to the modulated subcarrier and the resulting signal is used to modulate the RSOA, as shown in Figure 4. The receiver front end comprises a PIN photodiode and an amplifier of bandwidth up to 1.7 GHz. By appropriate filtering of the received signal [2], the data is separated from the signalling information. The signalling information is retrieved by mixing it with a locally generated carrier that is obtained using a frequency synthesiser. The microcontroller processes the signalling information and takes the appropriated action. The user interface is achieved through a LCD (Liquid Crystal Display) and a simple 4x4 keypad.
The tuneable optical filter located after the RSOA is the OTF-610 tuneable optical filter, with a 3 dB bandwidth of ~0.4 nm and a tuning time in the order of 10 ms. The voltage signal necessary to tune the optical filter is generated through a variable voltage signal controlled by the microcontroller.
An optical circulator was used to separate the CW optical signal entering the RSOA from the modulated signal.

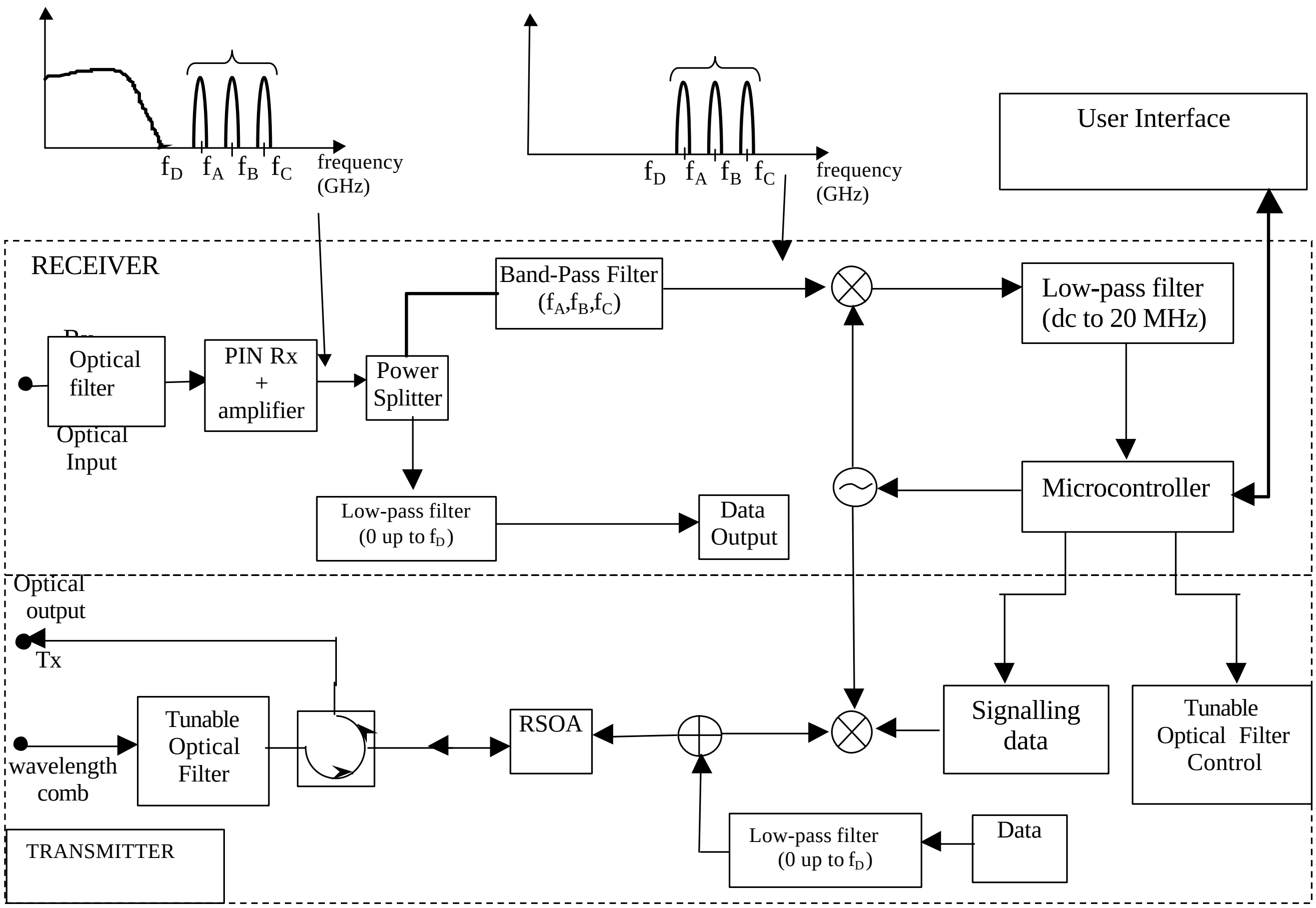

Fig. 3 – Detailed implementation of a user node.

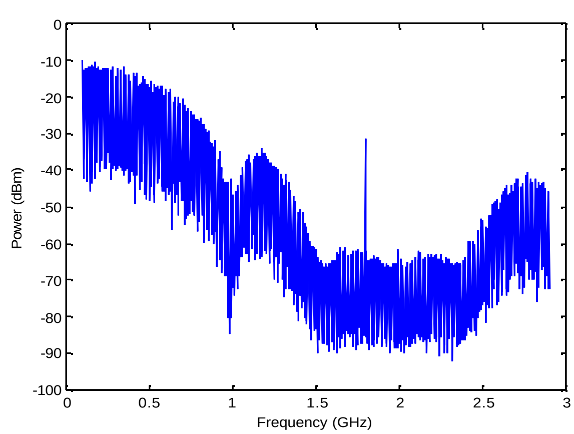

Fig. 4 – 1 Gbit/s NRZ data after filtering plus a 1.7 GHz SCM channel.

B. Microstrip filter design

The transmitter low pass filter up to f_D as well as the receiver low pass and band pass filters were implemented in the form of microstrip circuits.The low pass filters were designed to give a square root raised cosine response with a roll-off factor of 50%. To design this filters we start with an all pole Butterworth low-pass filter with a 3 dB cut-off of 1 GHz, but with the addition of one or more open circuit stubs at its output. The stubs were designed to have an effective length of $\lambda/4$ at 1.5 GHz, thereby producing an effective short-circuit in the filter response and creating the required zero transmission. The band pass filter was implemented in microstrip using a parallel-coupled structure [3], this structure was chosen over the end- or edge-coupled structures because : i) the length of the filter

is approximately reduced by half, ii) an almost symmetrical frequency response is obtained with the first spurious response at three times the centre frequency and iii) a much larger gap between adjacent microstrips is permitted, thereby simplifying the manufacturing process. The number of resonators determines the order of the filter.
The filter dimensions, based on odd and even mode impedance calculations, were obtained using commercially available design tools. The filter dimensions were further optimised, to account for edge effects and undesired coupling, by studying its behaviour using the simulators "Momentum" and "Libra". The band-pass filter was specified to have a Butterworth response with a 1.8 GHz centre frequency, 1 dB attenuation at 1.8 ±0.15 GHz and >35 dB attenuation at 1.5 and 2.1 GHz.

C. Transmitter characteristics

The key element of the transmitter is the reflective semiconductor optical amplifier. In the demonstrator we used devices made specifically for this application by Opto Speed Figure 5 shows the spontaneous emission spectrum of one RSOA for four values of bias current.

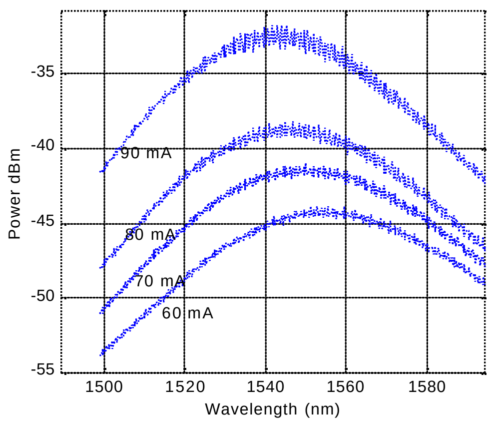

Fig. 5 – Measured spontaneous emission power spectrum.

From the measured spontaneous emission spectrum the mode spacing was measured to be ~ 0.8 nm, which corresponds to amplifier length L of 1.4 mm. The gain ripple was measured to be ~3 dB. The value of the two facet reflectivies were estimated comparing the measured response of the RSOA with a simulated response, to be R_1=0.001% and R_2=0.1%. The device has an unsatured gain in the region where the DFB lasers operated (1547.5, 1549.2 and 1550.9 nm) of ~12 dB for a bias current of 100 mA. The gain can be increased by increasing the bias current. However increasing the gain also leads to an increase in the spontaneous emission noise leading to an overall performance degradation.
The implementation of the DAWN network relies in the ability of the RSOA to be intensity directly modulated up to 1 Gbit/s NRZ and by the SCM channels located at 1.7, 1.8 and 1.9 GHz. As shown in Figure 6 the devices used in the demonstrator satisfy the necessary requirements. The 3 dB modulation bandwidth increases when an optical signal is injected into the RSOA [4].
Figure 8 shows the received eye diagram for 1 Gbit/s NRZ data, the data was low pass filtered at the transmitter and receiver by square root raised cosine filters. A –30 dBm optical signal at 1547.5 nm was applied to the RSOA, under these conditions the RSOA was operating in the unsatured regime.

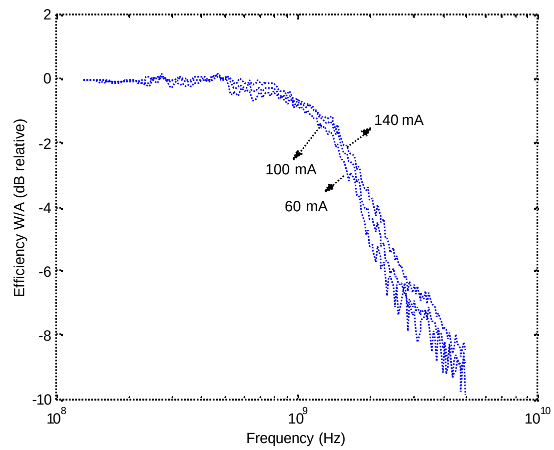

Fig. 6 – Measured RSOA modulation response without input optical power.

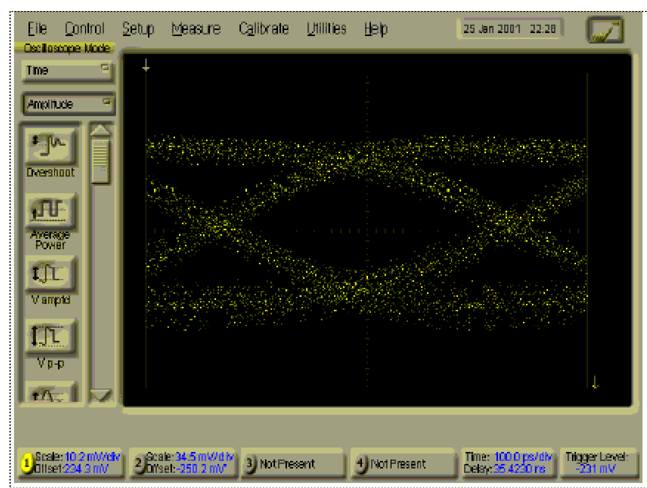

Fig. 7 – Measured received eye diagram for 1 Gbit/s NRZ data.

V. MAC PROTOCOL

The MAC protocol for the DAWN network is based on a simple master/slave scheduler. It attempts to increase utilization and avoid contention by co-ordinating and scheduling the transmissions among the nodes. All nodes are identified by receiver wavelength l_i. After an event arrival, the node immediately begin to transmit a request. All nodes send their requests to the controlling node. The scheduler, located in the controlling node, schedules the requests continuously and informs the nodes of their turn to transmit. Upon receiving their assignments, nodes immediately tune their transmitter and start to transmit. Hence, nodes do not need to maintain any synchronization or timing information.

To implement the MAC protocol C++ was used in combination with a discrete event simulator called OMNeT++ [5]. With this object-oriented environment the model of our network was created using a hierarchical structure of nested modules connected to links via gates through which is possible to send messages. The network components are objects defined from C++ derived classes and their activity was programmed as distributed algorithms of concurrent processes defined by the following modules.

Transmitter module: the generator, which is modelled according to a Pareto distribution, generates messages. The sender selects the message destination randomly, defines the message length according to the geometric distribution and pass down the message to the MAC sublayer. The SenderMAC activity, is responsible for issuing the request for connection to the controlling station and for queuing the message while waiting for the response. Upon receiving the expected answer the message is picked from the queue and sent to the data channel after tuning the transmitter to the appropriate receiver wavelength, if different from the receiver of the previous message. The message is then broadcasted to all the stations.

Receiver module: after receiving a message the ReceiverMAC sends a release message to the controlling node warning its availability while the received message is sent to higher layer for processing. Here the higher layer is represented by the sink submodule whose activity is responsible for the extraction of some statistics and also for absorbing the traffic.

Controlling module: on the controlling station there is a table of wavelength availability, and a queue for pending requests. The activity of this module starts by initializing the wavelength table and proceeds by answering to requests for wavelengths. Whenever a request arrives for an already taken wavelength, that request is queued according to its destination address. Upon receiving a release message queued requests are satisfied on a FIFO (first in first out) manner.

To evaluate the MAC protocol performance the following assumptions were made: there are 10 user nodes and 10 wavelengths available; it takes 10 to 20 ms to tune a receiver to any particular channel; the distance between each station and the passive star coupler is approximately 10 Km; messages arrive at each station according to a Pareto process with shape value $1<\theta<2$; message lengths are geometrically distributed with the average message of 100 Mbit/s.

Fig. 9 shows the throughput of the network, defined as the fraction of connection requests successfully satisfied by the network at first try per unit of time, against mean arrival message rate for different values of θ (shape parameter of the Pareto process). As the arrival rate increases, the throughput decreases as the number of stations in request mode begin to outnumber the number of stations available to receive. We note that under bursty traffic (θ =1.1), the throughput decreases more rapidly than for higher values of θ. This result shows that this protocol is not appropriate for highly bursty traffic and needs to be modified to take into account this traffic behaviour.

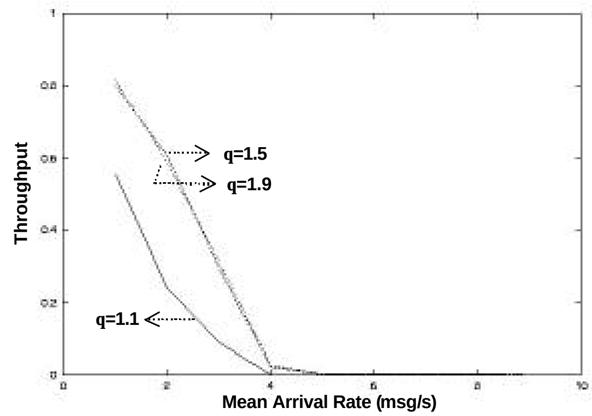

Fig. 9- Throughput vs Mean arrival rate

VI. SUMMARY

We have presented the overall implementation of DAWN optical network demonstrator. We discuss in detail the implementation of the nodes, and shown the feasibility of a WDM agile network based on a reflective optical network. The implementation of the necessary MAC protocol of the network is analysed and is performance is discussed.

VII. REFERENCES

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