Scalability of an All-optical Multiwavelength Slotted-ring Metropolitan Area Network

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In this paper simulation results of the bit error rate (BER) performance of an all-optical multiwavelength slotted-ring metropolitan area network (MAN) are presented. The simulation results provide insight into the signal-to-noise ratio (SNR) degradation as the optical ring is scaled up in terms of the number of access points on it. The results also enable us to understand the effect of inband crosstalk (generated by the adding and dropping of packets at the optically transparent access points) on the bit error rate. A few techniques to improve the BER performance, resulting from inband crosstalk, are proposed.

1. Introduction

Metropolitan Area Networks are expected to support a number of protocols and services. The different attributes of these services pose a challenge for the transport equipment and architecture. Common categories of services include SONET/SDH, ATM, Ethernet, and storage. Next-generation MANs must meet a wide set of requirements, which include scalability (both in terms of nodes and bandwidth); low installation and operational costs; support for next-generation differentiated services; support for legacy voice services; powerful, easy-to-use network management; and robustness. It should be optimised for IP transport, should be packet-switched, has to be backwards compatible with legacy transport, minimize circuit-switched layers and must support QoS.

2. Architecture of the ring network

The Slotted Ring Network: The FLAMINGO (a recently concluded STW funded project) network designed for interconnected city rings, as shown in figure 1, is based on an adaptation of the slotted ring concept to the multi-channel nature of WDM. Access to the slots is via the Access Points (APs) as shown in figure 1. The slotted ring concept of the FLAMINGO network has been treated in substantial detail by us in [1] and [3]. It is worth mentioning that each of the rings in figure 1 is all-optical in nature. However, the interconnections, (intelligent bridges in figure 1) that swap slots between rings make use of buffers, which are in the electrical domain.

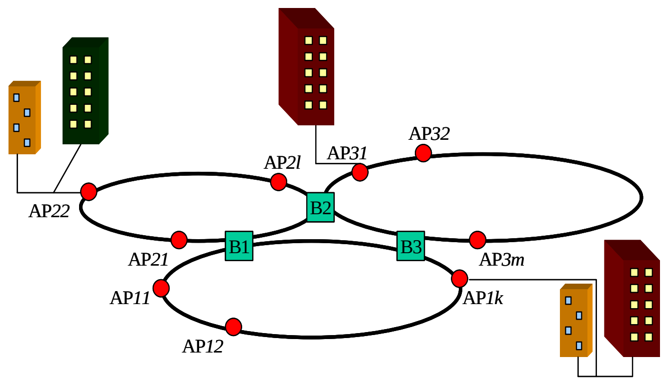

Figure 1: Interconnected City Rings,
AP= Access Point, B= Intelligent Bridge

3. Scalability Issues

The functioning of the Access Point (AP) and the Header Processor Unit (HPU) has been described in some detail in [1], [2] and [3]. In this paper we discuss scalability in terms of the number of APs that a ring (see figure 1) is able to support. From the architecture of the AP it is easy to observe that noise accumulating from the amplifier-filter cascade and the inband crosstalk arising from the 2x1 switches pose one of the primary drawbacks to scaling a ring in terms of the number of APs. The inband crosstalk arising at the 2x1 switches can be minimised by the usage of dilated switches (shown in figure 2). Usage of similar switches has been proposed in [4]. It is important to mention at this point that inband crosstalk does not pose a problem to scalability. For any connection, from a source AP to a destination AP, inband-crosstalk at the 2x1 switches results in a one-time power penalty and is independent on the number of intermediate APs. This is clear from the analysis below, which is based upon a similar analysis in [5].

Assume a crossconnect as shown in figure 3. Let the number of WDM channels be denoted by N. As is the case with the FLAMINGO network architecture, we assume that the space switches route channels of the same wavelength. At the output of demultiplexer, D_1 the wavelength λ_1^1 will be followed by first order crosstalk arising

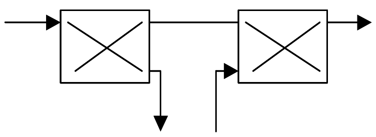

Figure 2: Dilated Switch

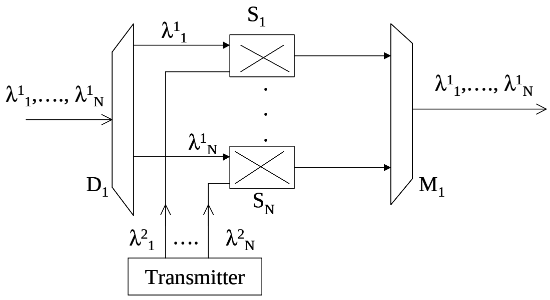

Figure 3: Model for analyzing Inband Crosstalk

from $\lambda_2^1,...,\lambda_N^1$. At the output of the switch S_1, λ_1^1 will be further followed by crosstalk arising from wavelength λ_1^2. Being a newly generated channel, we neglect crosstalk on this channel. At the output of M_1, all the first order contributions from D_1, i.e., $\lambda_2^1,...,\lambda_N^1$ will be suppressed to second order contributions. However, the first order contribution, λ_1^2, remains unsuppressed through the multiplexer. Without loss of generality we can safely assume that the above treatment holds for λ_i, $\forall i$ at the input of D_1 in figure 3.

We now try establishing the total number of first order and second order contributions at the output of the multiplexer, M_1. We have two possibilities; one in which the transmitter corresponding to λ_1 is OFF and the corresponding switch is in BAR state, and the other in which the transmitter corresponding to λ_1 is ON and the switch is in CROSS state. These states are related to the dropping/adding of data packets to slots.

When the transmitter corresponding to λ_1^2 is ON, we have at the exit of the multiplexer, M_1, the main signal, λ_1^2, followed by the following crosstalk terms:

- **First order**: λ_1^1 from the previous (first) upstream node, being suppressed once at the switch;

- **Third order**: $\lambda_2^1,...,\lambda_N^1$, being suppressed once at D_1, once by the switch and once at M_1.
- **Second order and accumulating**: λ_1^1 from the second upstream node, being suppressed twice by the switches at two nodes.

When the transmitter corresponding to λ_1^2 is OFF, we have at the exit of the multiplexer, M_1, the main signal, λ_1^1, followed by the following crosstalk terms:

- **First order and accumulating**: λ_1^1 from the node, which is upstream to the node at which the main signal originated. This is being suppressed once at the switch;

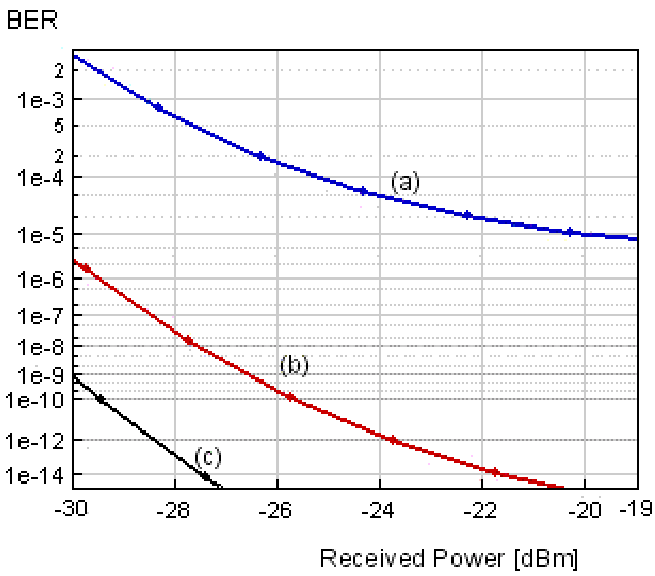

Figure 4: Scalability: (a) 10 APs, (b) 8 APs, (c) 6 APs, on a single ring

- **Second order**: $\lambda_2^1,...,\lambda_N^1$, being suppressed once at D_1, and once at M_1.
- **Second order and accumulating**: λ_1^1 from the second upstream node, being suppressed twice by the switches at two nodes.

Thus it is easy to conclude that including accumulating terms and neglecting third order terms a signal from its source to its destination is accompanied by one first order and one second order inband crosstalk term and $N-1$ second order crosstalk terms.

4. Simulation Results

VPI simulation software was used to analyse a single bi-directional all-optical ring network with 4 channels with a spacing of 100 GHz and centred around 1553 nm. The transmitter module comprised of a 2.5 Gbps directly modulated DFB laser. The receiver module comprised of a PIN photodiode with a preamplifier having a noise figure of 5 dB. The EDFA was modelled to have a small-signal gain of 22 dB with a maximum signal output power (excl. ASE) of 20 dBm. The noise figure was 5.5 dB. All 2x1 switches, including those in dilated switches, had an extinction ratio of 25 dB.

It was assumed that in going from the source to the destination, data could flow either clockwise or counter-clockwise depending upon the shortest path (in terms of the number of the APs). Figure 4 shows the plot of Bit Error Rate (BER) versus Received

Power as we scale the ring from six APs to ten APs. Figure 5 shows the power penalty when using a dilated switch in place of a normal 2x1 switch with 8 APs on a single ring.

5. Conclusion

From the graph of figure 4 it is easy to discern that an increase in the number of transparent nodes gives rise to a BER floor. However, reasonable performance is expected with 8 APs on a single ring.

It is clear from the graph of figure 5 that a reasonable improvement in BER can be achieved by the use of dilated switches. Another possible technique of achieving a similar improvement in BER performance is by the use of a protocol that restricts the reuse of a slot, once free at a particular AP, to 2 downstream APs. However this comes with reduced network throughput and is currently being investigated.

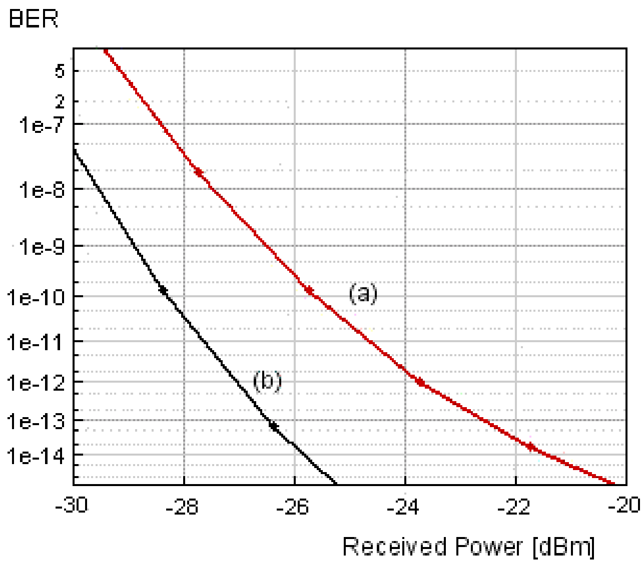

Figure 5: 8 APs on a ring: (a) With normal 2x1 switches, (b) With dilated switches

Acknowledgements

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