Performance analysis of optical network topologies in the presence of hybrid optical amplifier

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In this paper, we investigate the number of nodes supported in optical communication system with minimum optical input power considering different topologies like bus, ring, and hybrid network at 10 Gb/s with 30 Km distance between successive nodes in the presence of hybrid optical amplifier. It is found that in bus topology, maximum numbers of 18 nodes are supported for -20 dBm signal input power. In ring topology, 30 nodes are supported for -30 dBm signal input power but in hybrid topology, at -20 dBm signal input power, the number of nodes supported for bus is 6 but for ring, the maximum number of nodes supported is more than 10.

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1. Introduction

Optical networks are spreading outwards from internet backbones to corporation and even to the home. Optical technologies can meet bandwidth needs with cost-effectiveness. Metropolitan networks impose a bandwidth bottleneck between the local access networks and the backbone [1]. Presently, almost all the trunk lines of existing networks are using optical fiber. Optical multiplexing and switching techniques are used to increase the capacity and speed of the system [2-3]. In ring network inter channel crosstalk can arise from optical add drop multiplexer and from XPM. OADM is used to add and drop any frequency at intermediate nodes without affecting other channels. OADM enhances the capacity of the network as dropped wavelength can be reused [4-5]. In particular optical cross connects (OXC) and optical add drop multiplexer (OADM) provide wavelength routing capabilities so that each channel could be optically routed through all optical network (AON) to its own wavelength path [6]. EDFA alone has been used as booster and inline amplifier to transmit optical signals over thousands of kilometers [7] and Fiber Raman amplifiers (FRA) in long distance transmission line eliminates noise accumulation and improves the noise figure and reduce the nonlinear penalty of fiber systems. But overall performance can be enhanced by cascading two amplifiers, this leads to term Hybrid optical amplifier. Hybrid amplifiers have many advantages over individual amplifiers, like wide gain bandwidth and more flat gain profile; Hybrid amplifier provides high power gain. The gain of EDFA is calculated as [8]

$$G_{EDFA} = G_{max}(L, \lambda_p, \lambda_s) \quad = \exp\left[\mathrm{L}\frac{r_p(\lambda_p) - r(\lambda_s)}{1 + r_p(\lambda_p)}\right]$$

where the dependence of G_{max}, on λ_p (pump wavelength) and λ_s (signal wavelength), appear explicitly in the cross-section ratios $r_p = \sigma_{pa}/\sigma_{pe}$ (pump absorption/pump emission); $r = \sigma_{sa}/\sigma_{se}$(signal absorption/signal emission). The parameter $L=(L_{amp}.\Gamma_s.\sigma_{se}.\lambda_s.N_T)$ varies with signal wavelength, where, Γ_s is the signal to core overlap and the physical length of the amplifier L_{amp} is constant. In a Raman amplifier the power spectrum of the optical signal is affected by Raman pumping (only counter-propagation is considered here), Raman amplified spontaneous emission (ASE) noise and Rayleigh back- scattering. The signal gain of Raman amplifier is given as [9]

$$G_{Raman} = G(z) = \frac{P_s(z)}{P_s(0)} = exp\left(g_R\int_0^z P_p(z)dz - \alpha_s z\right)$$

where P_p and $P_s$is the pump and signal power, respectively. On the other hand, z is the longitudinal position along the fiber and α_s is the Rayleigh scattering coefficient.

The total amplifier gain (G_{Hybrid}) is the sum of the two gains $G_{Hybrid} = G_{EDFA} + G_{Raman}$ [10]. Rajneesh Randhawa et al. [11] Investigated and compared the various network topologies comprising of various nodes and concluded that in ring topology there is no appreciable signal degradation and in bus topology the Quality of signal goes on decreasing with increase in the number of nodes. Surinder Singh [12] investigated the performance of bus, ring, star, and tree network topologies for 10 Gbits/s differential-phase-shift-keying signals in the presence of optimized semiconductor optical amplifiers. By considering the signal quality factor and received power, the maximum number of users supported is calculated for different signal input powers. The number of users supported depends upon the number of semiconductor optical amplifiers and optical couplers in all topologies. Willner et al. [13] reported that a ring network can accommodate 25 nodes using erbium-doped fiber amplifiers (EDFAs) and a novel narrowband channel dropping filter at a bit rate of 2.5 Gbits/s. Emma Lazzeri et al. [14] presented new concept for all optical add and drop multiplexing (OADM) node for hybrid network topology. The node was meant to act as gateway node between optical network segments that exhibit diverse properties in terms of multiplexing systems, granularity and modulation format.

Till now, the work reported for a less number of nodes with EDFA [11] and SOA with less distance between successive nodes using dispersion compensating fiber. [12] There is no work reported for a large number of nodes supported Hybrid optical amplifiers and very less work has been carried out for hybrid network topology. In Section II, the System Set up for bus, ring and hybrid topology in the presence of hybrid optical amplifiers are presented. In Section III, the results are discussed in terms of quality factor and received optical power. Conclusions are made in Section IV.

2. System set up

2.1. Bus network topology

The schematic set up for the bus network topology is shown in Fig. 1. The bus network consists of twenty nodes with one channel added and another channel dropped. Each user is connected to bus through the optical add drop multiplexer. Every node is connected to each other by SMF of 30 km length. The placement of one hybrid optical amplifier is done in the start of each segment in order to continue broadcasting the information from transmitter users. In bus network topology, hybrid optical amplifiers are used after required number of nodes. The first hybrid optical amplifier is used after first node and further placement of hybrid optical amplifiers is done after four nodes. The hybrid optical amplifier module consists of combination of Raman and EDFA amplifier. The Raman amplifier is operating at a temperature of 300K with single pumping and consists of counter-propagating Raman pump unit with pump power 20 dB, pump frequency 206.35 THz, pump wavelength 1451.77nm and pump attenuation of 1.2 dB/Km. The EDFA has flat Gain shape and noise figure with a fixed Gain of 25 dB. Further, the node is composed of transmitter (TX1), receiver (RX1) and an Optical add drop Multiplexer (OADM). The optical add drop Multiplexer add new channels at different wavelengths and also drop the previous channel. Here, it has been considered that the dropped channel is the channel added at the previous node. Each transmitter section consists of a data source, a laser source, an electrical driver, and an optical modulator. The data source is in non-return-to-zero (NRZ) format at 10 Gbits/s. The electrical driver converts the binary sequence into the electrical signal.

The simulation is performed with a simulation bandwidth of 2.3 THz and a center frequency of 193.35THz.The analysis of results is made by means of measurement blocks i.e. electrical scope and optical power meter attached to each node.

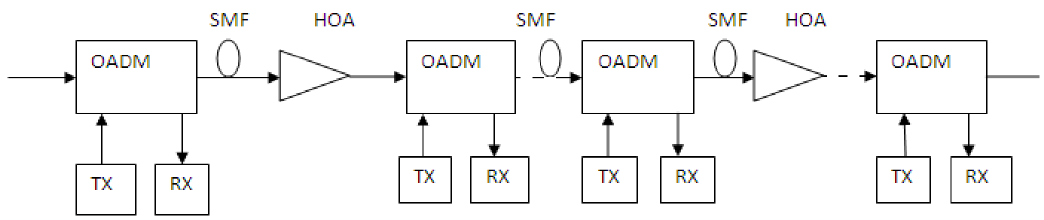

Fig. 1. Schematic setup for the bus network topology using Hybrid optical amplifiers

2.2. Ring network topology

The ring network consisting of forty nodes with one channel added and another channel dropped. As shown in Fig. 2, the fiber of length 30km and hybrid optical amplifier follow the node. The hybrid optical amplifier module is same as it describes in the bus topology. The placement of first hybrid optical amplifier is done after first node and further placement of hybrid optical amplifiers is done after four nodes and so on. The analysis of results is made at the nodes by means of measurement blocks i.e. electrical scope and optical power meter.

Further, the node is composed of transmitter (TX1),receiver(RX1)and an Optical add drop Multiplexer (OADM).At the forty nodes the used frequencies are f1,f2,f3,f4,f5,f6,f7,f8, f9, f10,f11,----f40.We have assumed that all these frequencies are used in circular fashion in the ring i.e. at the node1the frequency f1 is added and frequency f40 is dropped. At the node 2 the frequency f2 is added and frequency f1 is dropped and soon. The simulation of the ring optical network is done with the center frequency of 193.4THz and the reference bit rate of 10GB/s.

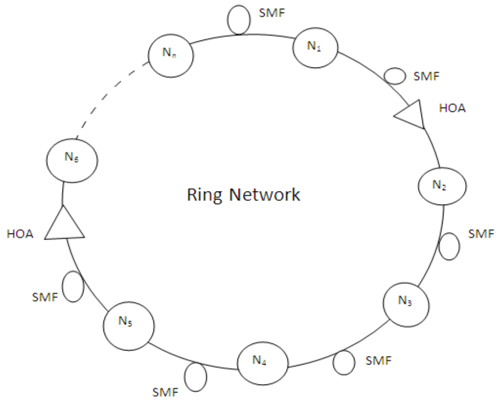

Fig. 2. Schematic setup for the ring network topology using Hybrid optical amplifiers

2.3. Hybrid network topology

The hybrid network topology consisting of two bus topologies i.e. upper bus and lower bus and two ring topologies i.e. upper ring and lower ring. These two topologies are connected with the hub (2x2 optical switch). Each bus and ring topology consists of ten nodes. Therefore, hybrid network topology incorporates twenty nodes. As shown in Fig. 3, the fiber of length 30 km and hybrid optical amplifier follow the node. The placement of first hybrid optical amplifier is done after first node and further placement of hybrid optical amplifiers is done after four nodes and so on in each topology. Hybrid amplifiers have many advantages over individual amplifiers, like wide gain bandwidth and more flat gain profile; Hybrid amplifier provides high power gain.

The analysis of results is made at the nodes by means of measurement blocks i.e. electrical scope and optical power meter. In hybrid network topology, the node is composed of transmitter (TX1), receiver (RX1) and an Optical add drop Multiplexer (OADM). Adding and dropping of different wavelengths are done in the same fashion as in bus and ring topologies. The simulation of the hybrid optical network is done with the center frequency of 193.35 THz and the reference bit rate of 10GB/s.

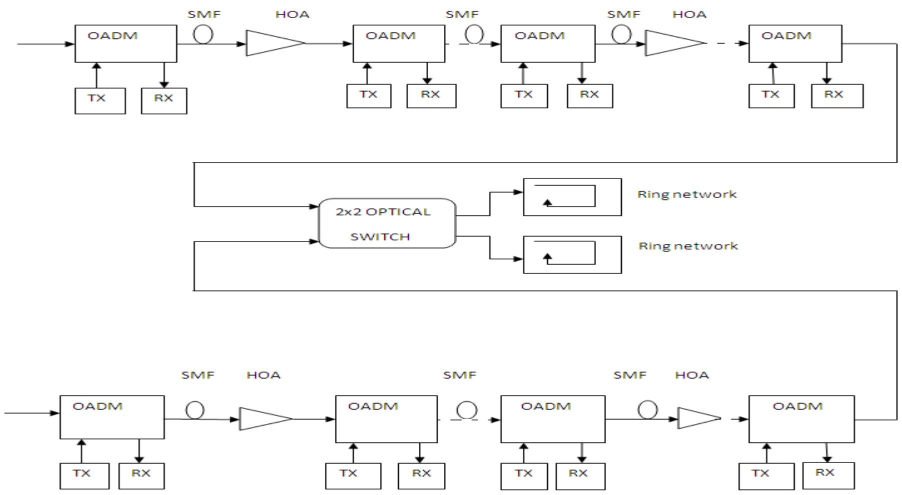

Fig. 3. Schematic setup for the Hybrid network topology using Hybrid optical amplifiers

3. Results and discussion

For the bus network topology with twenty nodes, the simulation is performed for different signal input powers by using five hybrid optical amplifiers only. As shown in Fig. 4, the quality of the signal decreases with a decrease in the signal input power and for our simulation setup at −30 dBm signal input power, no nodes are supported. This is due to the increase in ASE noise power, which reduces the quality of the received signal. At 0 & −10 dBm signal input power, the effect of ASE noise power is less. Therefore the maximum number of nodes supported is more than 20. But at -20 dBm signal input power, the number of nodes supported is 18. This is due to again increase in the ASE noise power. Also as shown in Fig. 5.At low values of the signal input power −30 dBm, the effect of ASE noise power is quite high. Therefore, the quality of signal broadcast in bus network topology continues to decrease. At high values of signal input power 0 dBm, significant gain fluctuation occurs. Therefore the gain of the hybrid optical amplifier drops, hence causing power penalty. It is also observed from Fig. 5 is that the power received continues to decrease from transmitting users to different receivers. This is due to the non uniform distribution of power among the nodes in the bus topology network, which shows good agreement with results in [12].

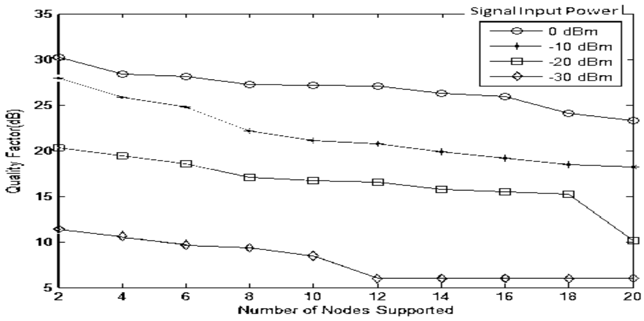

Fig. 4. Quality factor as a function of signal input power for a given number of nodes supported for the bus network input power for a given number of nodes supported for topology in the presence of HOA

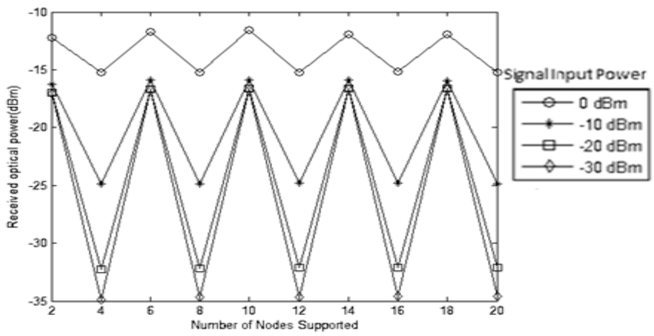

Fig. 5. Received optical power as a function of signal input power for a given number of nodes supported for Bus network topology in the presence of HOA

For the ring network topology with forty nodes, the two span simulation is performed for different signal input powers by using ten hybrid optical amplifiers only. The results for quality of signal as a function of number of nodes supported for different signal input powers and received optical powers are observed as shown in Figs. 6 and 7. It is observed that sufficient optical received power is available at the output for all nodes for different signal input powers as shown in Fig. 7. It is observed that the quality at −30 dBm input power drops for a low number of nodes i.e. 30 nodes as shown Fig. 6. This is due to an outside noise effect, which is greater for low numbers of users. For all input signal power, there is sufficient quality observed for all nodes. To observe the real performance of a ring network topology, the simulation was carried out for two spans. For a large number of nodes, sufficient quality and power is observed as shown in Fig. 6 and 7 in the simulation of two spans. The maximum number of nodes supported is 30 at -30 dBm signal input power. This result shows an improvement over the results reported in [12].

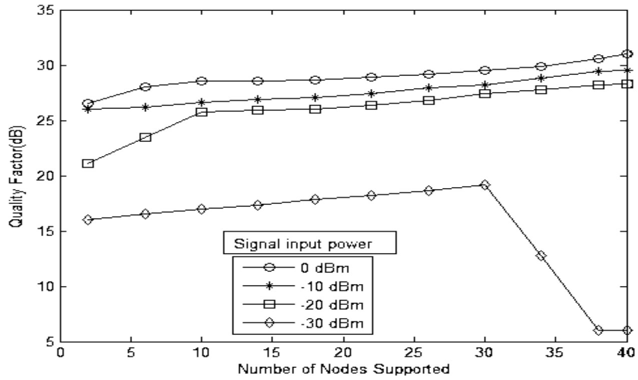

Fig. 6. Quality factor as a function of signal input power for a given number of nodes supported for ring network topology in the presence of HOA

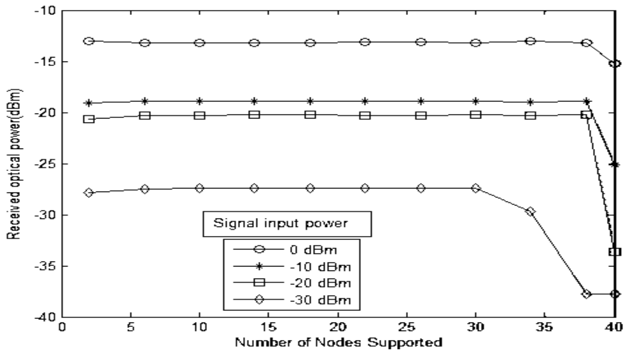

Fig. 7.Received optical power as a function of signal input power for a given number of nodes supported for ring network topology in the presence of HOA

For the hybrid network topology incorporates two bus topologies i.e. upper bus and lower bus and two ring topologies i.e. upper ring and lower ring. These two topologies are connected with the hub (2x2 optical switch). The simulation of hybrid network topology is performed for twenty nodes by using six hybrid optical amplifiers. As shown in Fig. 8, the quality of the signal decreases with a decrease in the signal input power and at −30 dBm signal input power, no nodes are supported in the upper bus and ring. This is due to the increase in ASE noise power, which reduces the quality of the received signal. At 0 & −10 dBm signal input power, the effect of ASE noise power is less. Therefore the maximum number of nodes supported is more than 10 for upper bus and ring. But at -20 dBm signal input power, the number of nodes supported for upper bus is 6 but for upper ring, the maximum number of nodes supported is more than 10.

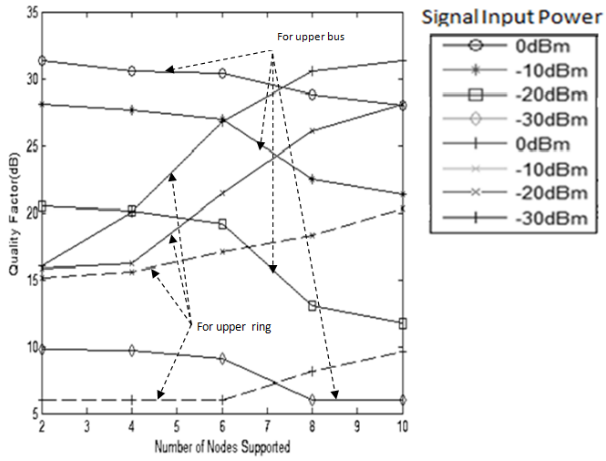

Fig. 8. Quality factor as a function of signal input power for a given number of nodes supported for hybrid Network topology in the presence of HOA

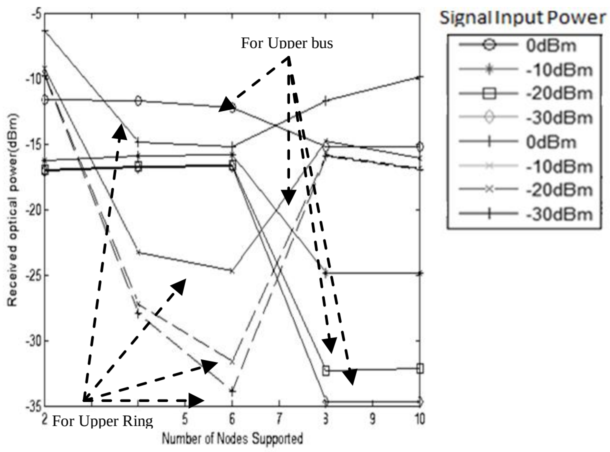

Fig. 9. Received optical power as a function of signal input power for a given number of nodes supported for hybrid network topology in the presence of HOA

Also as shown in Fig. 9. For the upper bus, at low values of the signal input power −30 dBm, the effect of ASE noise power is quite high. Therefore, the quality of signal broadcast in bus network topology continues to decrease. At high values of signal input power 0 dBm, significant gain fluctuation occurs. Therefore the gain of the hybrid optical amplifier drops, hence causing power penalty. It is also observed from Fig. 9 is that the power received decreases with the decrease in input signal power. The received optical power decreases from transmitting node to receiver node. This is due to the non uniform distribution of power among the nodes in the upper bus. For the upper ring, it is observed that sufficient received power is available at the output for all nodes for different signal powers.

4. Conclusion

The paper concludes that for the simulation of twenty nodes of bus topology, no node is supported at -30 dBm signal input power but at low input power of -20 dBm, the numbers of nodes supported are 18 and at signal power above -20 dBm, the numbers of nodes supported are more than 20. In ring topology, 30 nodes are supported at low input power of -30 dBm and at other signal power above -30 dBm, the numbers of nodes supported are more than 40 for the simulation of forty nodes and for twenty nodes hybrid topology, the quality of the signal decreases with a decrease in the signal input power and at −30 dBm signal input power, no nodes are supported in the upper bus and ring. But at -20 dBm signal input power, the number of nodes supported for upper bus is 6 but for upper ring, the maximum number of nodes supported is more than 10. In all these topologies, the received power decreases with the decrease in signal power.

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