Scalability of GMPLS Node Using Optical Frequency Shifters Based on SNR Analysis

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Abstract: *We propose an effective wavelength converter* method using frequency shifter for photonic node, and examine the scalability of Generalized Multiprotocol Label Switching (GMPLS) networks. The analysis is examined based on signal to noise ratio (SNR) for present 2.4 and 10 Gbit/s Synchronous Digital Hierarchy (SDH) networks, and next generation 2.7 and 10.8 Gbit/s Optical Transport Networks (OTN) format. The proposed 100 channels GMPLS networks using optical frequency shifters are shown to be applicable to transmission network spanning over 1206 km (24 nodes) in 2.7 Gbit/s trunk networks. Transmission over more than 310 km (6 nodes) is also possible in 2.7 Gbit/s Metroporitan Area Networks (MAN).

1. Introduction

Recently, Wavelength Division Multiplexing (WDM) [1][2] has been seen as a candidate technology for realizing future broadband and high speed networks to support the increasing bandwidth demands for enlarging transmission capacity up to Tbit/s. There is a problem of the throughput of delay by optic-electronic-optic (OEO) conversion and the limit of electricity which must be solved in the present Internet. All-optical network is expected as a means to solve these problems. In all-optical networks there is no electronic signal regeneration or optical/electric conversion for an end-to-end optical lightpath in IP over SDH/SONET/WDM networks. Since there is no optical/electric conversion in each intermediate node in the network, *the total transmission time will be reduced.*

Generalized Multiprotocol Label Switching (GMPLS) technology [3] is considered as *a cost-effective method for* realizing robust IP over photonic networks. The *wavelength converter will be one of the key devices in such* optical networks [4]. Many research activities have been reported such as O/E/O converters, semiconductor optical amplifier (SOA)-based converters, and four wave mixing (FWM) etc. [5][6].

We have proposed a simple method for wavelength converters using AO (acoust-optic)-type frequency shifters [7]. AO type frequency shifter operates at present in the range of several hundreds MHz frequency shifts. It is assumed to be expended to several GHz in the future. Path length and available optical wavelength channels depend on the loss of the wavelength converters in each intermediate nodes. In this paper, the scalability of the GMPLS node is discussed based on the SNR analysis.

After describing GMPLS or MPλS nodes and the design of wavelength converters, attainable transmission length is evaluated considering optical SNR. In conclusion, we *identify the advantages of the proposed method in medium* scale networks.

2. Network Topology

Modeled network topology is shown in Figure 1. They are trunk networks on bus type topology and Metropolitan Area Networks on ring type topology. In the trunk networks, many optical amplifiers are used as intermediate repeaters at 1550 nm wavelength. On the other hand, nodes are directly connected in the MAN. Assumed repeater spacing L_R is 50, 60 or 80 km, and the link length L_{link} is 300 or 320 km in the trunk network while L_R = L_{link} in the MAN. Optical amplifiers are installed to compensate for the signal loss caused by the optical fibers and by the optical frequency shifters in the GMPLS nodes.

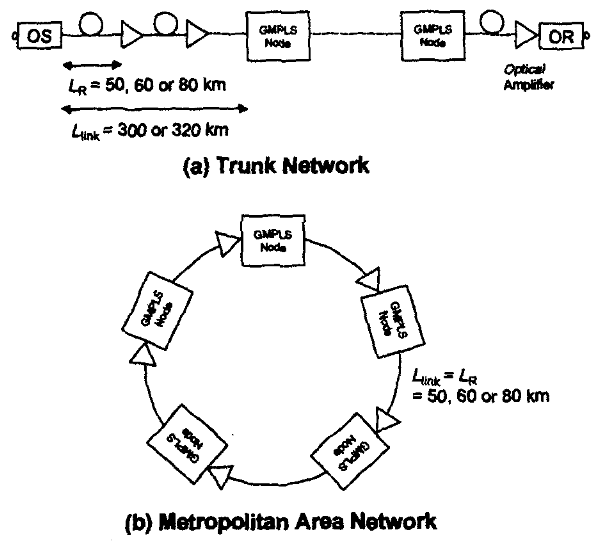
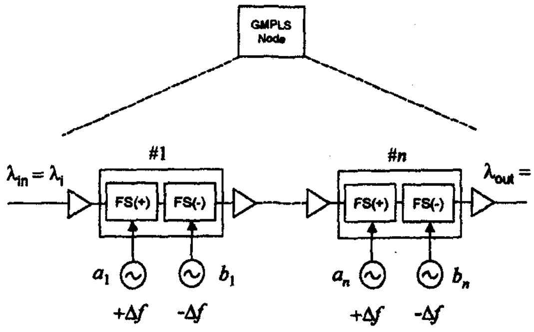


Figure 1. *Network topology for trunk network and* Metropolitan Area Network. P_0 = 0 dBm, f_0 = 2.4/2.7 or 10/10.8 Gbit/s, wavelength = 1550 nm, fiber loss = 0.3 dB/km, frequency shifter loss = 10 or 15 dB.

3. Design of Wavelength Converter

In a GMPLS node, wavelength conversion is performed using optical frequency shifters as shown in Figure 2. Two-elements unit includes a positive (increasing) frequency shifter element and a negative (decreasing) one. We



$$f_j = f_i + \sum_{k=1}^{n}(a_k \Delta f - b_k \Delta f)$$

where a_k, b_k = 0 or 1

$f\lambda = c$ (light speed)

Figure 2. Optical frequency shifters in GMPLS node.

assume two conditions of the optical frequency shifter loss value. Assumed loss of the one unit is 15 dB. Pre-amplifier of 6 dB gain and post-amplifier of 9 dB gain are used to compensate for the loss. Aassumed loss of the other unit is 10 dB, and the gains of the pre-amplifier and the post-amplifier are 4 dB and 6 dB, respectively.

Flexible wavelength conversion up to n+1 optical channels are possible by using n stages cascaded wavelength converters units. The merit of this configuration is easy to change wavelengths each other, without affecting the signal format itself.

4. Optical SNR Analysis

In order to investigate the scalability of the network, signal quality or SNR should be calculated considering optical amplification noise. Here, the design target is optical SNR of 21.6 dB, which is corresponding to the bit error rate (BER) of 10^{-9}.

Optical SNR of a single-stage optical amplifier output is approximated by the following formulas.

$$\left(\frac{S}{N}\right) = \frac{P_{sig}}{4S_{ASE}B} \quad (1).$$

Where P_{sig} is the optical signal power in optical amplifier, the power spectral density of ASE noise is $S_{ASE} = hfn_{sp}(G-1)$, where h is Planck constant, f is optical frequency, amplified spontaneous emission $n_{sp} = 0.5\times10^{(F/10)}$, G is optical amplifier gain, and optical amplifier's nose figure F = 7 dB. Optical receiver bandwidth B is set to 2.4/2.7 or 10/10.8 GHz, which coincides the bit rates.

For multi-stage connections, the optical SNR is approximated by the following equations.

$$\left(\frac{S}{N}\right)_1 = \left(\frac{N}{S}\right)_a^{-1}$$: SNR of optical amplifier. (2).

$$\left(\frac{S}{N}\right)_n = \left\{\left(\frac{N}{S}\right)_{n-1} + \left(\frac{N}{S}\right)_a\right\}^{-1}$$: SNR after n node relay or repeater. (3).

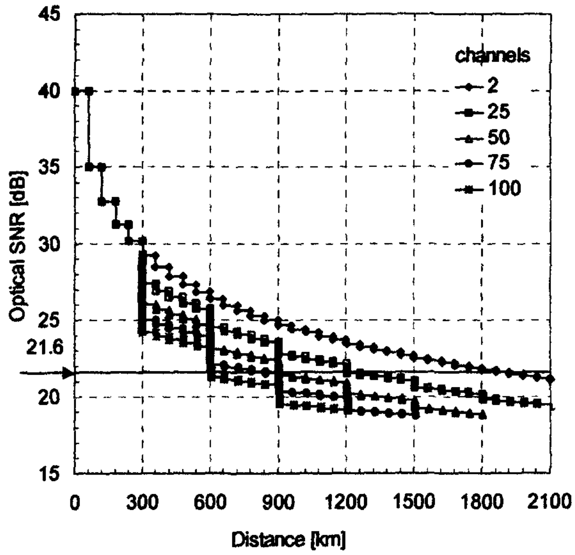


Figure 3. Attainable path length dependence on 2.7 Gbit/s optical wavelength channels in trunk networks. Repeater spacing is 60 km, optical frequency shifter loss is 15 dB.

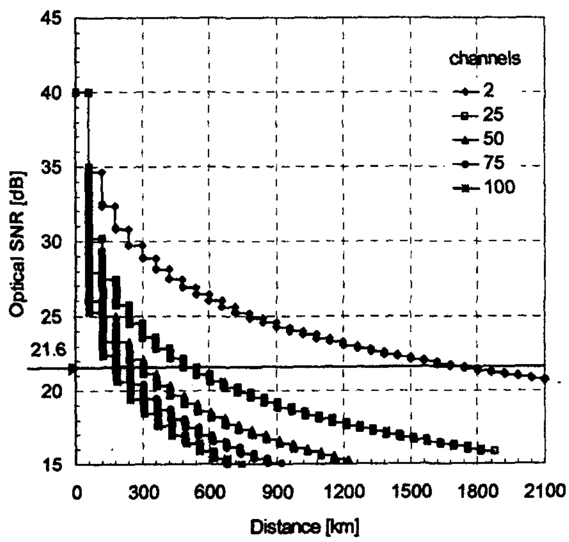


Figure 4. Attainable path length dependence for 2.7 Gbit/s optical wavelength channels in MAN. Repeater spacing is 60 km, optical frequency shifter loss is 15 dB.

Transition of 2.7 Gbit/s optical SNR along the distance of trunk network or MAN is shown in Figures 3 or 4, respectively. In these figures, repeater spacing L_R is 60 km, signal loss of the optical frequency shifter 15 dB, optical receiver's bit rate 2.7 Gbit/s. In the trunk networks, attainable path length L_{path} of 602 km (11 nodes) is feasible with 100 optical wavelength channels. That length of 184 km (3 nodes) with 100 optical wavelength channels is feasible in a Metropolitan Area Networks

Figures 5 and 6 show the attainable path length dependence on optical wavelength channels in trunk network and MAN, respectively. Figures 7 and 8 show the summary of the maximum transmission distance dependence on the bit-rates. The bit-rate is SDH 2.4 or 10 Gbit/s and OTN 2.7 or 10.8 Gbit/s. In these figures, repeater spacing L_R is 50, 60 or 80 km, loss of optical frequency shifters is 15 or 10 dB. Long distance transmission of 904 km (15 nodes) in trunk network and 308 km (5 nodes) in MAN are achieved at 2.7 Gbit/s when repeater spacing L_R 60 km, and loss of frequency shifters 10 dB.

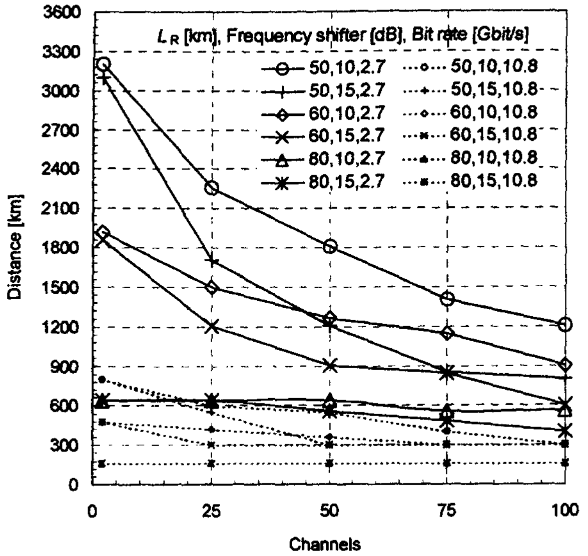


Figure 5. Attainable path length dependence for optical wavelength channels in trunk networks. Repeater spacing is 50, 60 or 80 km, optical frequency shifter loss is 10 or 15 dB, and bit rate is 2.7 or 10.8 Gbit/s.

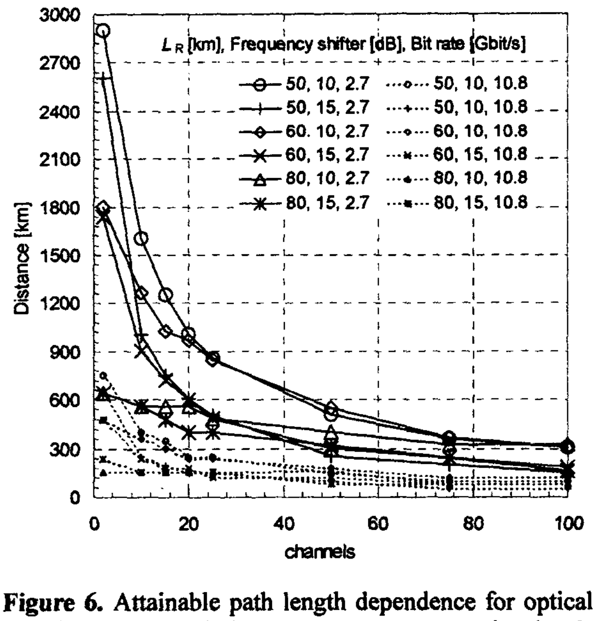


Figure 6. Attainable path length dependence for optical wavelength channels in MAN. Repeater spacing is 50, 60 or 80 km, optical frequency shifter loss is 10 or 15 dB, and bit rate is 2.7 or 10.8 Gbit/s.

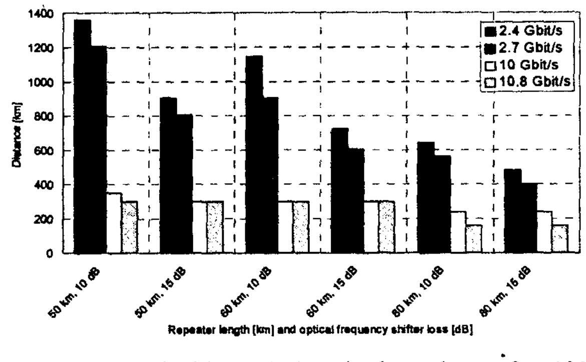


Figure 7. Attainable path length dependence for 100 channels in SDH 2.4 or 10 Gbit/s and OTN 2.7 or 10.8 Gbit/s trunk networks.

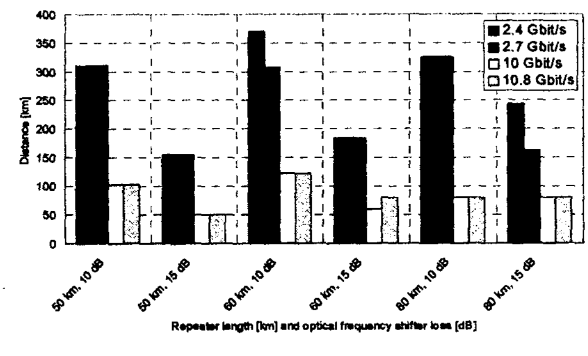


Figure 8. Attainable path length dependence for 100 channels in SDH 2.4 or 10 Gbit/s and OTN 2.7 or 10.8 Gbit/s MAN.

5. Conclusion

We have proposed an effective wavelengtgh converter method using optical frequency shifter for the burst mode GMPLS nodes. The method could be applicable in the trunk networks and the Metropolitan Area Networks. Scalability of these networks is evaluated considering accumulated optical amplifiers noise.

It turned out 100 optical wavelength channels are realized at 904 km (15 nodes) path length in trunk networks and 308 km (6 nodes) in MANs, when bit rate is 2.7 Gbit/s, repeater spacing 60 km, frequency shifter loss 10 dB. It is also clarified that scalability of 10.8 Gbit/s networks is small.

The proposed wavelength converter methods using optical frequency shifters are very effective as they have simple configurations, and it will be promising in the future when wideband and low loss optical frequency shifter becomes available.

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