INCREASING THE CAPACITY OF FIBER-OPTICAL TRANSMISSION SYSTEMS DUE TO DECREASING DISTANCES BETWEEN BEARING

Augustin Vyukusenge,
University of Bujumbura, Bujumbura, Burundi,
vyukusengeaugustin@yahoo.fr

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ABSTRACT

The load on transport networks based on fiber-optic transmission systems is increasing at an accelerating rate. This paper discusses the possibility and limitations of increasing the throughput of fiber-optic transmission systems by reducing the distance between carriers. A comparison is made between fixed and flexible grids in terms of the spectral bandwidth efficiency. It is concluded that the use of flexible mesh technology is promising when switching to channel speeds above 100 Gbit / s.

KEYWORDS: *Bandwidth, fixed mesh, flexible mesh, number of channels, spectral efficiency, fiber optic transmission system.*

INTRODUCTION

The current period of development of the information and communication technologies (ICT) sector is characterized by the widespread introduction of a variety of multimedia services, the rapid development of Internet networks, the emergence of data processing centers, the massive introduction of mobile applications requiring high bandwidth and advanced technologies for high-speed packet transmission. The implementation of these trends necessitates a sharp increase in the throughput of fiber-optic transmission systems (FOTS). Obviously, under these conditions, a transmission medium is of particular interest, which has a high potential throughput and allows the volume of transmitted information to be multiplied. Thus, fiber-optic cables act as the main transmission medium of the transport network, on the basis of which a layer of transparent optical channels is formed using the technology of spectral multiplexing (DWDM). The data transfer rate achieved by fiber-optic systems over the past 30 years has increased by more than four orders of magnitude [1]. Traffic forecasting in the construction of optical communication networks is a difficult task, which requires the development of methods to increase the bandwidth of FOTS without significant costs for the modernization of expensive line-cable facilities. In this regard, in order to expand the physical network, it is advisable to make more significant efforts to improve the efficiency of fiber-optic information transmission systems. One of the ways to effectively use the capabilities of optical fiber is to increase the number of channels in a frequency band by reducing the distance between channels, the path along which the developers of the G.692 standard [7] went.

Applying a fixed grid

The number of channels, channel spacing, width of each channel and channel bandwidth are important parameters in design and construction of a high-speed communication network.

In traditional DWDM systems, the optical spectrum in C-band, consisting of approximately 4.1 THz, is divided into hard spectral intervals of 50 GHz as defined in ITU-T Rec. G.694.1. This forms a “grid of wavelengths, where the center frequencies of adjacent channels have fixed spectral intervals of 50 GHz. The frequency grid defined in this recommendation supports a variety of fixed channel spacings from 12.5 GHz to 100 GHz or more (integer multiples of 100 GHz), as well as flexible grid [2].

When using DWDM technology, one can try to estimate the limiting value of equivalent FOTS bandwidth, a parameter defined as the product of transmission rate in optical channel B_{ch} for the number of channels N.

$$B_{max} = B_{ch} \times N ,$$

Using the standardized range (192.10 - 196.10 THz), the total frequency width is 4.1 THz. If the channel spacing is 50 GHz, a maximum of 81 channels can be accommodated. If the channel spacing is reduced to 25 GHz, this range can accommodate 163 channels, and thus double the bandwidth of the FOTS.

Although systems with reduced channel spacing will be able to provide significant FOTS bandwidth, this decrease places more stringent demands on the devices used in the system, which reduces the number of potential equipment manufacturers and also increases its cost. From the transmitter's point of view, wavelength stability becomes very important, since even a small drift can cause serious inter-channel interference [3]. With small values of inter-channel gaps, the influence of the effect of four-wave mixing and cross-phase modulation increases, which begins to limit the maximum range of non-regenerative information transmission due to a decrease in the signal-to-noise ratio. A small inter-channel distance can also limit the ability to transmit information at a high channel rate, since there is an overlap in the spectra of adjacent channels (Fig. 1).

Interchannel interference together with intersymbol interference presents itself as serious influencing factors that degrade the quality of signal reception. They generate two-dimensional (2D) interference that must be efficiently processed by digital signal processing at the receiver [4].

In the absence of interchannel distortion, intersymbol distortion can be compensated for by an adaptive equalizer and an FEC decoder. Some form of joint processing of spectrally overlapping asynchronous WDM channels is required to address the combined effects of this interference [4].

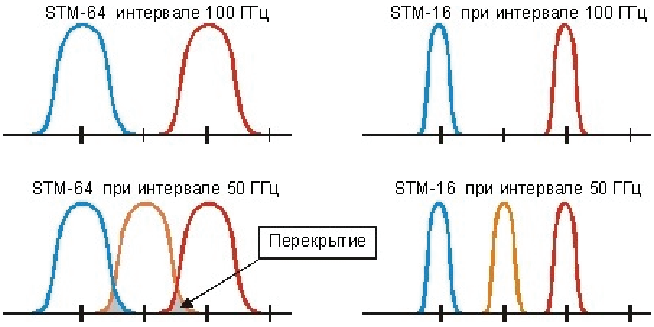

Figure 1. Multiplexing of STM-64 and STM-16 channels at intervals of 100 GHz and 50 GHz

The use of advanced modulation formats and photonic techniques allows signals to be transmitted at a channel rate of 100 Gbit / s in WDM with a fixed grid of 50 GHz. However, for higher traffic rates such as 400 Gbps and 1 Tbps, the required bandwidth using standard modulation formats becomes too wide to fit in a 50 GHz grid. To prevent channel-to-channel crosstalk, one option may be to increase the fixed mesh width from 50 GHz to 100 GHz. The disadvantage of using a wider grid is not only that fewer wavelengths will be transmitted, but also that channels with low speed channels will use a grid up to 100 GHz each, which leads to a decrease in the efficiency of spectrum resource use. Another attempt would be to use higher spectral efficiency (SE) modulation formats such as QPSK and QAM. This option leads to a reduction in the transmission range due to the increased requirements of the optical signal-to-noise ratio (OSNR).

Flexible mesh application

To overcome the aforementioned disadvantages in transition to a transmission rate of more than 100 Gbit / s, Flex Grid technology was proposed, defined in ITU-T G.694.1 recommendation based on 12.5 GHz channel spectral separation (Fig. 2). Thanks to this technique, it becomes possible to flexibly shape the spectrum of any channel, including a superchannel in a certain range of optical frequencies and to scale capacity of the optical network [5].

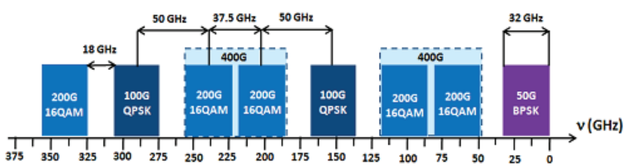

Figure 2. ITU-T G.694.1 flexible frequency grid based on 12.5 GHz grid

The possibility of using Flex Grid technology in commercial systems appeared only after the creation and start of mass production of tunable wavelength selective switches (WSS) using LCoS (liquid crystal on silicon) technology [6].

In [5], a theoretical analysis was carried out comparing flexible mesh and standard mesh, taking into account optical channels between 10 Gbps and 400 Gbps. The characteristics of signals of each type of grid (modulation format, spectrum efficiency in bits / symbol and guard band) are given in Table. 1 derived from data from several transmission studies.

Table 1

Comparison of the use of spectral for different modulation formats

		Fixed Grid 50 GHz		Flexible mesh		
Transmission speed, Gbps	Modulation format	Number of wavelengths	Spectrum, GHz	Number of slot	Spectrum, GHz	Capacity gain
10	NRZ-OOK SE= 1bit / s/Hz	1	50	2	25	100%
40	DP-QPSK SE= 4bit / s/Hz	1	50	2	25	100%
100	DP-QPSK SE= 4bit / s/Hz	1	50	3	37.5	33.3%
400	OFDM-DP-QPSK SE= 4bit / s/Hz	4	200	10	125	60%

As you can see from the table, a 10 Gbps channel using the NRZ-OOK modulation format requires a 25 GHz slot (2 slots) in a flexible mesh, while 50 GHz is used in a fixed mesh case. The remaining channel types (40, 100 and 400 Gbps) use DP-QPSK as the modulation format, reaching a spectral efficiency of 4 bits / symbol. The spectral bandwidth shown in table. 1, takes into account a 7 GHz guard band between optical channels. It also takes into account the effect of forward error correction by increasing the data rate by 12%. In the case of a fixed mesh, the 400 Gbps link requirements are served by four 100 Gbps links, so 4 carriers are used (total 200 GHz in the case of a 50 GHz grid). The values in the last column indicate that using the DP-QPSK modulation format, total FOTS bandwidth can theoretically be increased by 33.3% using 100 Gbps links or 60% using 400 Gbps links.

The overall increase in FOTS throughput using Flex Grid technology, coupled with the ability to transfer speeds in excess of 100 Gbps over long distances, are consecutive reasons for the development of flexible grid technology. However, from the perspective of network operator, it is important to know when this increase in FOTS capacity will represent a viable solution for their networks and how this can be implemented. Depending on the existing fixed grid infrastructure, some solutions may not be supported due to the required spectrum bandwidth. For example, transmissions above 100 Gbps using the DP-QPSK or OFDM-DP-QPSK modulation formats are not possible within the fixed 50 GHz grid. Although there are modulation formats with higher spectral efficiency, such as DP-16-QAM, which can fit into a fixed 50 GHz grid, such formats cause a drop in the maximum transmission range.

Conclusion

As the ICT industry develops, so does the need to increase bandwidth and maintain bandwidth flexibility. Reducing the distance between channels is one of the ways to increase FOTS bandwidth. However, the effect of co-channel interference (the effect of four-wave mixing and cross-phase modulation), leading to a decrease in the signal-to-noise ratio, must be taken into account. Comparison of flexible mesh and fixed network for different bit rates and modulation formats showed the advantage of flexible mesh in bandwidth efficiency. The use of Flex Grid technology, which allows spectrum management, offers the prospect of increasing FOTS operation efficiency at channel speeds above 100 Gbit/s.

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