COMBINED (SYMBOL AND CLASSICAL) DWDM DATA TRANSMISSION

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Abstract: Symbol DWDM transmission: every wavelength is symbol, carrying Log_2N bits, where N – number of wavelengths; one wavelength in fiber every moment. Combined transmission: several wavelengths (symbols) in fiber every moment. Application: ultra long haul.

1. INTRODUCTION

The essence of symbol technology is that standard DWDM equipment (for example, with 16 carriers λ_1-λ_{16}) is used not for simultaneous modulation of all carriers but in serial operating mode. That means the original data is divided into 4-bit clusters (i. e. 100010100010 = 1000 1010 0010), and every carrier is assigned to a single cluster (from 0000 to 1111). Each 4-bit cluster is transmitted in one time-slot, the first part of that time-slot is taken by corresponding carrier λ_i (pilot) and the second part is taken by carrier λ_{i+1} (co-pilot). The co-pilot for λ_{16} is λ_1. This is first FEC1. Under such modulation scheme (1 - turned on, 0 - turned off) the transmission rate of the pair "pilot - co-pilot" - i. e. 4-bit cluster - is equal to clock rate. Every five information clusters are accompanied by redundant sixth cluster with bit-by-bit control sum of theirs. This is second FEC2. So to transmit 10 Gbit/sec stream ir requires to transmit 10/4*(6/5) = 3 Gsymbols/sec. This case is shown on fig.1.

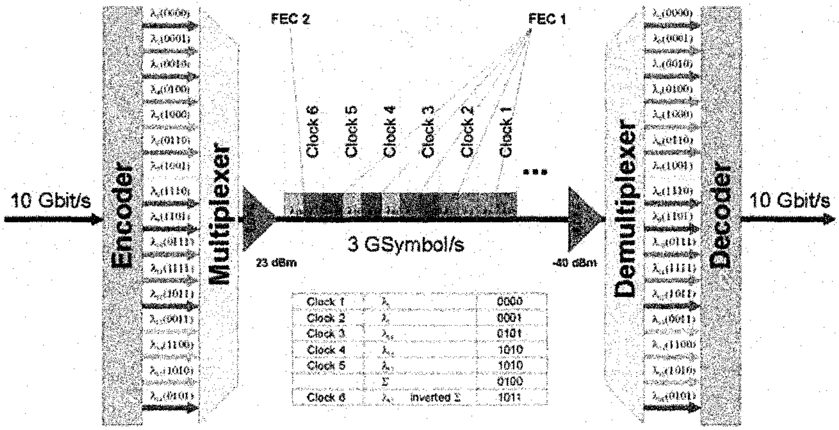

Fig. 1. Symbol DWDM data transmission.

An evolution of the symbol DWDM transmission idea gives rise to a combined DWDM transmission concept. Since modern production DWDM equipment supports up to 80 channels in a single fiber in 1530-1565 nm range, let us divide this range into 5 "tubes" with 16 carriers in every tube, fig. 2. Using the symbol transmission technology in every tube and applying 3 Gsymbol/sec lasers, it's possible to organize 10 Gbit/sec transmission in every tube or 50 Gbit/sec transmission over single fiber.

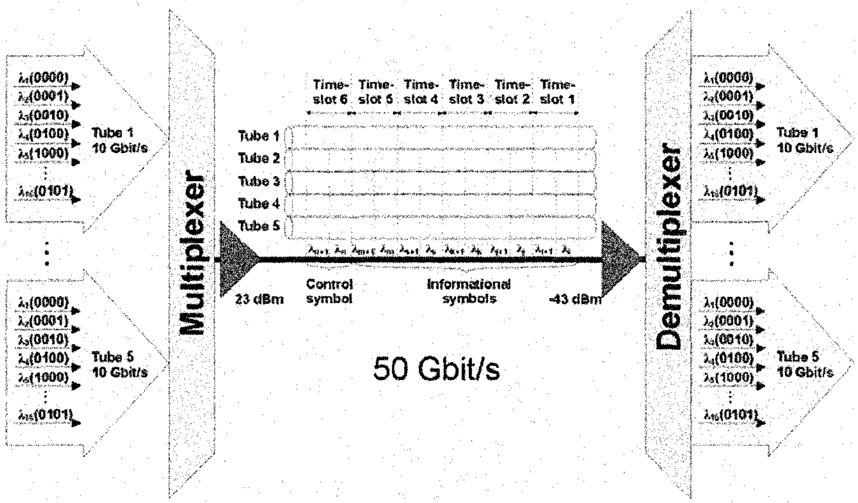

Fig. 2. Combined DWDM data transmission.

2. BODY

Symbol transmission has a high noise immunity because of code redundancy (140% in our example). Indeed, let the probability of receiving "1" instead of "0" and vice versa on photodetector is P(0/1) = P(1/0) ~ 10^{-3}. Let us consider "superframe" as table consisting of 16 positions vertically , as λ1- λ16, and horisontally of 6, that is 5 time-slots as payload data and 6^{th} time-slot as FEC2. Table 1 represents transmitted data λ1, λ2, λ16, λ15, λ15 payload data and λ12 control sum. "1"s and "0"s are green and true. Table 2 represents operation of decoder with mistakes due to optical and electrical noise at receivers. "Unfortunately" (probability is 1/16) control sum of λ1 + λ2 (true) coincides with λ7 + λ5 (false), correct data has probability ½. The exact calculation of all possible combinations with simultaneous 4 false events (see www.tt.ru/eng) has shown next results:

FEC input	10^{-3}	10^{-4}	10^{-5}
FEC output	10^{-9}	10^{-13}	10^{-17}

But additional employment of in-band triple-error-correcting Bose-Chaundhuri-Hocquenghem BCH-3 code (with was documented in an October 2000 revision to the ITU-T G.707 standard) can improve FEC1,2 significantly since the location of mistakes has been already known.

One of significant problems in symbol transmission is the chromatic dispersion compensation. Indeed, the dispersion factor in SMF is 17 ps/nm*km. Signals at neighbouring wavelengths in third spectral window (1530-1565 nm) with the interval between carriers 50 GHz are distanced at about 0,4 nm. After 1000 km they will come at receiver with time shift 8,5 ns. The time shift between λ_1 and λ_{16} will be 16 times more - about 136 ns. If the symbol length on one carrier is 0,17 ns then it will be necessary to process time-slots at receiver with a shift of 50-800 symbols (at 1000 km distance already). But this is hardly realizable even at 200 km distance. Nethertheless the solution of this problem has been found. Since ultra-long-haul fiber links (which the symbol technology is mainly designed for) operate in SDH mode, the SDH data format can be used for receiver synchronization at different wavelengths. In fact, in SDH systems data is transmitted by consecutive STM-1 frames with frequence 8 KHz. Every STM-1 frame consists of heading (81 bytes) and informational fields which sizes are fixed. Let us divide the heading data in 4-bit clusters (for 16 carriers symbol transmission).

Table 1. Transmitted values.

	Time-slot 1		Time-slot 2		Time-slot 3		Time-slot 4		Time-slot 5		Time-slot 6		Cluster
λ1	1					1							0000
λ2		1	1										0001
λ3				1									0010
λ4													0100
λ5													1000
λ6													0110
λ7													1001
λ8													1110
λ9													1101
λ10													0111
λ11													1111
λ12											1		1011
λ13												1	0011
λ14													1100
λ15							1		1				1010
λ16					1			1		1			0101

Table 2. Received values.

	Time-slot 1		Time-slot 2		Time-slot 3		Time-slot 4		Time-slot 5		Time-slot 6		Cluster
λ1	0					1							0000
λ2		1	0										0001
λ3				1									0010
λ4													0100
λ5			0										1000
λ6				1									0110
λ7	0												1001
λ8		1											1110
λ9													1101
λ10													0111
λ11													1111
λ12											1		1011
λ13												1	0011
λ14													1100
λ15							1		1				1010
λ16					1			1		1			0101

Let us define the first 4-bit cluster as "pilot - co-pilot" pair - λ_{16} and λ_1, the second cluster - as λ_8 and λ_9, the third cluster - as λ_{12} and λ_{13} and so on (so that every posterior pair take place in the middle of already appointed pairs). As a result, a bit succession which is specific for heading, known beforehand and repeated with 8 kHz frequency will be formed at every wavelength. Since the length of every frame and transmission rate are known, it is easy to determine which group of bits the received signal belongs to and to recover symbol spreaded in time. In fact, the buffer is necessary which size is determined by scattering of signals at λ_1 and λ_{16}. DWDM management system which operates at 1510 nm carrier must transmit all necessary information for that. It is worthy to remark that in the scheme of synchronization considered above pilot and co-pilot signals may be placed not at neighboring wavelengths but arbitrarily. This fact has a great significance because frequency response function of EDFA transparent section is not linear and has irregular nature. It results in the fact that signals at some wavelengths are transmitted better than at others. But choosing "good" co-pilots for "bad" pilots (and vice versa) it's possible to achieve nearly equal BER for every symbol, and so essentially mitigate and simplify complex and expensive procedure of gain equalization and tilt control of EDFA spectrum (which inevitably reduces OSNR after attenuation of signal power, especially when number of wavelength increases). Note that regeneration station may operate in 2R mode (reshaping, reamplification) or in 3R mode (2R+retiming). The latter means that STM frames recognition, error correction and data recovery take place. It is evident that during symbol transmission regeneration station operates in 3R mode. Combined method has significant competitive advantage for security of data - in classical DWDM intruder can copy digital information from one photodetector, but here he will be forced to copy even not 16 , but all 80 channels together (since inside one logic tube every wavelengh among 16 may be arbitary among 80) with general clock!

3. CONCLUSIONS

Our competitive advantages for target – 50 Ggbit/sec over SMF 4000 km regeneration distance – are as follows:

- Sensitivity +6 db
- Chromatic dispersion +2 db
- Polarisation dispersion +2 db
- Nonlinearities about +2 db (for example, Double Relay Scattering (DBS) puts upper limit to Raman amplification essentially, but we have every wavelength 8 times rarely – 16 pilots and 16 co-pilots – so can increase Raman pump power significantly)
- FEC is approximately the same as usual Reed Solomon
- 3R and SDH framing exist
- Security of data is extremely high

As a result the span (distance between optical amplifiers (Raman and EDFA combined) is at least 50 km longer than usual, so the main conclusion of this project is:

SDH nodes become "heavier" (or more expensive) and fiber links become "easier" (or cheaper), in the long distance we gain in cost significantly.

REFERENCES

The patent address of this idea is http://www.fips.ru, patent 2161374.