ADVANCED TECHNIQUES AND TECHNOLOGIES OF TRANSMISSION AND ROUTING FOR ULTRA-LONG HAUL ULTRA-BROADBAND TELECOMMUNICATIONS NETWORKS

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ABSTRACT

Recent advanced techniques and associate technologies of transmission, wavelength multiplexing and channel routing for Tera-b/s photonic transport networks and their impacts on optical networking are discussed including (i) optical modulation formats and associate coding for optimising dispersion tolerance in linear and nonlinear operating regimes (ii) dispersion management and compensation techniques (iii) equalisation of gain by lumped and distributed amplification and demultiplexing sub-systems; and (iv) optical routing technology including potential applications of photonic signal processing.

MULTI-Tb/s AGGREGATE OPTICAL TRANSMISSION CAPACITY

Optical networking has progressed tremendously over the last few years [1]. The transmission bit rate has matured at 40 Gbps, 80 Gbps and reaching 160 Gbps. Simultaneously several optical carriers of equally spaced wavelengths across S-, C- and L- bands, are multiplexed carrying signals over several thousand kilometres leading to an aggregate capacity of multi-Tb/s in a single optical fibre. With a frequency spacing of 50 GHz or slightly wider higher number of channels could be achieved depending on the spectral efficiency of different modulation formats [2,3].

The multiplexing of several optical carriers lead to high average optical power and thus the fibre would suffer nonlinear effects, particularly the self phase modulation (SPM), four wave mixing (FWM) and cross phase modulation (XPM). Optical amplifiers, both distributed and lumped types, must also be used to compensate and equalise the optical gain over the ultra-wide band. This would result in modulation instability. Thus recently efficient line coding and efficient modulation formats attract much attention. Furthermore forward error coding techniques have been used to improve the transmission system bit-error-rate [5].

This paper describes recent novel techniques and technologies for ultra-broadband (UBB), in tera-b/s and ultra-long haul (ULH, longer than 1000 kms) transmission systems and routing of these systems for photonic transport networking. Modulation formats and photonic transmitters are discussed. In addition dispersion (chromatic and polarisation mode) management and compensation techniques in conjunction with distributed and lumped optical amplification and equalisation are described.

MODULATION FORMATS

For multi-tera-b/s the modulation format serves two principal objectives: first to minimise the average optical power of all channels as perceived by the fibre refractive index, second to reduce the effective signal bandwidth for efficient spectrum and hence minimise the chromatic dispersion effects. Such an optical transmitter employing external Mach-Zehnder interferometric (MZI) modulators in an ULH and UBB is shown in Figure 1(a) and 1(b). Generating different formats can be implemented in various ways and are given in Table 1.

Duo-external modulation devices are required for these transmitters and can be implemented in tandem in LiNbO3 or polymeric integrated optic structures [3,6,7]. The CS-RZ format should be implemented by biasing the MZI at minimum transmission, ie. at V_π and the signals are switching between the quadrature points of the operational characteristics of the MZI modulators. For SSB modulation it is more complicated due to the requirement of phase matching between the two travelling wave electrode arms of the interferometers at very high and ultra-broadband frequency region. The average optical power would be around –10 dBm of each channel in DWDM transmission systems in order to avoid the nonlinear effects. The spectral efficiency can also be doubled with polarisation division multiplexing (PDM) and 0.8 b/s/Hz has been demonstrated in 10.7 tera-b/s (273x40 Gb/s) over 117 km transmission [5]. In association with efficient modulation formats forward error coding has become important to enhance system margins [8].

Table 1: Modulation formats, bandwidth and dispersion impairment/efficiency of 40 Gb/s rates

Modulation format	**Signal bandwidth**	**Remarks – spectral efficiency (4000km)**
Return-to-zero (RZ)	80 GHz + carrier	Double sidebands no carrier suppressed – 0.42 b/s/Hz
Carrier-suppressed RZ (CS-RZ)	40 GHz + carriers of pi-phase difference (i.e. virtually suppressed)	Carrier suppressed – most efficient in reduction of dispersion. 0.4 b/s/Hz.
Single side band RZ (SSB-RZ)	40 GHz + carrier	No carrier suppressed. Electrical phase matching of UBB signals for modulation.
Vestigial sideband RZ	40 GHz	Carrier suppressed – most efficient in reduction of dispersion impairment – addition optical filters required. 0.6 B/s/Hz
Chirped RZ	80 GHz + chirped carrier	No carrier suppressed and chirped frequency carrier – 0.4 B/s/Hz
Duo-binary [4]	70 GHz	Complexity in phase matching of tri-level electrical modulation signals

DISPERSION COMPENSATION AND ULTRA-BROADBAND OPTICAL GAIN

Advanced optical fibres, e.g. NZDSF, dispersion compensated fibres with W- profile have been used in ULH DWDM transmission system and networks. Dispersion compensation modules (DCM) incorporated with in-line erbium doped fibre amplifiers (EDFA) are normally inserted between spans to compensate for loss and dispersion [10]. The entire band of the EDFA gain spectrum has been used up, i.e. the C- and L-bands. Furthermore the level of multiplexed optical channels must be optimised so that they would not suffer nonlinear distortion effects and accumulated noises from cascaded amplifiers. Thus Raman amplifiers as distributed amplifying media that are the transmission fibres. High-level GeO_2 doped fibres have also been used to create lumped amplifiers with different wavelength pumping to flatten the gain coefficients and thus equalisation over the extended spectrum [11,12,14]. The Raman distributed amplifiers are also used to reduced adjacent pulse interaction in soliton transmission systems [13].

Polarisation mode dispersion is critical in UBB ULH DWDM optical fibre communication systems. PMD compensators using a integrated optic polarisation rotator and a high birefringence fibre delay line with receiver signal filtering feedback to rotate the state of polarisation can be used to compensate for first order PMD and partially compensating higher order PMD [13,14]. These compensators are placed in the post- transmission receiver systems as indicated in Fig. 1. Furthermore compensation of residual post-transmission dispersion by fibre Bragg gratings (in association with optical circulators) must be conducted after the demultiplexing of optical channel. Polarisation dependent losses and dispersion of photonic components in photonic transport networks are also very critical. The control and minimisation of these effects must be carefully considered during the fabrication process.

CHANNEL MULTIPLEXING/DEMULTIPLEXING AND ROUTING FOR PHOTONIC TRANSPORT NETWORKS

For ultra-broadband and ultra-wide photonic transport, networks multiplexing, demultiplexing [16] and possibly full or limited wavelength conversion [17] of DWDM optical channels are essential prior to receiving [17], routing and distributing to other photonic networks. Further all-optical regeneration (2R or 3R) of different modulation formats are critical in these networks. The use of nonlinear optical loop mirror can offer 2R [18].

With massive parallel transmission and interconnection of UBB and ULH photonic networks, network topologies are to be deployed with extremely high fault tolerance. Photonic ring networks can be structured with high number of photonic cross-connect systems or photonic mesh networks should be used. Wavelength re-use and conversion techniques are important for network flexibility in control and management of wavelength channels. Agile photonic networks should be considered rather than “dump” optic in point-to-point transmission systems currently employed [22]. The 3R all-optical regenerators using photonic signal processing are critical for photonic networks as they would provide reconstructed signals and wavelength channels for further transmission after routing.

CONCLUDING REMARKS

Multi-tera-b/s photonic communications and networking techniques can be very important for intercontinental and terrestrial information networks. For the network layer structured with ULH and UBB dense wavelength multiplexed channels at 40 Gb/s would form a super-backbone for all-optical networks operating at lower level, for example 10 Gb/s over several thousand km networks which are currently developed for national and local Ethernet networks. The design, modelling and deployment of a future super-photonic transport network backbone remain a challenging problem.

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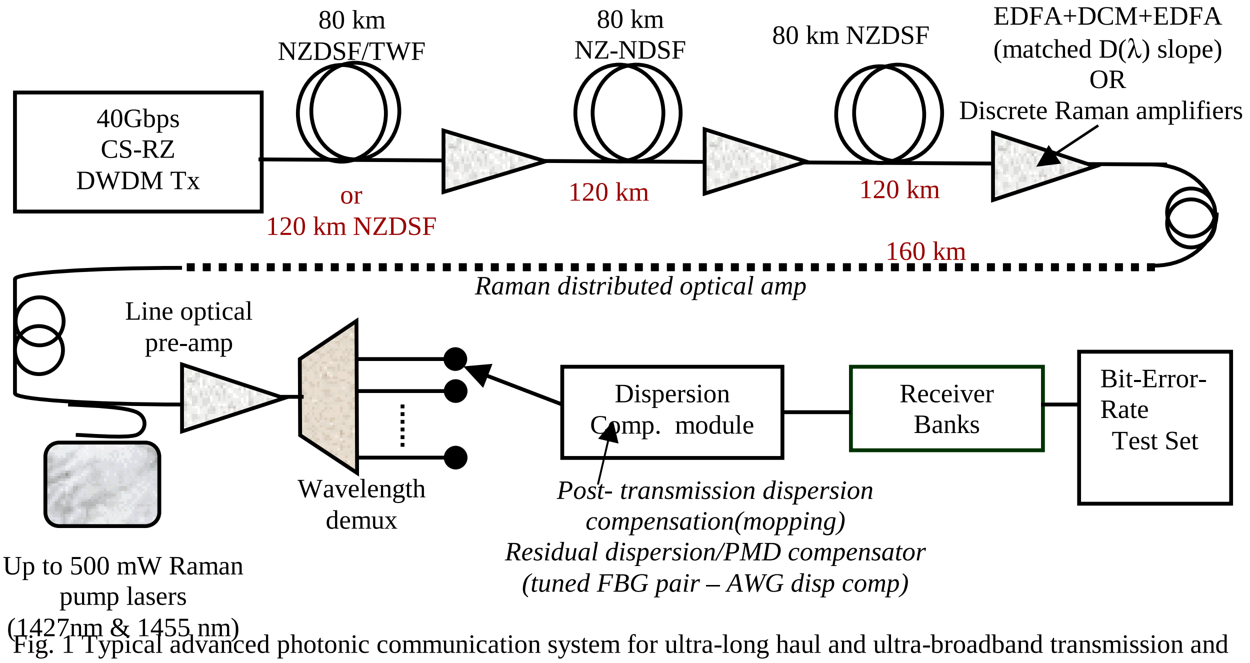

Fig. 1 Typical advanced photonic communication system for ultra-long haul and ultra-broadband transmission and networking

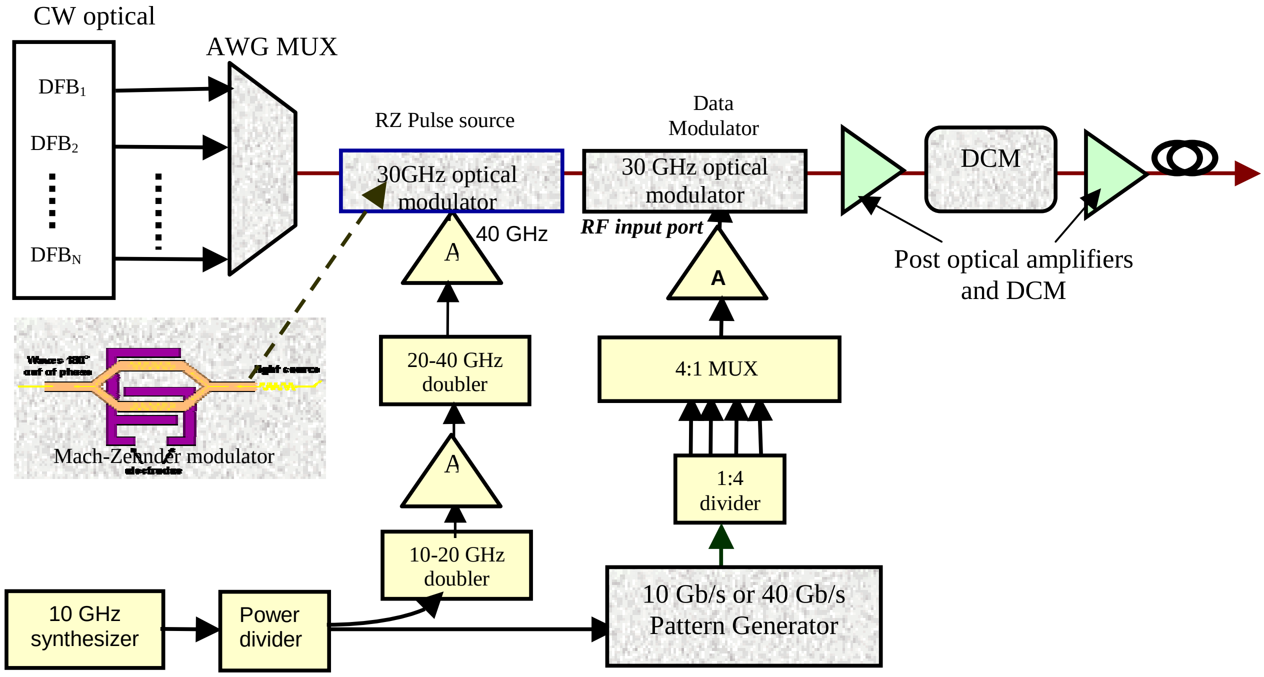

Figure 2 Photonic transmitters for different modulation formats. Inserted is the integrated optic modulator.