SEEFIRE

Optical Signals Modulation and Compensation of Chromatic Dispersion

www.seefire.org

SEEFIRE

South-East Europe Fibre Infrastructure for Research and Education

Jan Radil
CESNET
Czech Republic

The SEEFIRE project is co-funded by the European Commission under the FP6 IST contract no. 15817

Overview

- Modulation (and demodulation) formats
- Signal formats
- Chromatic dispersion (CD)
- CD management
- Conclusions

Modulation Formats (Schemes)

- How to convert an electrical signal into an optical stream?
- On-Off Keying (OOK)
- A simple digital modulation scheme, easy to implement
- Intensity modulation with direct detection (IM/DD)
- Incoherent (the intensity only, no phase coherence)
- Direct or external ($LiNbO_3$) modulations
- Two basic choices for the signal formats – return-to-zero (RZ) and nonreturn-to-zero (NRZ)
- Carrier suppressed (CS), Single side band (SSB), Vestigial sideband (VSB), Chirped (C) both for RZ and NRZ (CS-RZ, C-RZ,…)

Advanced Modulation Formats

- Coherent modulations - well known from radio and microwave systems and literature
- Improvement of receiver sensitivity (up to 20 dB) when compared to IM/DD systems [1]
- More efficient use of bandwidth by increasing the spectral efficiency (higher tolerance to nonlinear effects, chromatic dispersion CD, polarization mode dispersion PMD)
- More complicated and more expensive

Advanced Modulation Formats

- Amplitude-shift keying (ASK)
- Phase-shift keying (PSK)
- Frequency-shift keying (FSK)
- Differential phase-shift keying (DPSK)
- Differential quadrature phase-shift keying (DQPSK) – Wi-Fi
- Optical Duo Binary ODB (also known as phase shaped binary modulation)

Advanced Modulation Formats

- Signal formats can be RZ, NRZ, CS-, etc. again
- DQPSK, ODB are *multilevel* modulations
- Multilevel – more amplitude levels (to achieve spectral efficiency better than 1 bit/s/Hz), 40 Gb/s is 10 Gbaud for a 16 level modulation
- DQPSK (information is encoded in the 4 differential optical phase between successive bits)
- ODB (in simplest scheme - two consecutive bits are summed -> a three level code is created, AM-PSK)
- RZ-DPSK, NRZ-DPSK, CS-RZ OOK, RZ-ODB have been studied extensively (better tolerance to different impairments)

Demodulations

- Optical signals are modulated and transmitted
- Attenuation, dispersion, noise, nonlinear effects
- The data must be recovered @ BER 10^{-9}, 10^{-12},10^{-15} …
- Coherent (transmitted signal plus local oscillator) and incoherent (OOK) receivers
- Photo detector, pre-amplifier, filter (equalizer)

Chromatic Dispersion

- The speed of light is wavelength dependent
- Spectral broadening of pulses because different spectral components of the pulse travel at different speeds
- Critical at higher bit rates e.g. >= 10 Gb/s
- Can be (easily) compensated - a deterministic phenomena
- Different measurement methods (TIA/EIA)
- D – chromatic dispersion coefficient, ps/(nm*km)
- D = 17 ps/(nm*km) for G.652 fibre (standard single mode fibre)

CD Measurements

- Modulated Phase-Shift Method (FOTP 169)
- Differential Phase-Shift Method (FOTP 175)
  - Both phase-shift methods are accurate, measurement throught optical amplifiers, expensive
- Spectral Group Delay Measurement in the Time Domain (FOTP 168)
  - Still accurate enough, no measurement through optical amplifiers
- Relative group delay is measured and the dispersion coefficient D is calculated

CD Management

- Dispersion compensating fibres (DCF)
  - A special kind of fibre, compensates all wavelengths (the only solution for „grey“ transmitters)
  - Adds link loss (and money), especially for long-haul applications
  - Stronger non-linear effects (due to a smaller core diameter)
- Fibre Bragg gratings (FBG)
  - Narrow-band elements – a stabilized DWDM laser is a must
  - „Wide-band“ FBGs available today (for 50 ITU DWDM channels)
  - Signal filtering, spectrum shaping, tuneable compensators
  - Cost effective solution

CD Management

- Optical Phase Conjugation (OPC)
  - A nonlinear optical technique (midspan spectral inversion)
  - The complex conjugate of a pulse-propagation equation
  - Four-wave mixing in a nonlinear medium (phase conjugators)
- Electronic pre-compensation
  - A relatively new technique
  - An electrical signal is pre-distorted before converting into an optical domain
  - Dispersion can be tuned for up to thousands kilometers of G.652 fibre

CD limitations

- Typical values (receivers can have different tolerance to CD!)

Bit rate (Gbit/s)	Maximum length of G.652 link (km)
2,5	1000
10	80
40	4

Conclusions

- OOK, NRZ: the most important and wide-spread today
- DPSK, ODB, RZ are promising technologies (still simple enough)
- Soliton systems (dispersion managed solitons)
- Compensating fibres are in the same position as NRZ-OOK
- But Bragg gratings and electronic pre-compensation are emerging technologies (as new modulation formats)

References

- ECOC 2004
  - We3.4.6, Performance Comparison of *85.4 Gb/s* Pre-Filtered *DQPSK* Signals with and without *RZ* Pulse Carving, N. Yoshikane, I. Morita, KDDI R&D Laboratories Inc., Japan.
  - Th2.5.3, C-Band Terrestrial WDM Transmission of 1 Tb/s (*25x43 Gb/s*) over DSF Using *CSRZ* up to 1600 km and *DPSK* up to 2400 km, H. Bissessur, C. Bastide, S. Ruggeri, A. Hugbart, ALCATEL, France, A. Klekamp, W. Idler, ALCATEL, Germany.
  - Th2.5.5, Location Optimization of a Single *Optical Phase Conjugator* in a 3,200km, 40-Gb/s Pseudo-Linear Transmission System, G. Raybon, A. Chowdhury, R. J. Essiambre, C. Doerr, Bell Laboratories, Lucent Technologies, United States.
  - Th3.5.4, Error Free Transmission over 6000 km of *50 x 42.8Gb/s*, FEC-Coded *CS-RZ* Signal in EDFA and Medial-Dispersion MDF System, Y. Inada, T. Ito, K. Mino, R. Yokoyama, Y. Hara, K. Fukuchi, T. Ogata, Y. Aoki, NEC Corporation, Japan.

References

- OFC 2005
  - OThO2, Experimental Comparisons of *DPSK* and *OOK* in Long Haul Transmission with 10 Gbit/s Signals, DMF Span and Raman Assisted EDFA, Takanori Inoue[1], Kazuyuki Ishida[2], Eiichi Shibano[1], Hidenori Taga[1], Katsuhiro Shimizu[2], Koji Goto[1], Kuniaki Motoshima[2]; [1]KDDI-SCS, Japan, [2]Mitsubishi Electric Corp., Japan.
  - OFG5, Optimal Receiver Bandwidths, Bit Error Probabilities and Chromatic Dispersion Tolerance of 40 Gbit/s Optical *8-DPSK* with *NRZ* and *RZ* Impulse Shaping, Michael Ohm, Joachim Speidel; Univ. of Stuttgart, Germany.
  - OFN2, Performance Comparison of Modulation Formats for 40 Gbit/s DWDM Transmission Systems, Masahiro Daikoku; KDDI R&D Labs Inc., Japan.
  - OThJ3, *Electronic* Domain Compensation of Optical Dispersion, John McNicol, M. O'Sullivan, K. Roberts, A. Comeau, D. McGhan, L. Strawczynski; Nortel Networks, Canada.

References

- [1] Agrawal G.P., „Fiber-Optic Comminications Systems, 2002.
- [2] Ramaswami R., Sivarijan K.N., „Optical Networks“, 2nd edition, 2002.
- [3] ECOC 2004 proceedings
- [4] OFC 2005 proceedings

Thank you for your attention!