High Speed Optical Networks--Experiments

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Goals—Past year(s)

• Carry out experiments on installed optical communication systems

• To identify and investigate issues of interest in helping establish high speed operation of optical networks
This year’s effort

• We have shown in laboratory experiments that dispersion distribution is important for communications performance
• We moved these experiments from the lab to ATDNET/BossNet
• Implications for network management
• Investigated novel formats that can increase performance and relax constraints
Nonlinear Interaction

- Dispersion causes adjacent pulses to spread in time and overlap for part of the transmission distance
- The nonlinear interaction due to the optical fiber between adjacent pulses leads to timing jitter
- The dispersion distribution can alter the amount of timing jitter
- Large amounts of timing jitter causes errors
Nonlinear Interaction—Frequency Shift

Intensity variation of $u_T$ shifts frequency of $u_L$

\[ u = u_L + u_T \]

FWHM = 100 ps

\[ \frac{d f_L}{dz} = -\gamma \frac{d |u_T|^2}{dt} \]
Residual compensation all at the end
Nearly closed eye and large error rate due to timing jitter

10 Gb/s
Split compensation between beginning and end
Open eye end low bit-error rate

10 Gb/s
Laboratory Results

• Intra-channel cross-phase modulation $\rightarrow$ timing jitter

• Dependent on dispersion map configuration
  – Most work to date on undersea transmission systems
  – Mitigated by symmetric pre- and post-compensation

• Laboratory investigation of terrestrial system
Experiments on ATDNET/BossNet

- Measure timing jitter at 10 Gb/s on an installed terrestrial fiber path
- Obtain excellent qualitative agreement between measured values and numerical simulations
- Arrangement of dispersion compensation important for obtaining best transmission
Installed fiber path

One way distances:

Segment 1 (ATDNet):
- TrueWave RS (+4.5 ps/nm-km), 41 km
- Uncompensated

Segment 2
- AllWave (+17 ps/nm-km), 16 km
- Uncompensated

Segment 3 (BOSSNet):
- TrueWave Classic (+2.8 ps/nm-km)
  - To Wilmington: 186 km
  - To New York City: 389 km
- Compensated at 1550 nm
- Uneven EDFA spacing
Experimental setup

**Tx:**
- CW Laser @1558.98nm
- EAM
- 10 GHz Clock
- EOM
- 10 Gb/s PRBS
- Pre-Compensation
- Tx/Rx co-located in D.C.
- EDFA

**Rx:**
- BERT
- Clock/Data Recovery
- Oscilloscope
- Post-Compensation
- OBF
- OSA
- Installed network
  - NYC
  - DC
- • Tx/Rx co-located in D.C.

**UMBC**
Dispersion maps

- Not including pre- and post-compensation
- Total accumulated dispersion for round trip at 1558.98 nm
Numerical model

Timing jitter results compared with numerical simulation:

- Full nonlinear Schrödinger equation
- 200 Monte Carlo simulations
- Utilizing best estimate of system parameters:
  - Dispersion map
  - Amplifier noise figures
  - Power map
Eye diagrams

Wilmington, DE

New York, NY

50 % Pre-compensation

90 % Pre-compensation
Wilmington loopback results

- Total transmission distance ~520 km
- Symmetric dispersion compensation minimizes timing jitter
- Excellent qualitative agreement with theory
New York loopback results

- Total transmission distance ~930 km
- Jitter increased, but similar trend
Summary

• Timing jitter measured on installed terrestrial link
• Qualitative agreement with simulations
• Ability to control dispersion compensation layout will be important in typical terrestrial systems may influence network management when paths change
Novel Formats

- Explore Novel formats
- DPSK
- QPSK
- QPSK and PolMux
- Others
DPSK

- Phase modulated signal
- 3 dB advantage over ASK
- Constant amplitude pulses
- Less “patterning”
- Security implications
DPSK Transmitted Intensity Pattern

10 Gb/s
Receiver
Demodulated Eye Pattern—10Gb/s
DPSK Loop Back from LPS to ISI

Error Rate < 1 \(\cong 10^{-13}\)
DPSK

- 3 dB performance advantage over ASK
- Less Pattern Dependence in Transmission—maybe smaller timing jitter
- More difficult to detect—need specialized receiver
- Provides different information to network management
New Directions for Upcoming Year

- We are working with LTS to adapt measurements and theory to interactions with system and optical control plane

- LTS Personnel: Mark Ciccarello, Dave Hardesty, and Walter Kaechele