Performance of Digital Nyquist-WDM

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Outline

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  - Description of the technique
  - Motivations of this work

- Generation of Nyquist-WDM signals in the digital domain
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  - Realistic analog-to-digital conversion

- Simulation results
  - System set-up description
  - Back-to-back results

- Conclusions
"Nyquist-WDM" is a technique used to generate high spectral efficiency optical signals.

It is based on the idea of limiting the crosstalk between adjacent sub-channels by means of tight filtering at the transmitter:

The ideal “Nyquist pulse” is designed in order to satisfy the Nyquist criterion for the absence of ISI.
Tight spectral shaping can be performed:

- in the **optical domain**, through narrow transmitter (Tx) optical filtering

- in the **digital/electrical domain**, combining digital signal processing (DSP) and digital-to-analog (D/A) conversion.
Motivations of this work

- Ideally, both techniques can achieve the same ultimate performance (with an optimum “matched filter” receiver).
- What limits the performance is the “practical” implementation of the transmitter, i.e. how well the spectral shaping can be performed [*].
- The goal of this work is to analyze the characteristics of Nyquist-WDM generated in the digital domain, taking into account the implementation characteristics of realistic D/A conversion:
  - Sampling speed
  - Bandwidth

The “Nyquist sampling theorem” states that any analog signal $x(t)$, band-limited in $[-W, W]$, can be perfectly reconstructed from its samples provided that the sampling frequency $f_{\text{samp}}$ is greater than $2 \cdot W$.

Reconstruction of the signal:
To generate a perfectly rectangular Nyquist spectrum a DAC is needed operating at a speed equal to \( R_s \) samples/s (i.e. 1 sample/symbol) and with a perfectly rectangular transfer function with bandwidth \( B_{DAC} = 0.5 \cdot R_s \).

Today commercial DACs are characterized by a maximum sampling speed \( f_{samp} \) around 24-30 Gsamples/s and a transfer function which is far from rectangular.
In “real” DACs, the “sampled” version of the signal is not composed of a sequence of delta functions, but it is generated by “sample&hold” circuits.

Moreover, the interpolating filter is not an ideal low-pass filter, but a realistic one.
Spectra evolution in the D/A process

Ideal spectrum

After sampling at 2 samples/symbol
Spectra evolution in the D/A process

After sample & hold

After interpolating filter

\[ H(f) \]

DSP → S&H → DAC
ISI and aliasing (2 samples/symbol)

Spurious frequencies $\rightarrow$ WDM inter-channel cross-talk

Not flat $\rightarrow$ ISI
Analyzed system set-up

- 12-Gbaud PM-QPSK (or PM-16QAM) modulation format
- WDM signals with $R_s$ (or 1.1 $R_s$) spacing

- DAC characteristics (Tektronix AWG 7000):
  - 24 Gsamples/s $\rightarrow$ 2 samples/symbol
  - bandwidth equal to 9.6 GHz (0.8 $R_s$)
  - 8 resolution bits

- The IQ modulator was biased in order to work in a quasi-linear regime and a proper pre-enhancement was applied to the digital samples in order to compensate for both the interpolating filter and the S&H process.
12-Gbaud PM-QPSK with $\Delta f = R_s$

- Optical filter: 4th order Supergaussian with optimized bandwidth (12 GHz)
- Digital spectra: square-root raised-cosine with roll-off 0.15
12-Gbaud PM-16QAM with $\Delta f = 1.1 \cdot R_s$

- Optical filter: 4$^{th}$ order Supergaussian with optimized bandwidth (12 GHz)
- Digital spectra: square-root raised-cosine with roll-off 0.15
Conclusions

- The generation of Nyquist pulses in the digital domain through digital-to-analog conversion overcomes the need for a steep optical filter at the Tx side, which has been identified as one of the major drawbacks of “Optical Nyquist-WDM” technique.

- Preliminary results achieved using state-of-the-art DAC technology makes “Digital Nyquist-WDM” a promising technology for the generation of ultra-high spectral efficiency signals.
Thank you!

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