

Routing and Wavelength Assignment Incorporating the Effects of Crosstalk Enhancement by Fiber Nonlinearity

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Overview

- ▷ Introduction
 - All-optical networks
 - Crosstalk
 - Modeling
- ▷ Accounting for crosstalk
- ▷ Routing and Wavelength Assignment
- ▷ Conclusion

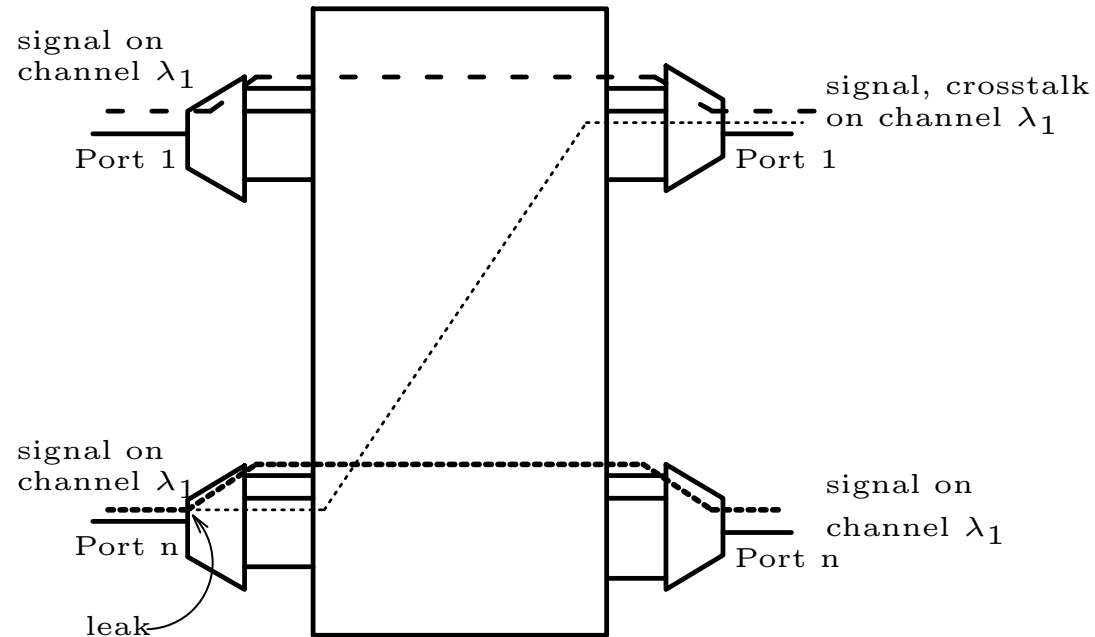
All-optical networks

- ▷ Current high-speed optical networks
 - Bottleneck due to electrical conversions

- ▷ New issues arise with all-optical networks
 - Nodes (OXCs) are subject to crosstalk
 - Crosstalk is transmitted over extremely long paths without electrical signal regeneration

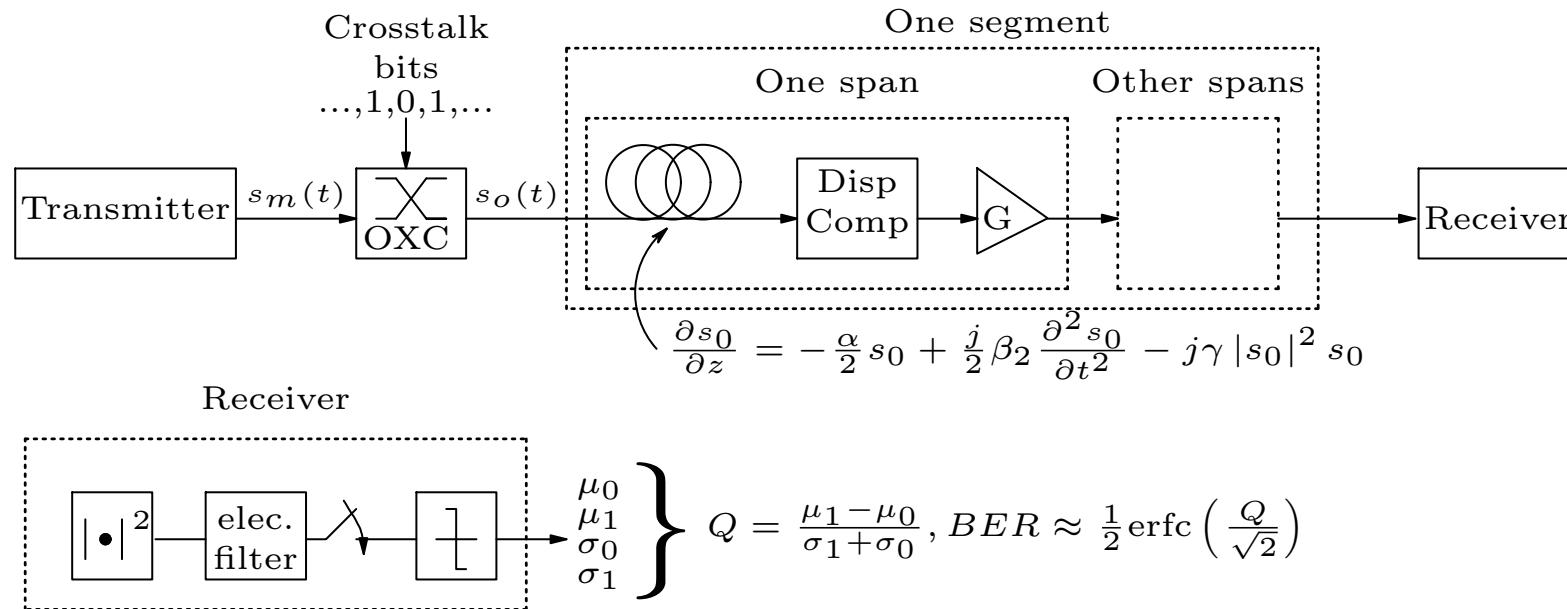
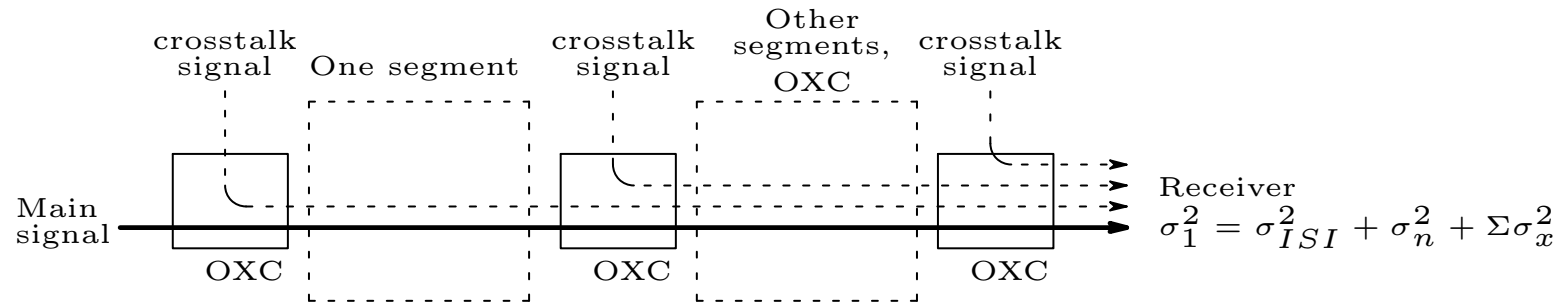
OXC (all-optical switch) and crosstalk

Input fibers Demux Switching fabric Mux Output fibers



- ▷ Leaks can originate from imperfect demultiplexing, or transmission within the switching matrix

Lightpath and physical layer models



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Crosstalk model

$$\triangleright s_0(t) = s_m(t) + \sum_{\ell} m_{\ell} g_0(t - \ell T_b)$$

- The main signal $s_m(t)$ and the crosstalk signal are modulated

$$\triangleright g_0(t) = \sqrt{\eta P_0} h(t - \tau) e^{j\omega_s(t-\tau) + j\varphi}$$

- Bits m_{ℓ} , delay τ and phase φ are uniformly distributed over $\{0,1\}$, $[0, T_b)$, $[0, 2\pi)$, respectively.
- Crosstalk detuning ω_s
- Pulse shape $h(t)$

Delay-dependent crosstalk pulse shape

- ▷ For a single main bit and crosstalk bit — output:

$$s_{out}(t) = \sqrt{P(t)} \exp(j\theta(t)) + mg_{\tau,\varphi}(t)$$

- ▷ Splitting in in-phase and quadrature phase components and projecting:

$$s_{out}(t) = \exp(j\theta(t)) \left(\sqrt{P(t)} + m \left(g_{\tau}^{I+}(t) \exp(j\varphi) + g_{\tau}^{I-}(t) \exp(-j\varphi) + jg_{\tau}^{Q+}(t) \exp(j\varphi) + jg_{\tau}^{Q-}(t) \exp(-j\varphi) \right) \right)$$

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▷ Current due to crosstalk:

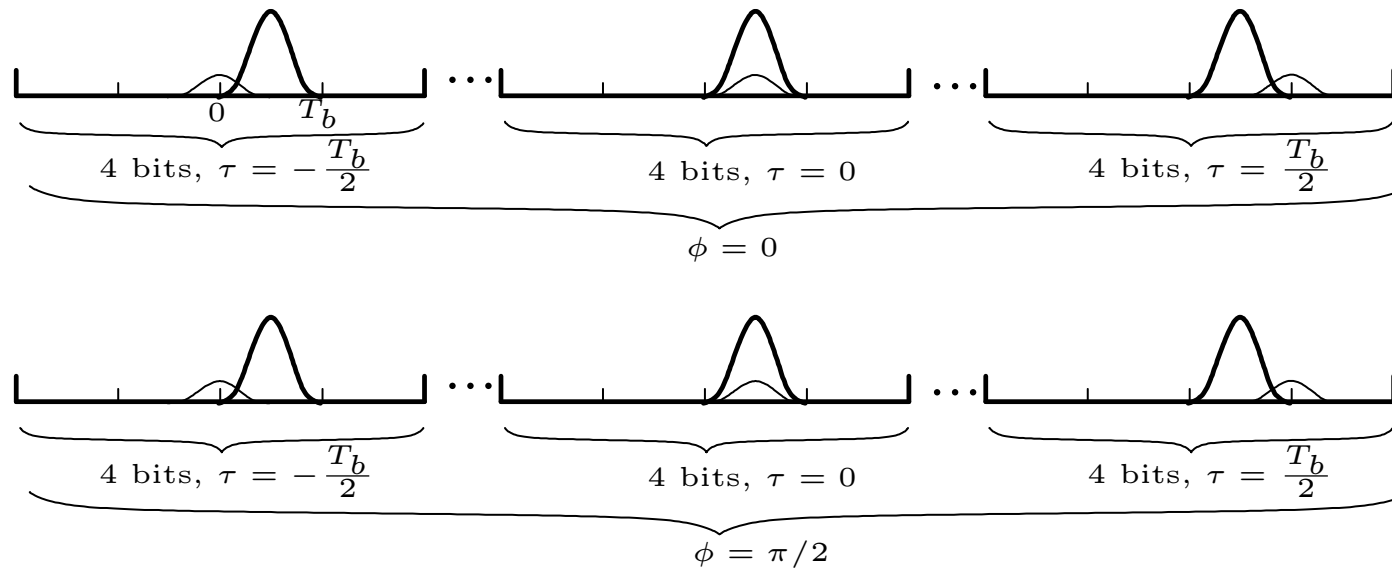
$$\Delta i(t) \approx \rho f(t) * \left(2\sqrt{P(t)}m \left(g_{\tau}^{I+}(t) \exp(j\varphi) + g_{\tau}^{I-}(t) \exp(-j\varphi) \right) \right)$$

▷ Variance:

$$\sigma_x^2(t) = 4 \int_{-\frac{T_b}{2}}^{\frac{T_b}{2}} \frac{\rho^2}{T_b} \left| f(t) * \left(\sqrt{P(t)}g_{\tau}^{I+}(t) \right) \right|^2 d\tau$$

▷ We need to determine $g_{\tau}^{I+}(t)|_{t=T_b/2}$ for all τ

Semi-analytical method



- ▷ Use short simulations, use N values for the random delay τ :
 $\tau_k = k/NT_b$, and 2 phases: $\phi = 0$ and $\phi = \pi/2$

Continued ...

- ▷ Short simulation output:

$$s_{k,\phi}^{out}(t) \approx \sqrt{P(t)} \exp j\theta(t) + g_{\tau_k,\phi}(t)$$

- ▷ Estimate of the crosstalk pulse shape for τ_k

$$\begin{aligned} \hat{g}_{\tau_k}^{I+}(t) &= \frac{1}{2} \Re \left\{ \exp(-j\theta(t)) (s_{k,0}^{out}(t) - \sqrt{P(t)} \exp j\theta(t)) \right\} \\ &\quad - \frac{j}{2} \Re \left\{ \exp(-j\theta(t)) (s_{k,\frac{\pi}{2}}^{out}(t) - \sqrt{P(t)} \exp j\theta(t)) \right\} \end{aligned}$$

- ▷ Estimate for the crosstalk variance:

$$\hat{\sigma}_x^2 = \left(\frac{\rho^2}{N} \sum_{k=0}^{N-1} 4 \left| f(t) * \left(\sqrt{P(t)} \hat{g}_{\tau_k}^{I+}(t) \right) \right|^2 \right) \Big|_{t=T_b/2}$$

Conclusions: modeling of crosstalk effects

- ▷ Reduced number of bits transmission simulation by 2 orders of magnitude
 - $2048 \times 32 = 65536$ vs. $\underbrace{32}_{ISI} + \underbrace{4 \times 2 \times 32}_{crosstalk} = 288$ bits
- ▷ Still able to assess accurately Q over broad ranges of physical parameters
- ▷ Crosstalk effect cannot be ignored
- ▷ Crosstalk effect may not be constant along a lightpath

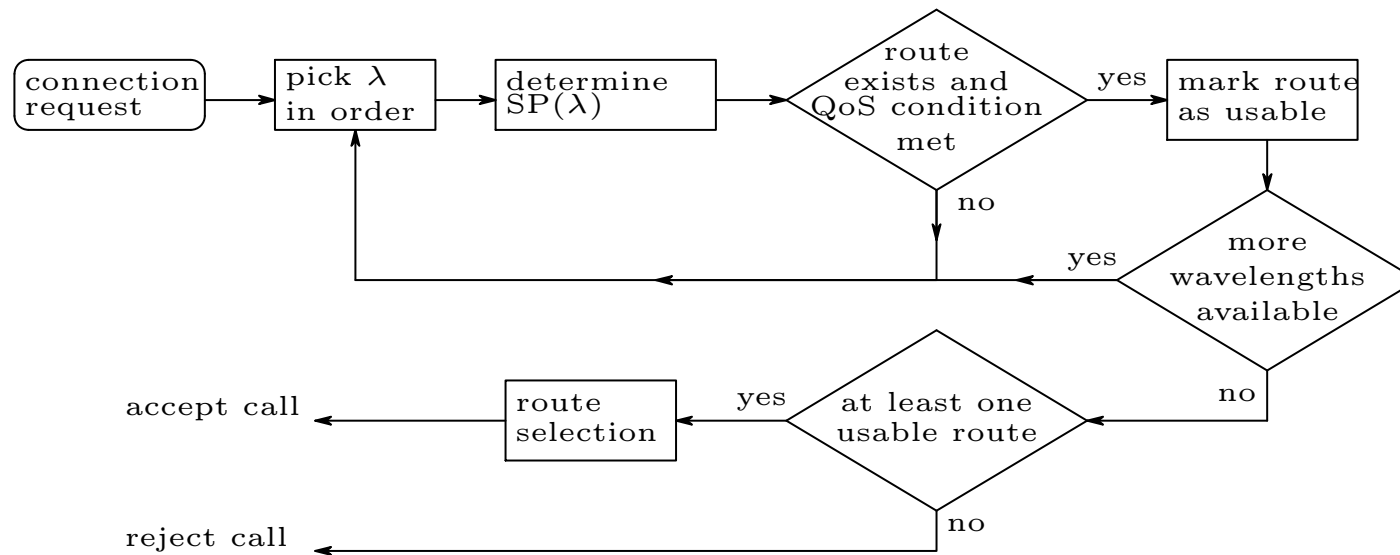
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RWA problem

- ▷ A way to mitigate crosstalk effects
- ▷ Wavelength continuity condition
- ▷ Calls can be blocked because no path/wavelength is available or because of a QoS violation
 - In this work, $QoS \leftrightarrow BER \leftrightarrow Q$
- ▷ Traditionally: do routing (fixed shortest path) and then find a wavelength
- ▷ Adaptive routing: pick wavelength, find shortest path

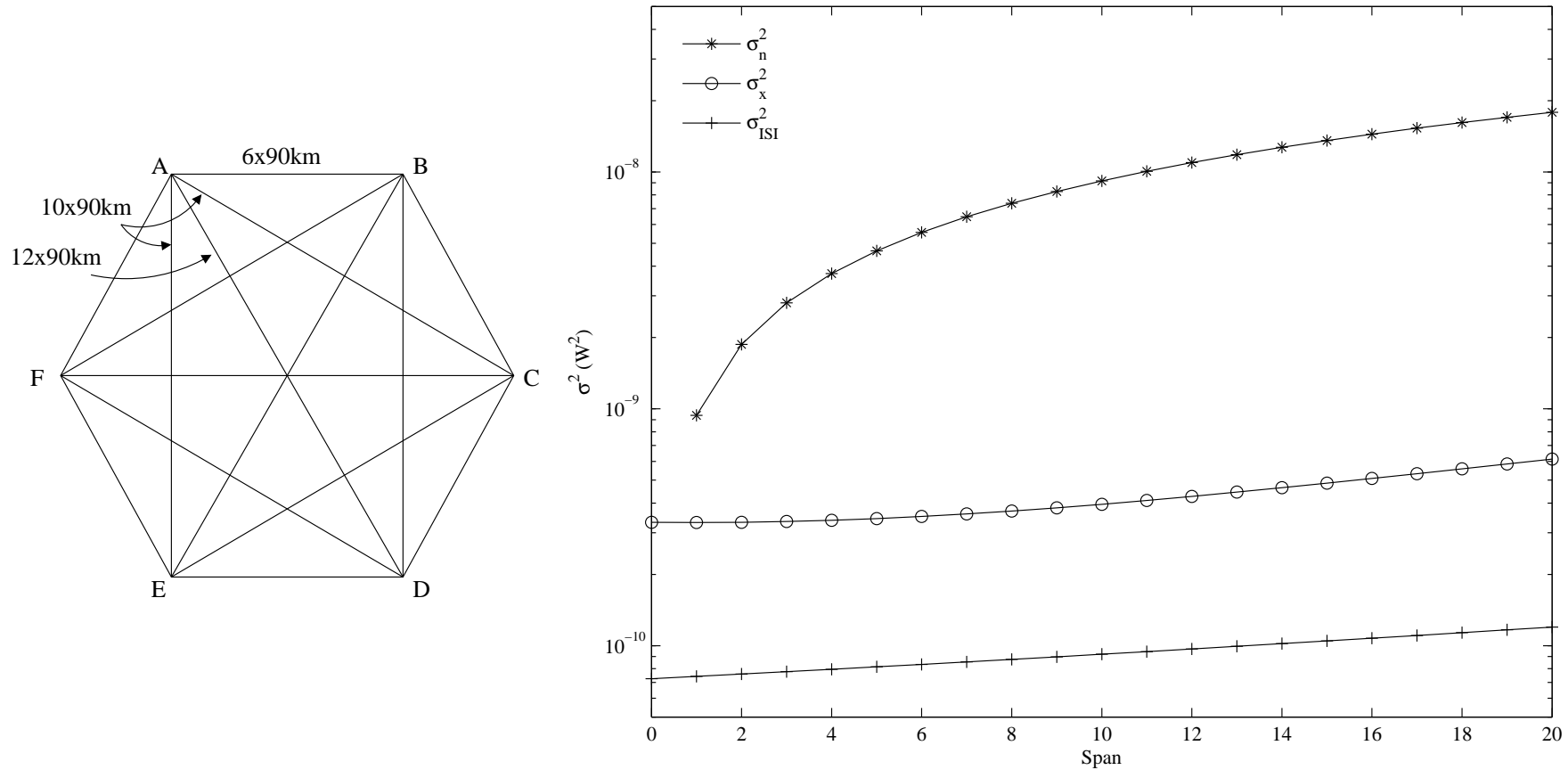
QoS aware algorithms



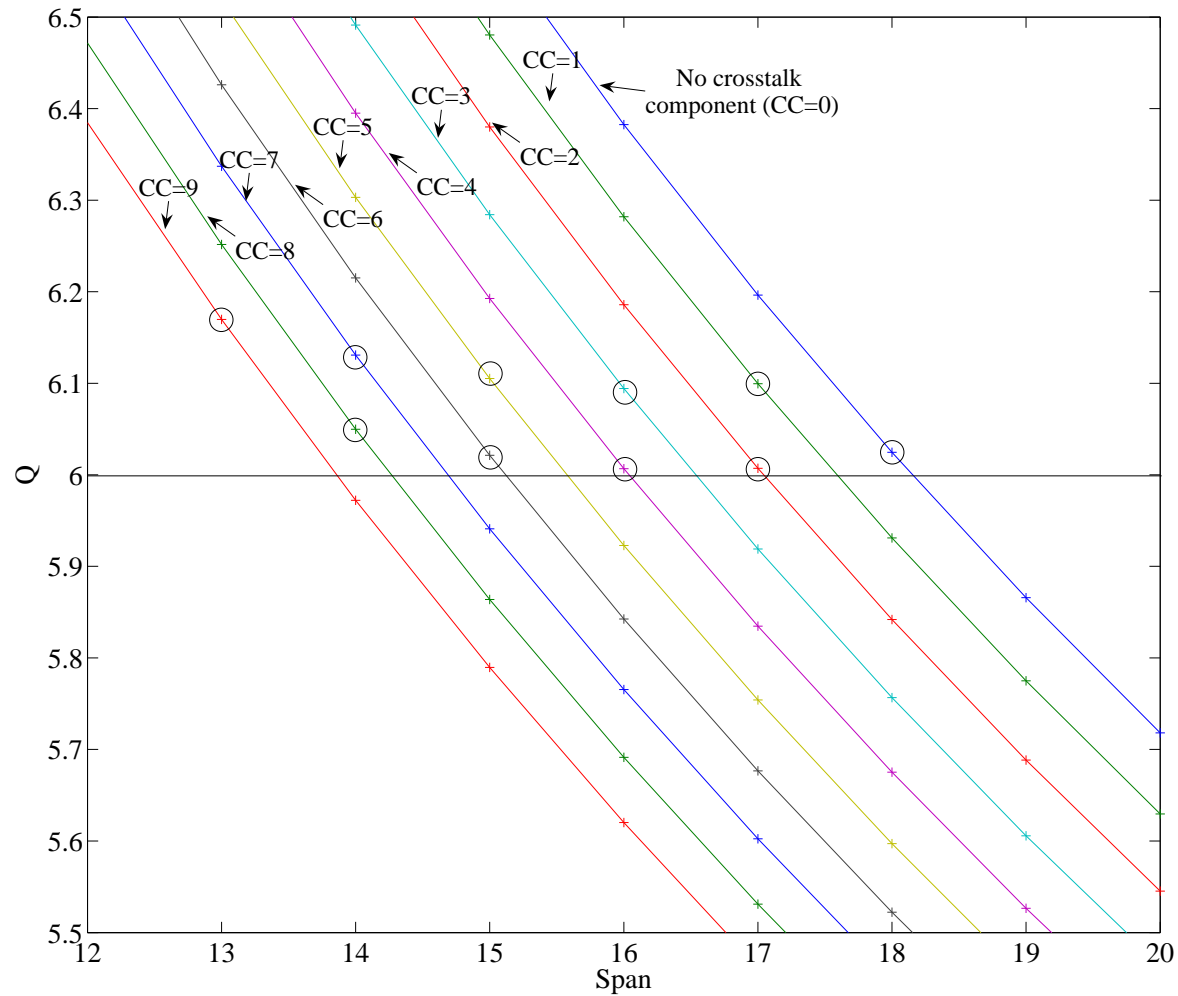
Parameters

	Description	Value
L	Span length	90 km
P_0	Signal peak power	2 mW
R_b	Bit rate	10 Gbps
	Pulse shape	RZ, gaussian
η	Crosstalk attenuation (power)	-30 dB
α	Fiber loss	0.22 dB/km
γ	Nonlinear coefficient	$2.2 (\text{W km})^{-1}$
D	2 nd order dispersion	2 ps/nm/km (NZ-DSF)
NF	Noise figure	2
	Dispersion compensation	100% post-DC
ρ	Photodetector reponsitivity	1 (arbitrarily)
B_e	Electrical filter bandwidth	7 GHz

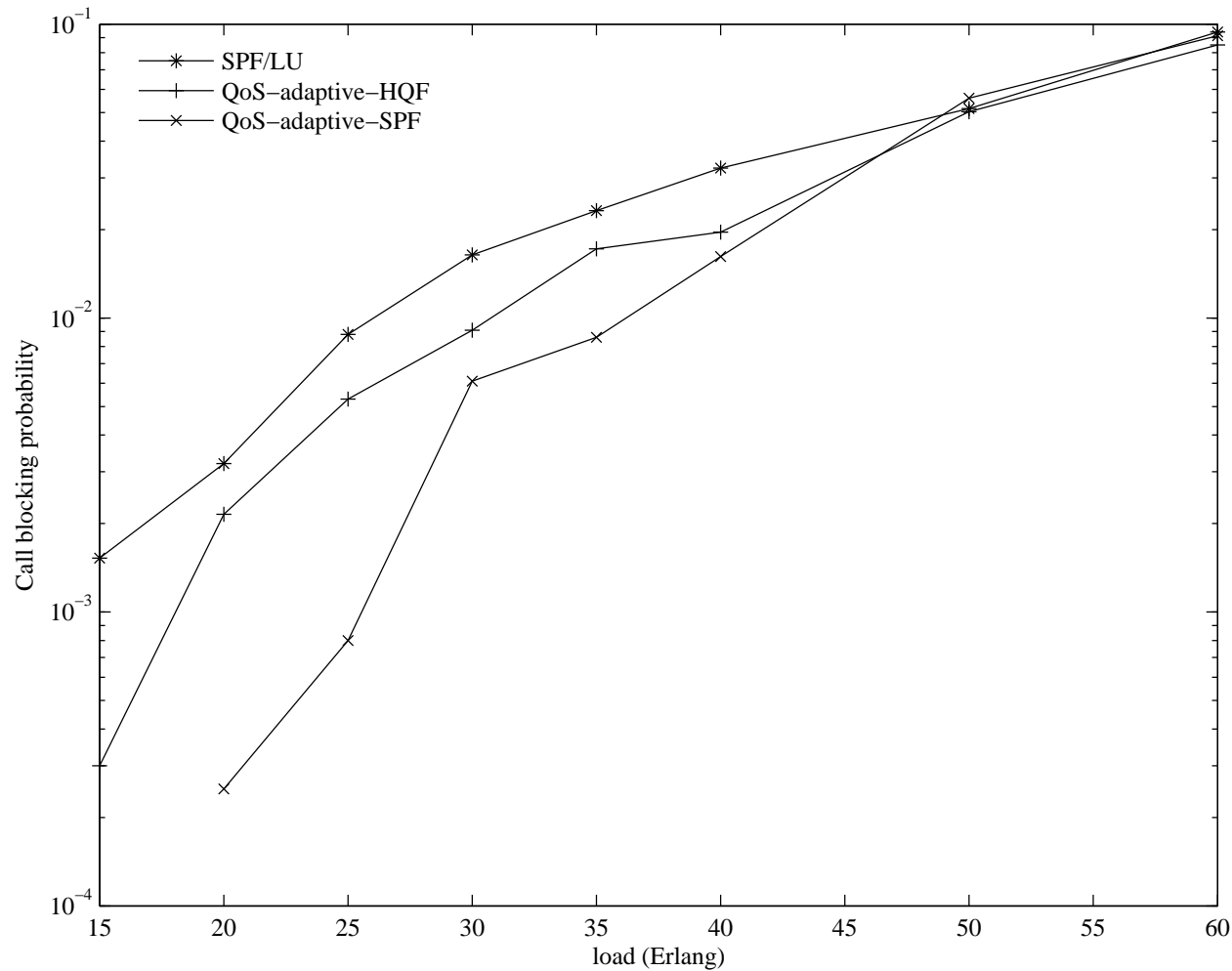
Example setup



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Simulation result



Discussion

- ▷ The QoS-aware adaptive algorithms perform better than traditional algorithms
- ▷ The HQF algorithm does not perform as well as the SPF algorithm
 - HQF tends to avoid heavily used wavelengths, hereby “spreading” calls among the wavelengths
 - Work in progress: we will account for this behavior in future versions of the algorithm

Conclusions and future work

- ▷ Crosstalk has a lightpath physical parameters-dependent impact on network performance
- ▷ Fast, new method to account for crosstalk, based on perturbation theory and small-scale simulations
- ▷ Crosstalk impairment mitigation is possible through combined RWA
- ▷ Improve HQF RWA to account for wavelength spreading issue
- ▷ Design power-RWA to choose signal powers locally or even globally