# Reinforcement Learning Based Routing in All-Optical Networks with Physical Impairments

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IEEE BROADNETS: Optical Cross-Layer Design

# Cross-layer design

- Current high-speed optical networks
  - Bottleneck due to electrical conversions
- Features of all-optical networks
  - Circuit switched $\rightarrow$ lightpaths
  - Flexibility (traffic engineering), speed, cost
- New issues arise with all-optical networks
  - Optical regeneration currently unavailable
  - Signal impairments are transmitted over extremely long paths without any regeneration
  - Physical layer cannot be considered as perfect $\Rightarrow$ Bit-Error Rate (BER)

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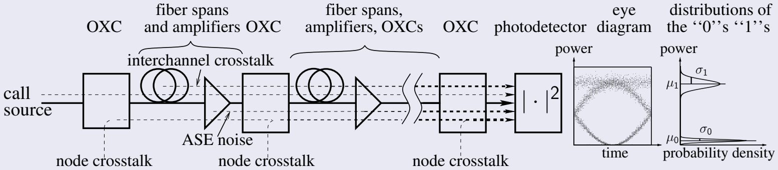
# Lightpath model




$$Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1}, \; BER = \frac{1}{2}\mathrm{erfc}\left(Q/\sqrt{2}\right)$$

- ISI (chromatic dispersion, SPM)
- Amplifier (ASE) noise
- Interchannel crosstalk (XPM, FWM)
- Node crosstalk (optical leaks within nodes)
- BER depends on all these effects (and more)

# Routing



**Offline Routing**

- Fixed Routing
- Time Dependent Routing

**Online Routing**

- State Dependent Routing
- Event Dependent Routing
    - Reinforcement learning

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# RWA in all-optical networks





**Specificities of RWA in all-optical networks:**

- Wavelength continuity constraint
- QoS constraint $\Rightarrow$ cross-layer design
- Distributed algorithms are desirable

- Design a reinforcement learning algorithm
  - Account for physical impairments
  - Distributed
  - Make routing decisions based on network feedback

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# Reinforcement learning



## Setup

- Alternate routing, wavelength assignment fixed (first-fit)
- Routes between $s$ and $d$: $\{R_i^{s,d}\}$
- Load Sharing Factor ($P_i^{s,d}$): probability of selecting $R_i^{s,d}$

## Algorithm description

Upon receiving of a new lightpath establishment request between $s$ and $d$:

- Select one route $R_i^{s,d}$ at random using $\{P_i^{s,d}\}$
- Check all wavelengths in turn for the wavelength continuity and the QoS constraint
  - Accept call on first wavelength that meets all constraints
- Update $\{P_i^{s,d}\}$ using reinforcement learning techniques and Accept/Reject information

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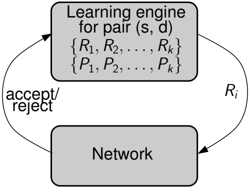
# Reinforcement Learning Engine

## Need an updating scheme suitable for

- Incomplete information about the network
- Learn routing policy via trial and error

## Learning Automata

- Linear Reward $\mathcal{E}$-Penalty (LR$\mathcal{E}$P)
  - Linearly increase $P_i$ when lightpath is accepted on route $R_i$
  - Linearly decrease $P_i$ when lightpath is rejected on route $R_i$
- penalty param. $\ll$ reward param.
- Performs well in non-stationary environments
- Does not get stuck in absorbing states
- Suboptimal



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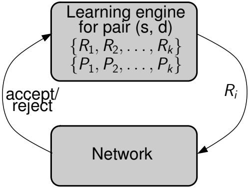
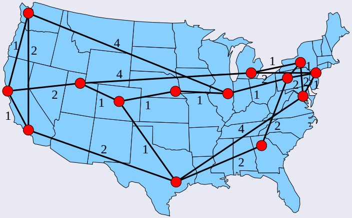


# Simulation parameters



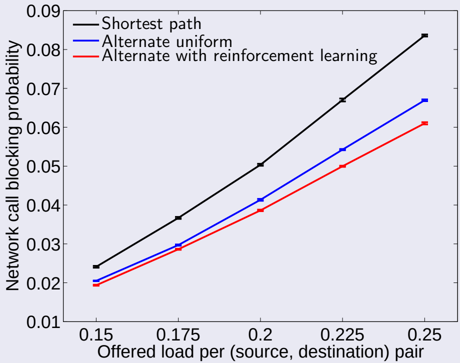
## NSF topology




## Parameters

| Description | Value |
| --- | --- |
| Span length | 70 km |
| Fiber type | SMF |
| Nonlinearities | 2.2 $(W/m)^{-1}$ |
| Dispersion | 100% post |
| Pulse shape | NRZ |
| Peak power | 2 mW |
| Bit rate | 10 Gbps |
| Max BER | $10^{-9}$ |
| # wavelengths | 8 |
| # alt. routes | 4 |

# Simulation results




- Compare with plain shortest path and random route choice
- Blocking rates are lowered by $\approx 10\%$ at higher loads

# Conclusions and future work





## Conclusions

- Proof of concept
- Blocking rates can be lowered using Reinforcement Learning
- The routing technique is completely distributed

## Future work

- Combined routing and wavelength assignment
- Questions ?