Considering transmission impairments in Routing Wavelength Assignment algorithms

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The network guy point of view

- Network people have an “ideal” model of optical networks
  - Transparent or opaque solutions
  - Each fiber link may transport a large number of wavelength (e.g., >128)
  - Each node can optically route every incoming lightpath to every outgoing fiber
  - Wavelength converters may be used
- Using ideal components we face design problems like RWA:
  - Static network: fixed connections, minimize number of wavelength
  - Dynamic network: connections change in time, minimize the blocking probability. We study this scenario

The optical guy point of view

- Network transmission level is composed by
  - Fiber links, amplifiers, OXCs and OADMs supporting a limited number of λ (up to 100)
  - No wavelength converters
- There are several physical limitations:
  - Power budget, noise, dispersion, non linear effects…
- Every time a new lightpath is turned on, the operating point of the overall network may vary
- Hence, a transparent WDM network is far from being ideal, many physical constraints should be considered by network design algorithms

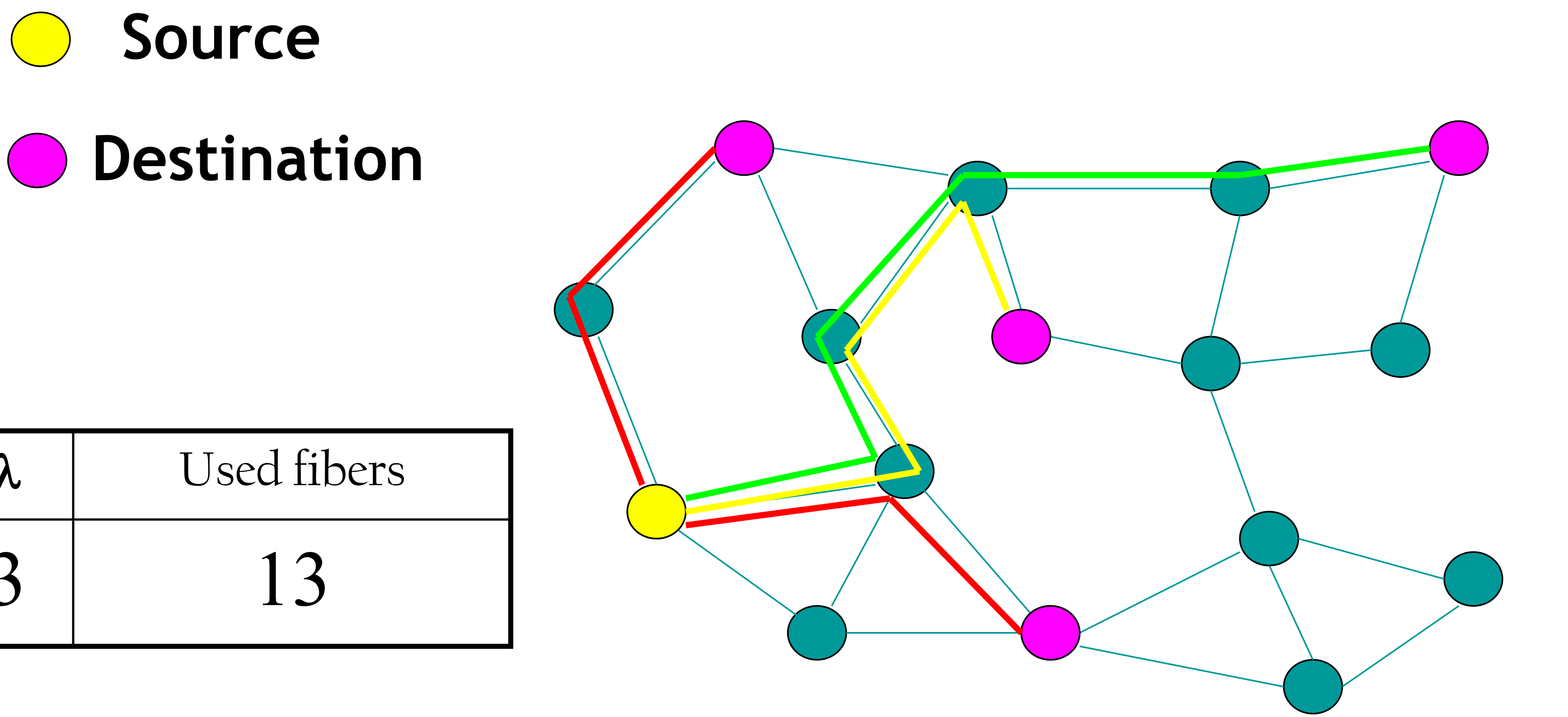
Routing and Wavelenght Assignment

Given

- A physical topology
- A set of lightpath request

- Find for each lightpath request
  - A physical route
  - And a suitable wavelength
- Constraints
  - Wavelength unicity: no more than a lightpath can be identified by a wavelength on fiber
  - Wavelength continuity: the same wavelength must be used on all fiber along the path of given lightpath (no wavelength conversion)

RWA: example



λ	Used fibers
3	13

The idea

Given a "real" optical network comprising fibers, amplifiers, OXCs, OADMs, etc.

↓

At the transmission level, optical constraints are evaluated and given to the networking design solver

→

At the logical level, these constraints are used as weights for the network design

At the present state of the art of computing power a rigorous analysis needs ***centuries*** *of CPU time because of nonlinear nature of transmission level analysis*

Physical level approximation

- We assume that each phenomenon leads to an equivalent noise component for each link
  - ASE noise ⇒ σ_{ASE}
  - Linear ⇒ σ_{LIN}
  - Non linearity ⇒ σ_{NL} (this depends on the number of simultaneous active λ on a fiber)
  - … other …

Impacts the path length (ASE noise, Linear)

Impacts the λ assignment (Non linearity)

- We evaluate $OSNR = P_{ch} / (\sigma_{ASE} + \sigma_{LIN} + \sigma_{NL})$
- *OSNR* may be used as quality parameter

$$BER \cong \frac{1}{2} e^{-0.98 \cdot OSNR}$$

ASE noise and XPM

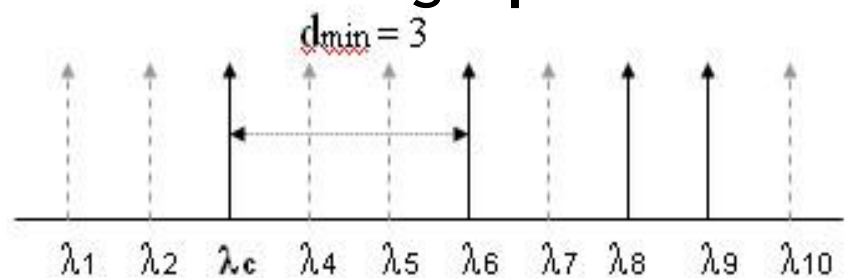
We considered the impact of ASE noise and nonlinear effect called Cross Phase Modulation (XPM)

ASE noise is accumulated considering gain recovering fiber loss and spontaneous emission factor

$$G_{ASE}(f) = 2 \cdot n_{sp} \cdot (GAIN - 1) \cdot h \cdot f$$

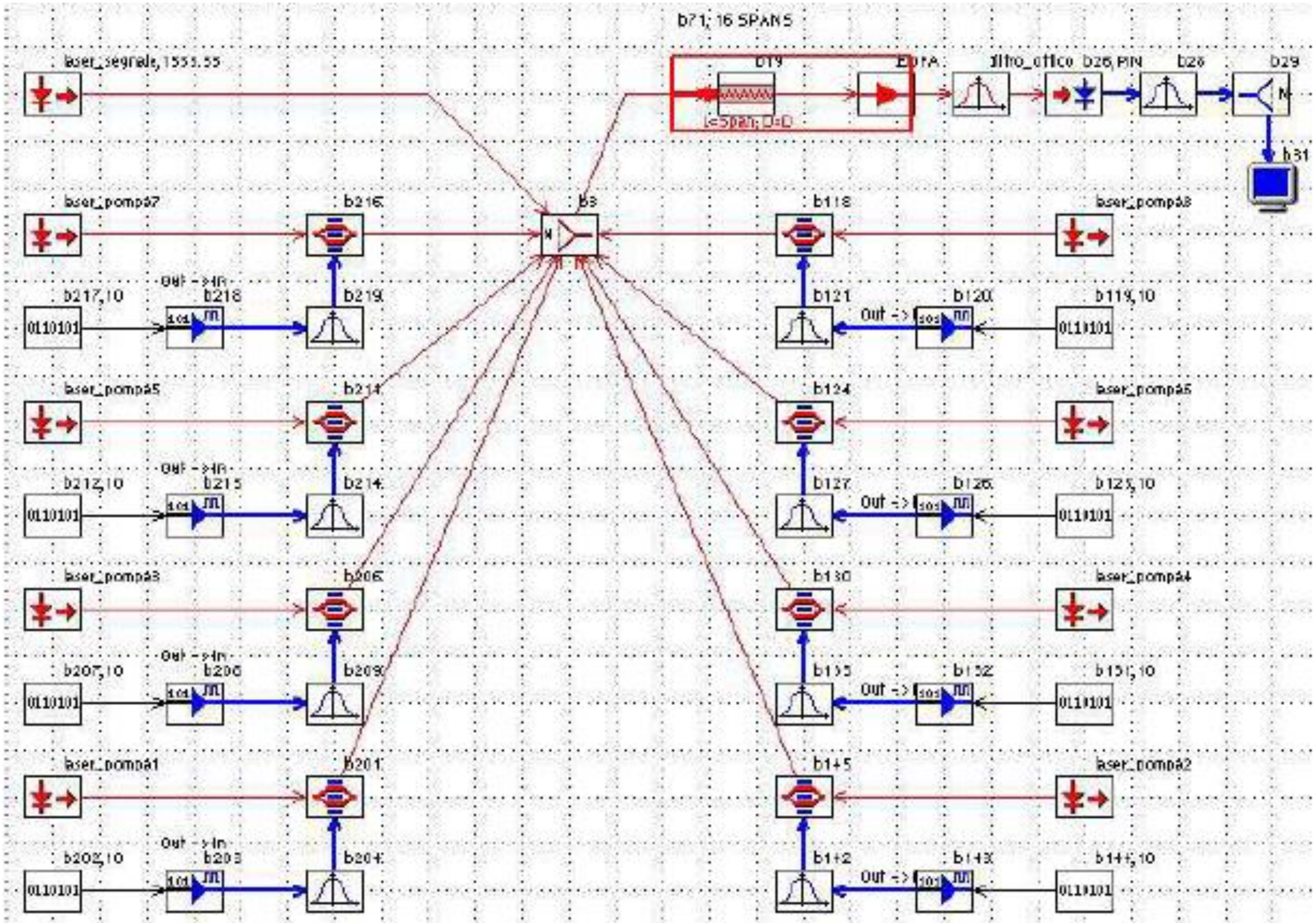
Empirical function for the inclusion of XPM, obtained throuugh a simulation analysis carried out using **OptSim**™**:**

$$\sigma_{XPM} = \frac{P_{TX}\, L_{eff}\, \gamma\, K \log(N_w)}{\Delta f\, d_{min}}$$

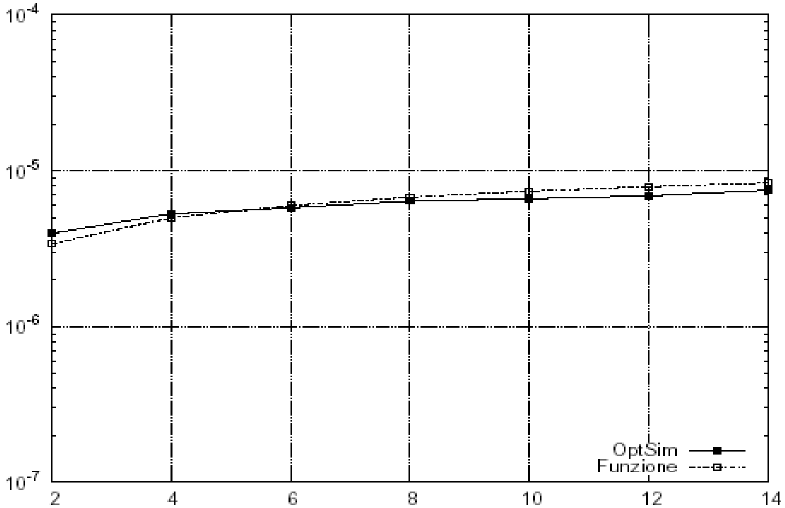


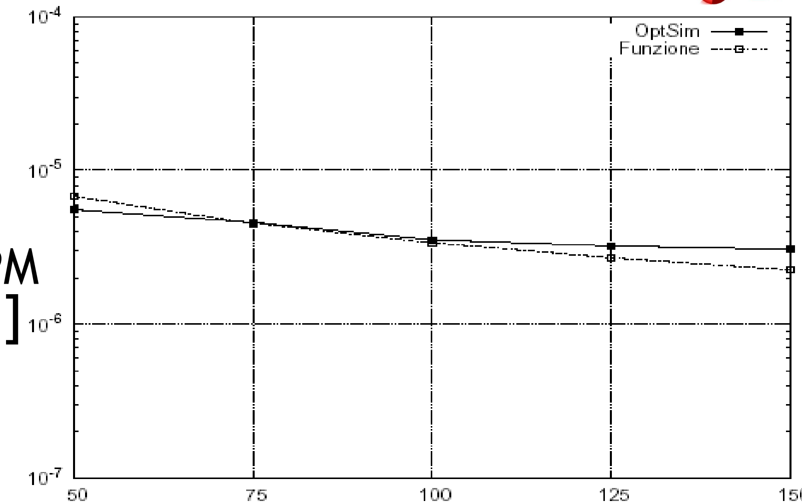
Fitting XPM function using optsim

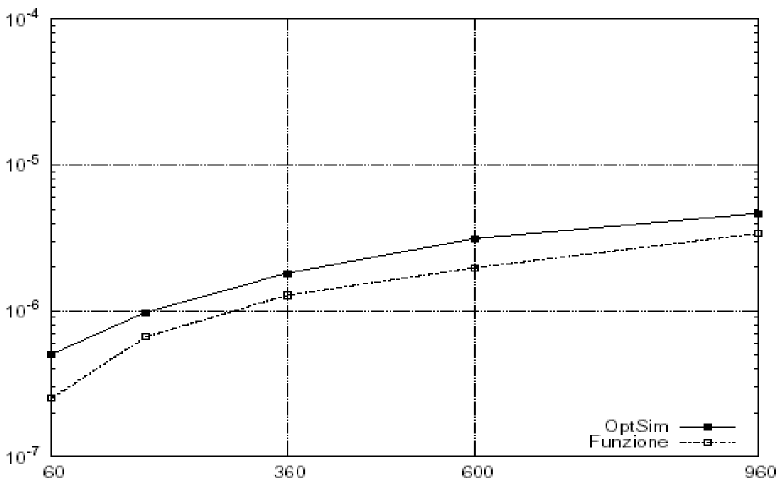
Pump and probe OptSim schematic

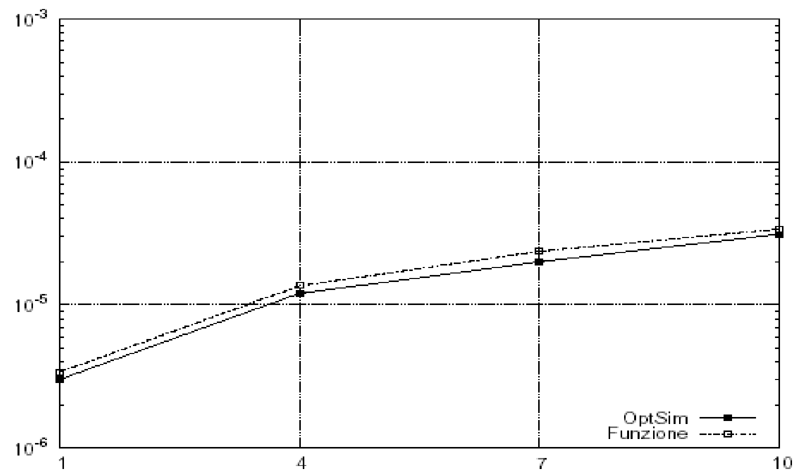


Fitting XPM function using optsim

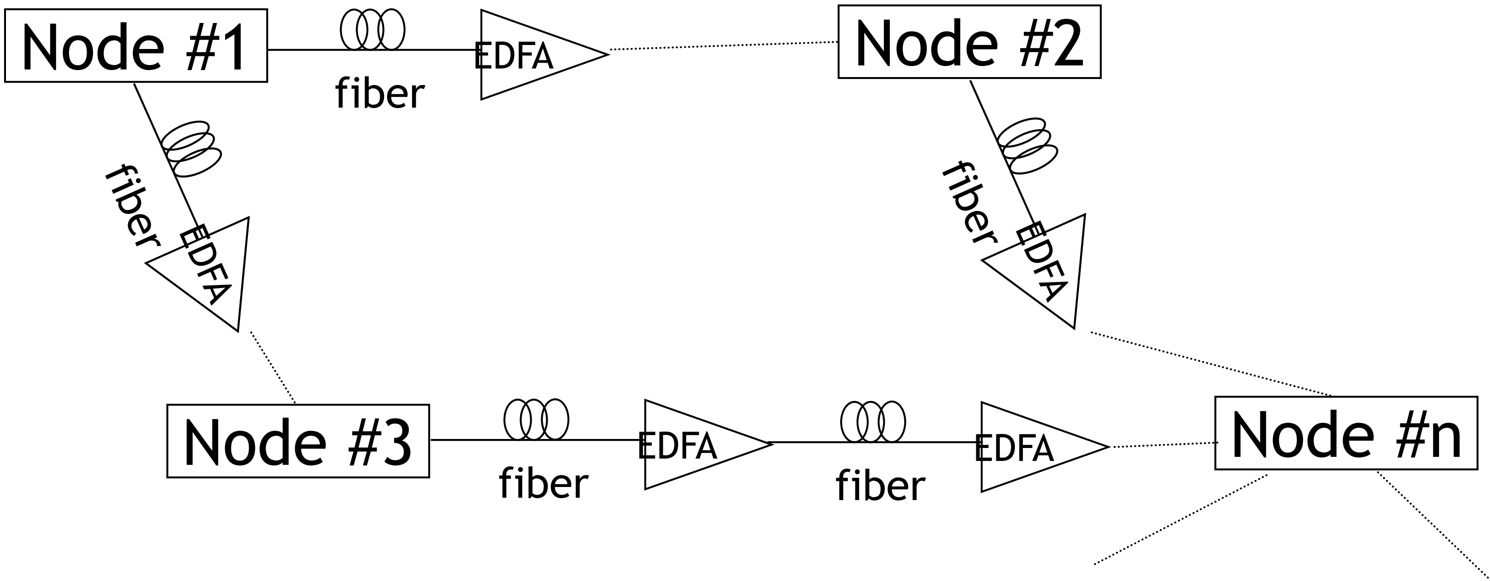






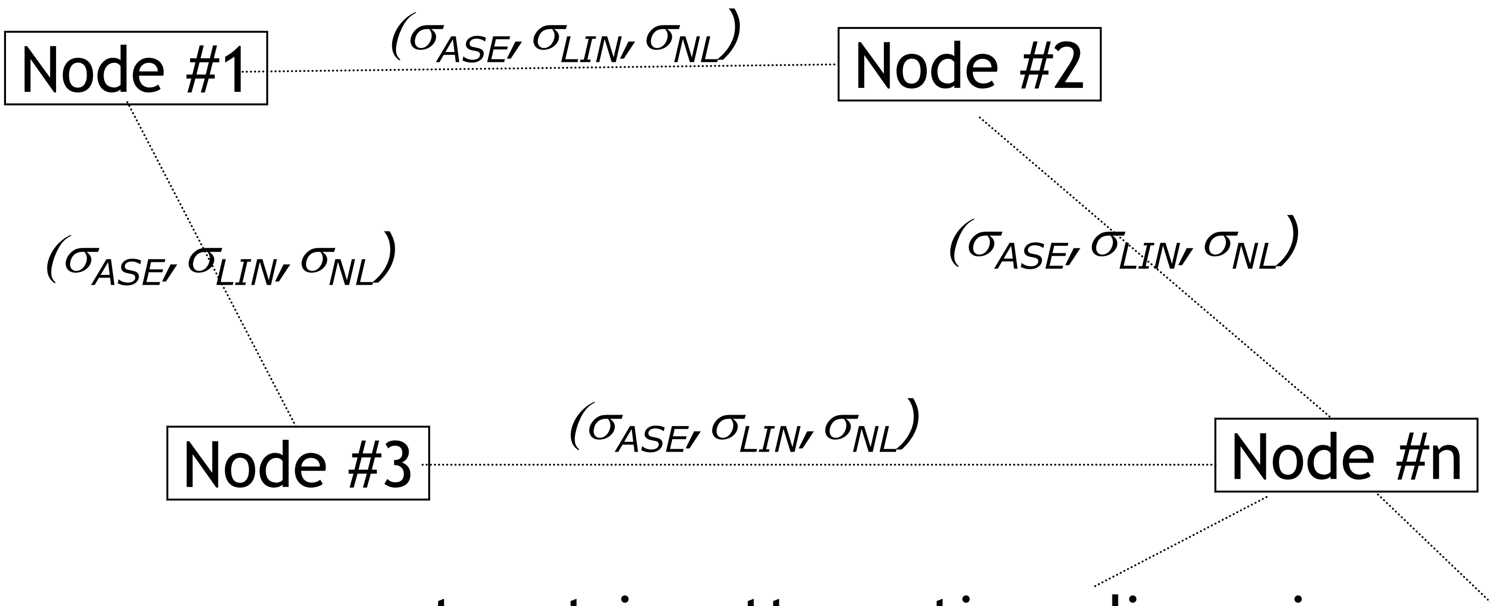


Network model



- Node: cross-connect matrix, attenuation, dispersion
- Fiber: length, attenuation, dispersion, non linear effects
- EDFA: gain, noise level

Network model



- Node: cross-connect matrix, attenuation, dispersion
- Fibre: length, attenuation, dispersion, non linear effects
- EDFA: gain, noise level
- σ_{NL} depends on the number of wavelength actually turned on on each fiber span and on their spectral position

Goal

What is the impact of physical layer constraints on the RWA problem?

- We consider
  - Transparent Wavelength Routed network
  - Dynamic scenario

- Lightpath request is refused if
  - Hard Block: no wavelength is available on any path
  - Soft Block: OSNR on the selected path is smaller than a minimum $OSNR_{min}$ ($BER > BER_{max}$)

First Fit Least Congested Path (FF-LCP)

- Selects the ***Least Congested Path***
- ***First fit:*** assigns the first available wavelength on the selected path
- Block if no λ available
- Check on OSNR
- Block if OSNR < $OSNR_{min}$

Best-OSNR

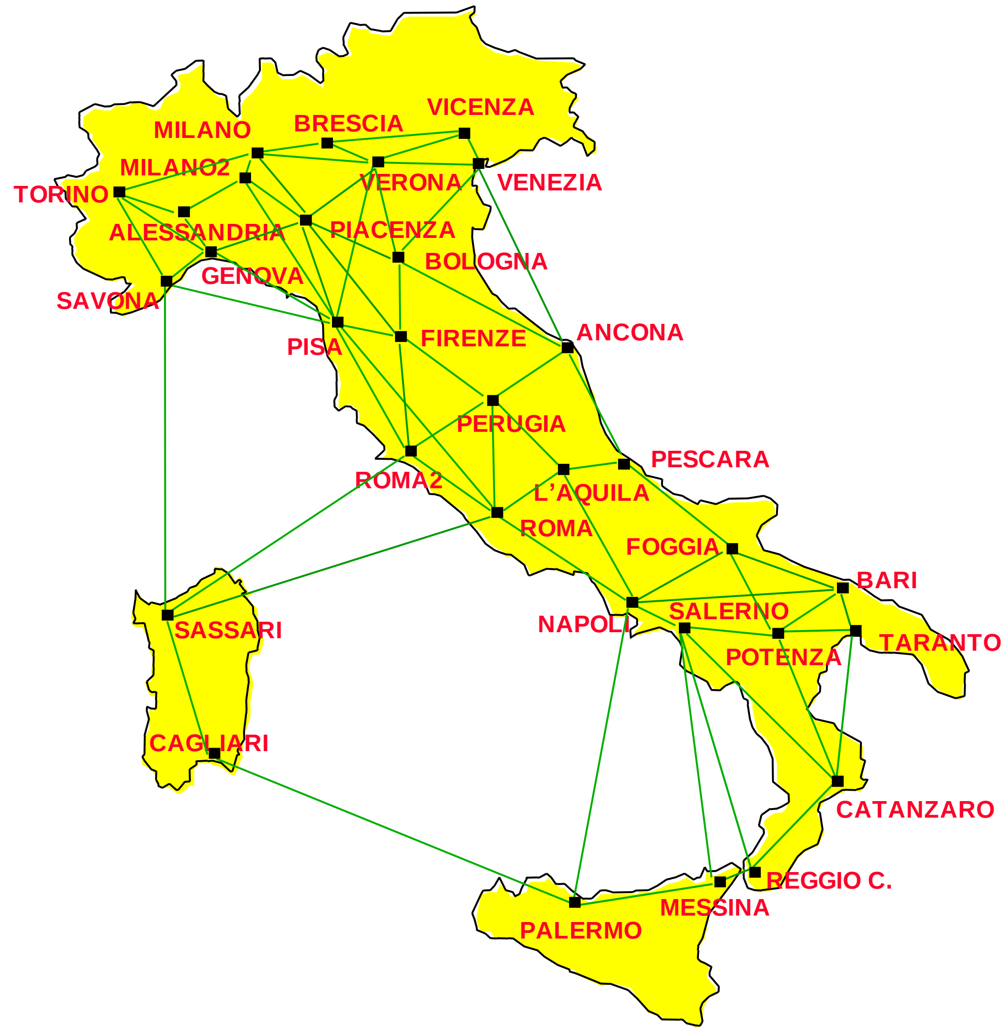
- Selects the path and wavelength presenting the max *OSNR*
- Block if no l available
- Check on OSNR
- Block if OSNR < $OSNR_{min}$

Wavelength Routed simulator

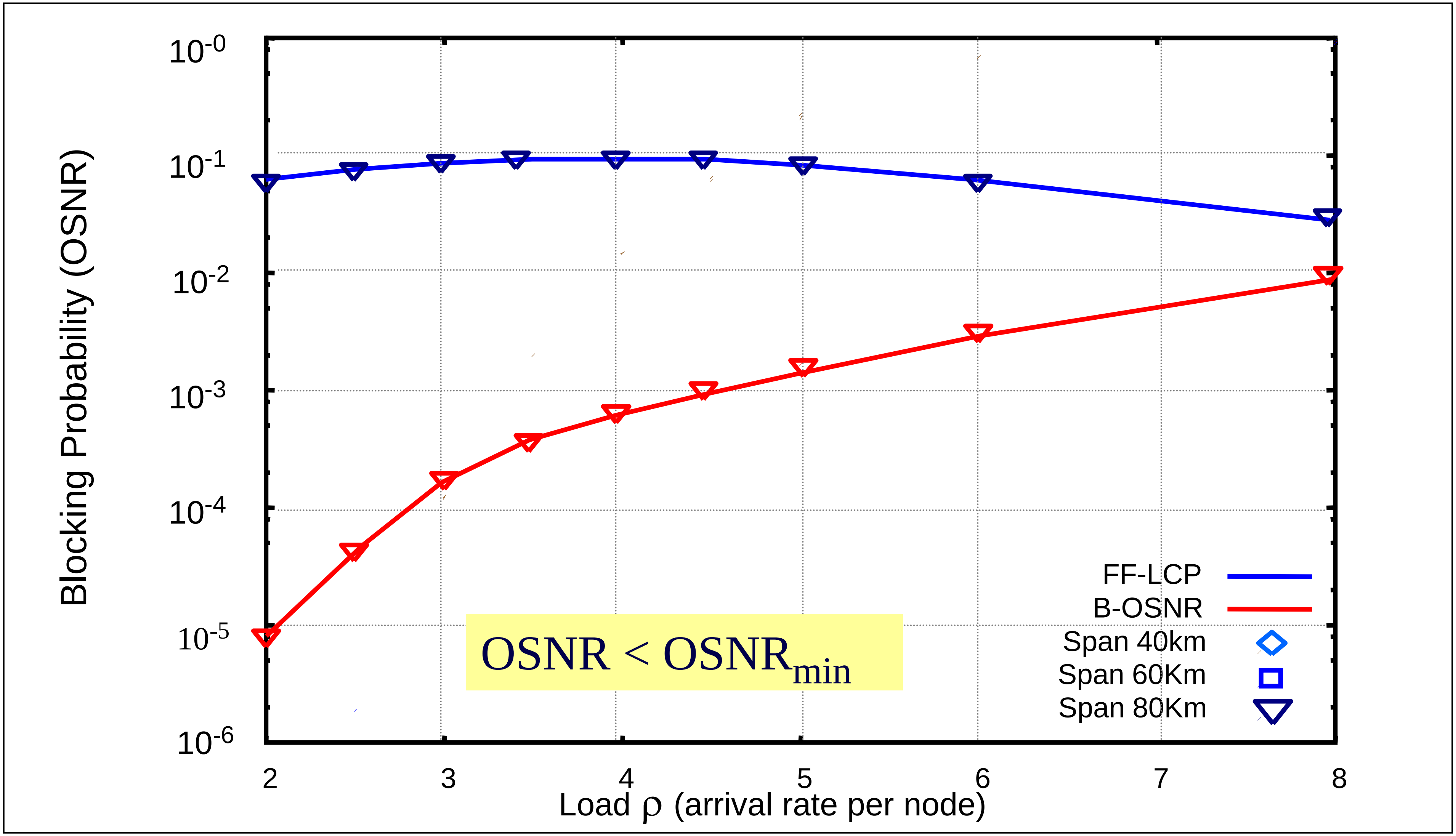
- Asynchronous events simulator
- Hypotheses:
  - Connection requests follow a *Poisson* random process
  - Connection durations follow an exponential random process
- Input:
  - Network physical topology
  - Network load
  - Traffic matrix
- Output:
  - Blocking probability
  - Fiber span loads
  - Other performance indexes..

Results

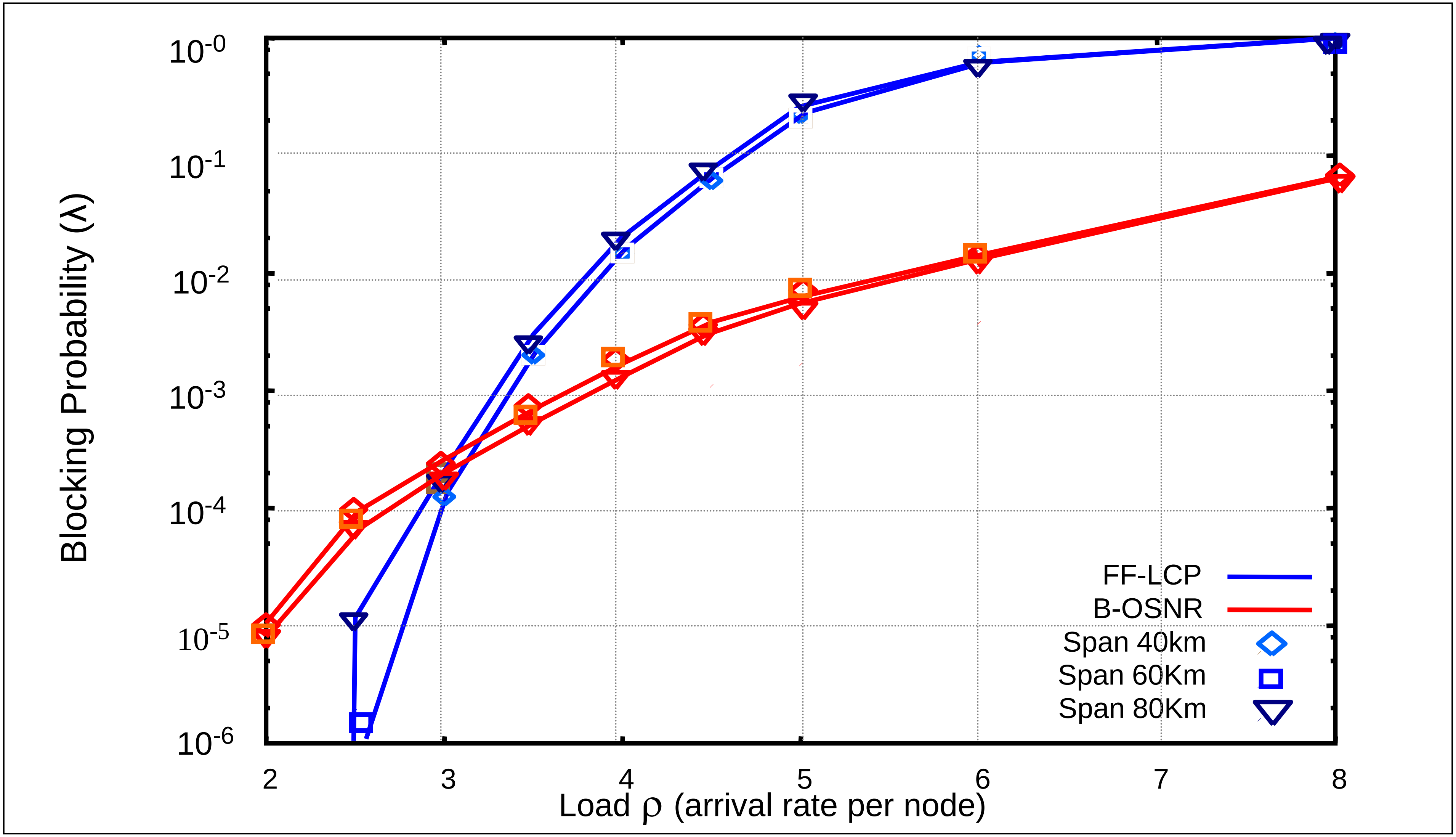
- Physical scenario
  - Italian Topology
  - Fibers: NZ-DSF
  - WDM: 16 λ, Φf = 100 GHz
  - All nodes are identical
  - All EDFA are identical (NF = 5 dB)
- Different span length: EDFAs recover fiber losses every 40, 60 or 80 km



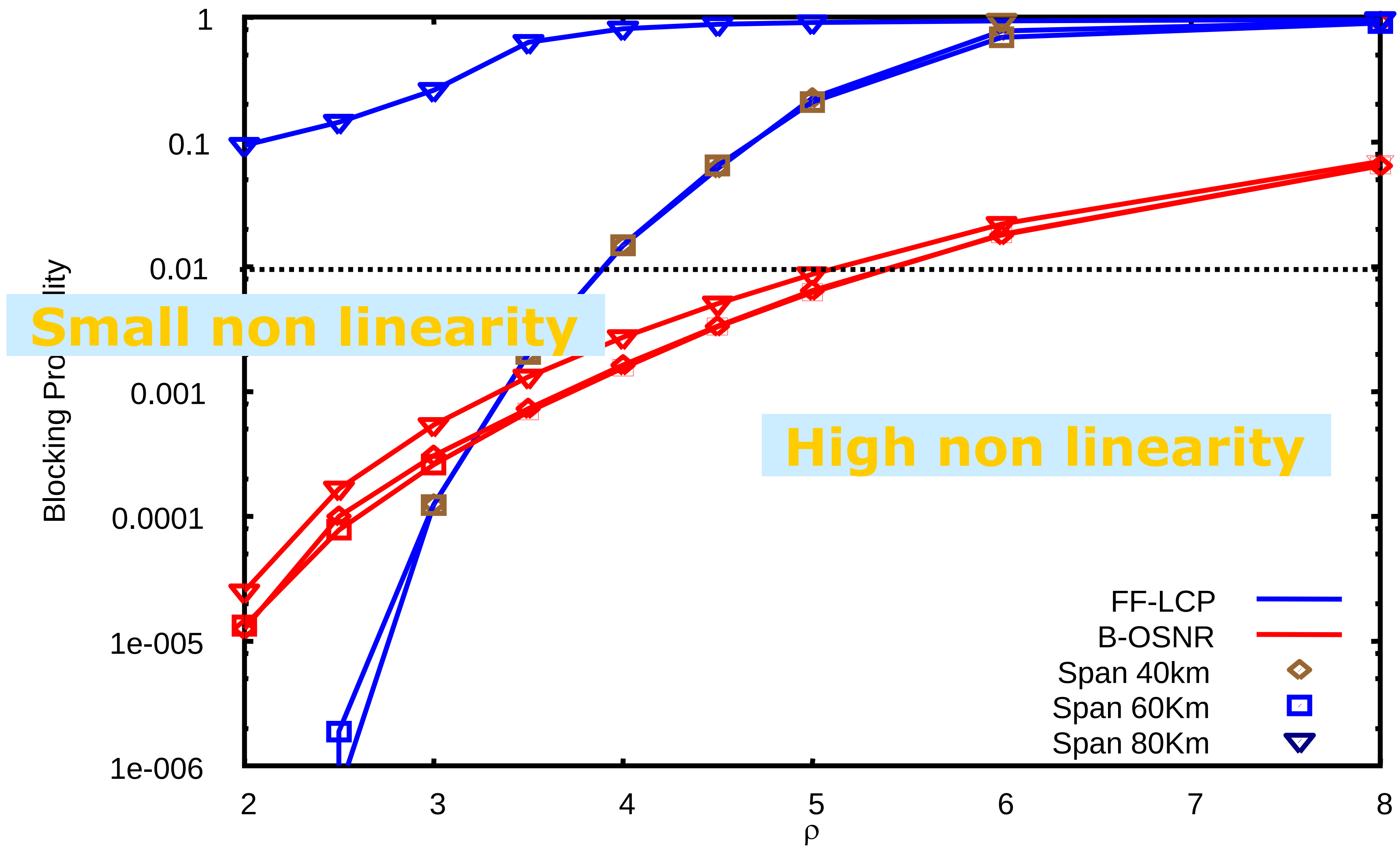
Blocking probability due to OSNR degradation



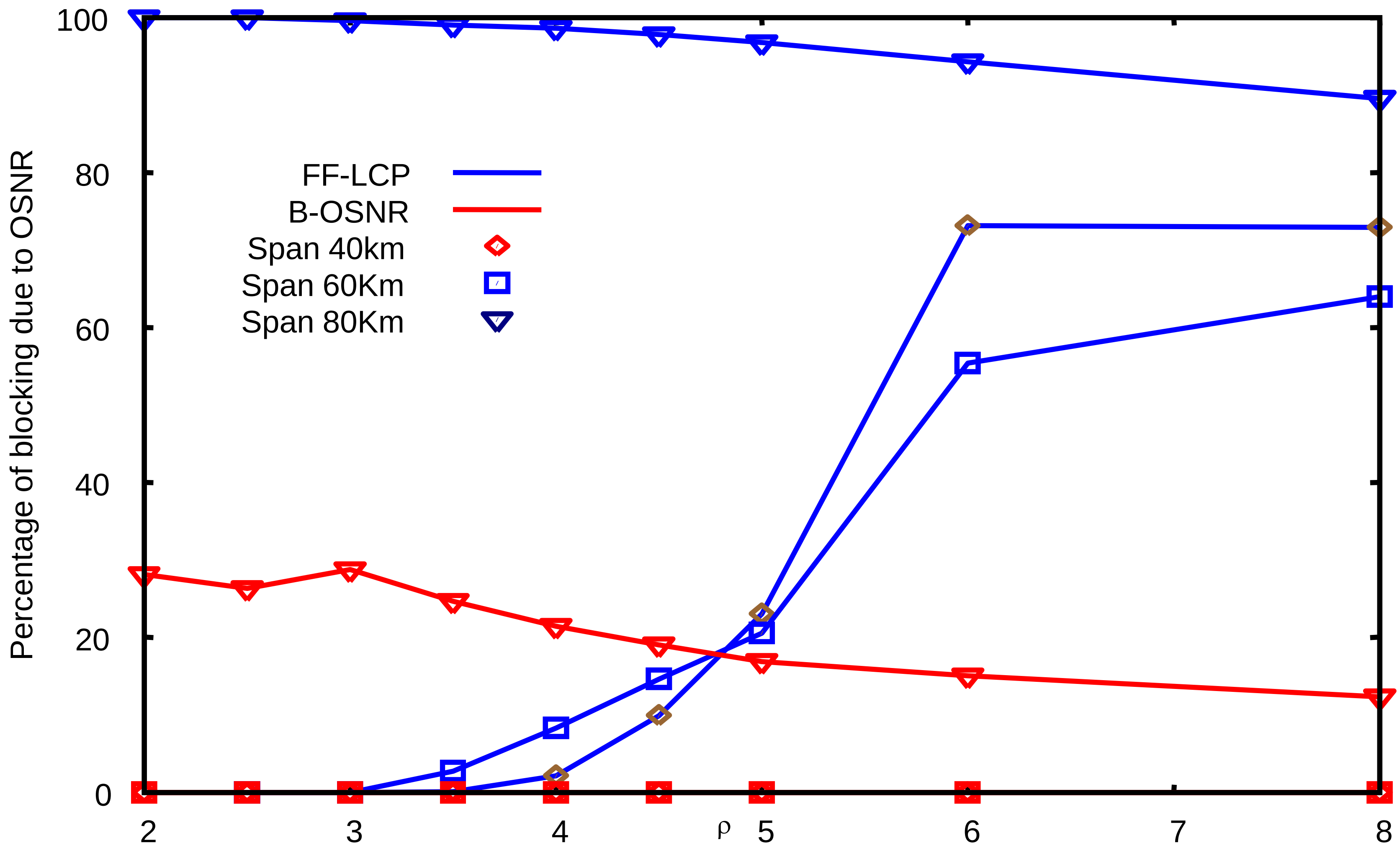
Blocking probability due to absence of available λ



Total blocking probability



Percentage of blocking due to OSRN



Conclusion and future work

- We faced dynamic RWA problem under physical impairment
  - Simple model for the physical layer
  - Efficient algorithm for RWA of dynamic requests
- Physical constraints play a big role in the RWA problem
  - Non linear effects must be considered in transparent WR networks
- What impact on the off-line RWA problem?
  - Optimization must be carried over considering simple physical models