Efficient Use of Network and Control Resources in Impairment-Aware All Optical Networks

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Acknoledgements

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- Amornrat Jirattigalachote
- Gabriel Junyent
- Kostas Katrinis
- Salvatore Spadaro
- Anna Tzanakaki
- Luis Velasco
- Lena Wosinska

Outline

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- Transparent optical networks
- Lightpath provisioning considering optical impairments and different QoS levels
  - Impairment constraint based routing with service differentiation (ICBR-Diff)
- ICBR routing in a distributed scenario (set-up time, GMPLS extensions)
  - Impairment-aware probabilistic provisioning method
- Performance assessment
- Conclusions

Optical transparency

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- Lightpaths routed from source to destination entirely in the optical domain
- Pros
  - Cost reduction (less O/E/O conversion)
  - High bit rate, less energy consumption and protocol transparency
- Cons
  - Physical medium not ideal (i.e., optical physical impariments)
  - Optical signal degradation
  - Less signal regeneration opportunities

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Traditional ICBR

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- RWA algorithm considers resource availability and physical layer parameters
- Q-penalty used as routing parameter
  - link cost in the routing algorithm
  - the path with lowest level of impairments
- Q-factor evaluation
  - Amplified Spontaneous Emission Noise (ASE)
  - Cross-Phase Modulation (XPM)
  - Four-Wave Mixing (FWM)
  - Optical Filtering
  - Self-Phase Modulation / Group Velocity Dispersion
- Path quality measured in terms of Bit Error Rate (BER)
- BER calculated through quality factor Q and compared against predefined threshold (e.g., $BER_{thresh} = 10^{-15}$)

Different QoS requirements

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- Next-Generation Internet will need to support a variety of services
  - High definition television (HDTV)
  - Audio Video On Demand (AVOD)
  - Peer-to-peer (P2P) applications
- Traditional ICBR schemes
  - Select the path with minimum BER (Impairment-Aware Best-Path IABP)
  - Single signal quality requirement
- Issue: no QoS differentiation and unnecessary blocking of requests

The ICBR-Diff intuition

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- Impairment Constraint Based Routing with service differentiation
- Different service classes with different signal quality requirements
  - *Class-1*: require high signal quality
  - *Class-2*: tolerate lower signal quality
  - Etc.
- Assign to each connection resources that are *good enough* to satisfy the BER requirements of a class
- Path selection mechanism
  - ICBR-Diff selects the path with maximum acceptable BER from a set of *candidate* paths

Path selection example

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- Class-1: BER < 10^{-15}
- Class-2: BER < 10^{-9}

BER of *5* feasible routes = [10^{-8}, 10^{-10}, 10^{-12}, 10^{-16}, 10^{-18}]

Path selection example

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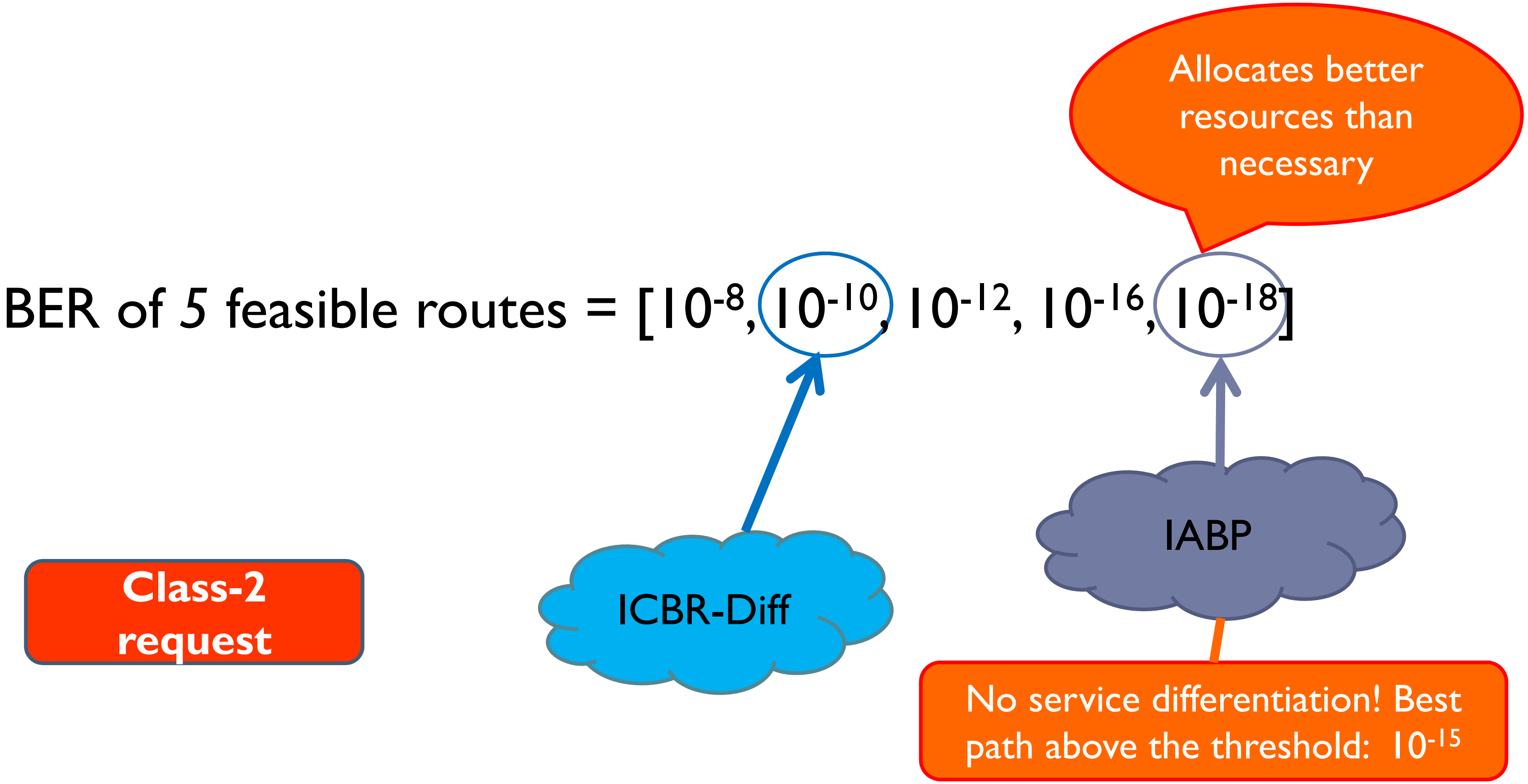
- Class-1: BER < 10^{-15}
- Class-2: BER < 10^{-9}



ICBR-Diff: algorithm

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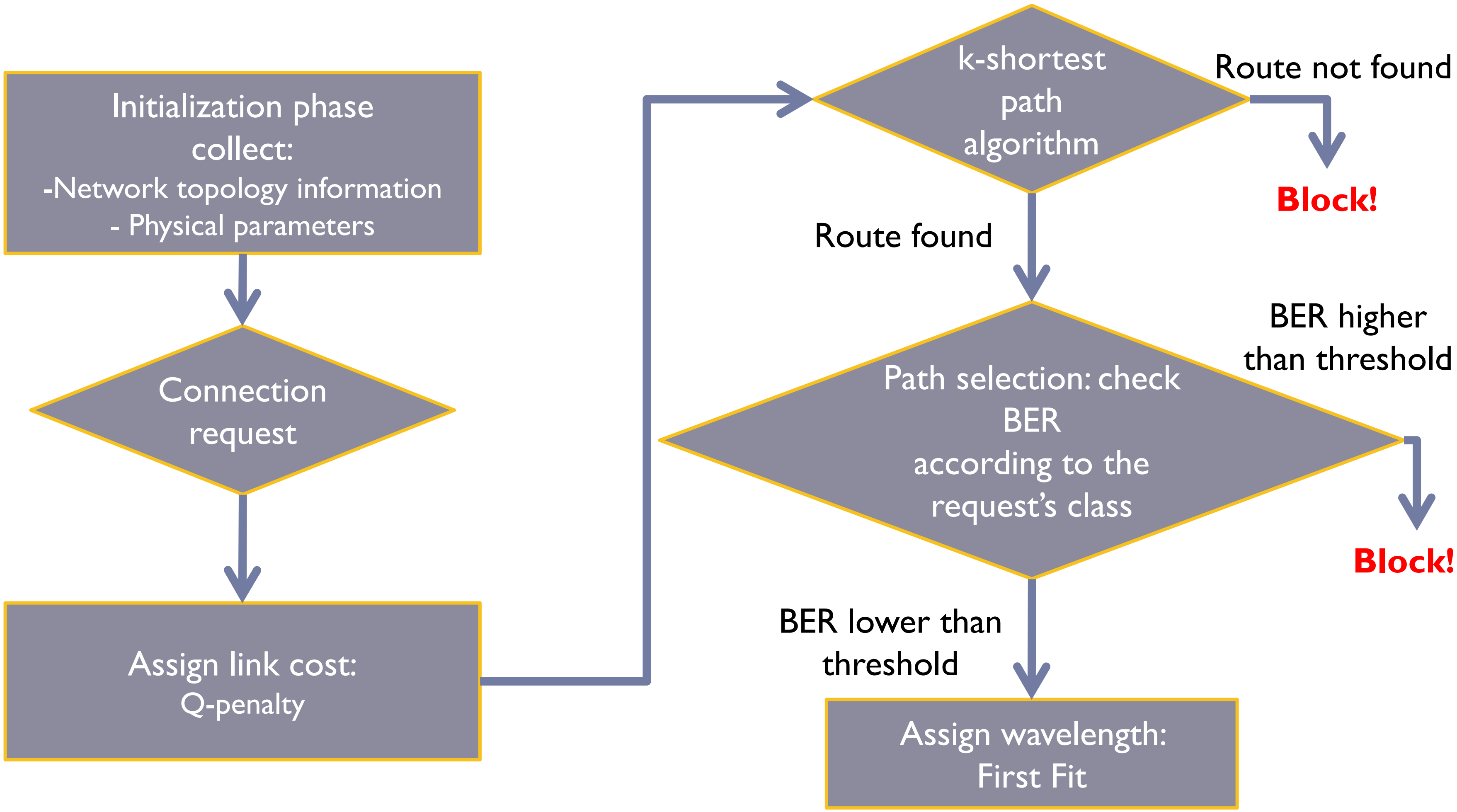

Performance study

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- Poisson arrival of connection requests and exponentially distributed service time
- Bandwidth of connection request: one wavelength unit
- No wavelength conversion
- Derivation of BER assumes all wavelengths on a fiber occupied (worst case analysis)
- Two classes of connection requests
  - Class-1: requiring BER < 10^{-15}
  - Class-2: requiring BER < 10^{-9}
- Two cases for traffic mix of Class-1 and Class-2 requests
  - Class-1 -- Class-2 = 30%--70%
  - Class-1 -- Class-2 = 50%--50%
- Pan European Cost 239 network topology (11 nodes 26 bi-fibers, 16 wavelength per fiber)

Results: total blocking

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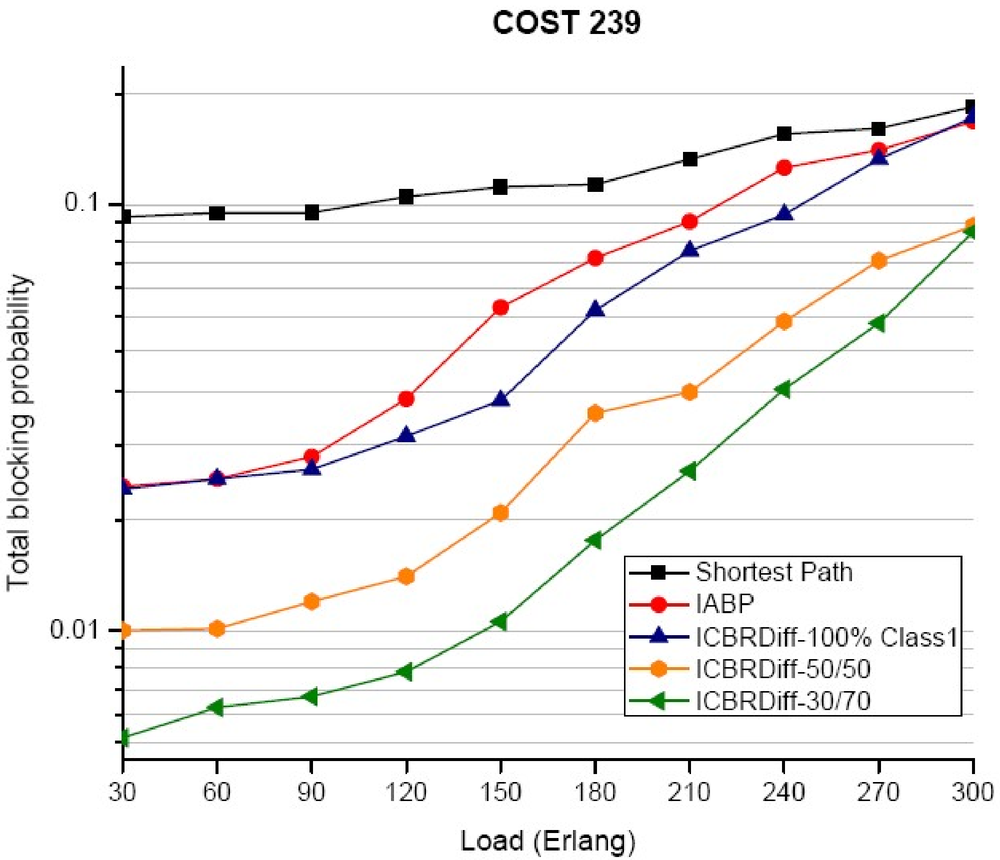

Traffic mixes	Shortest Path	IABP (10^{-15})
30/70	90%	83%
50/50	80%	66%

Lightpaths with acceptable BER with respect to the signal quality requirement of each specific service class

High quality links are kept for demanding services

Efficient utilization of network resources

Lower blocking probability

A. Jirattigalachote, P. Monti, L. Wosinska, K. Katrinis, A. Tzanakaki, "ICBR-Diff: an Impairment Constraint Based Routing Strategy with Quality of Signal Differentiation," *Journal of Networks, Special Issue on All-Optically Routed Networks*, 2010.

Survivability study

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- Performance of ICBR-Diff when protection is required
- Optical physical impairments considered also while computing the protection path
- Path protection with link (single) failure assumption
  - Dedicated path protection scheme
  - Shared path protection scheme

Survivable ICBR-Diff

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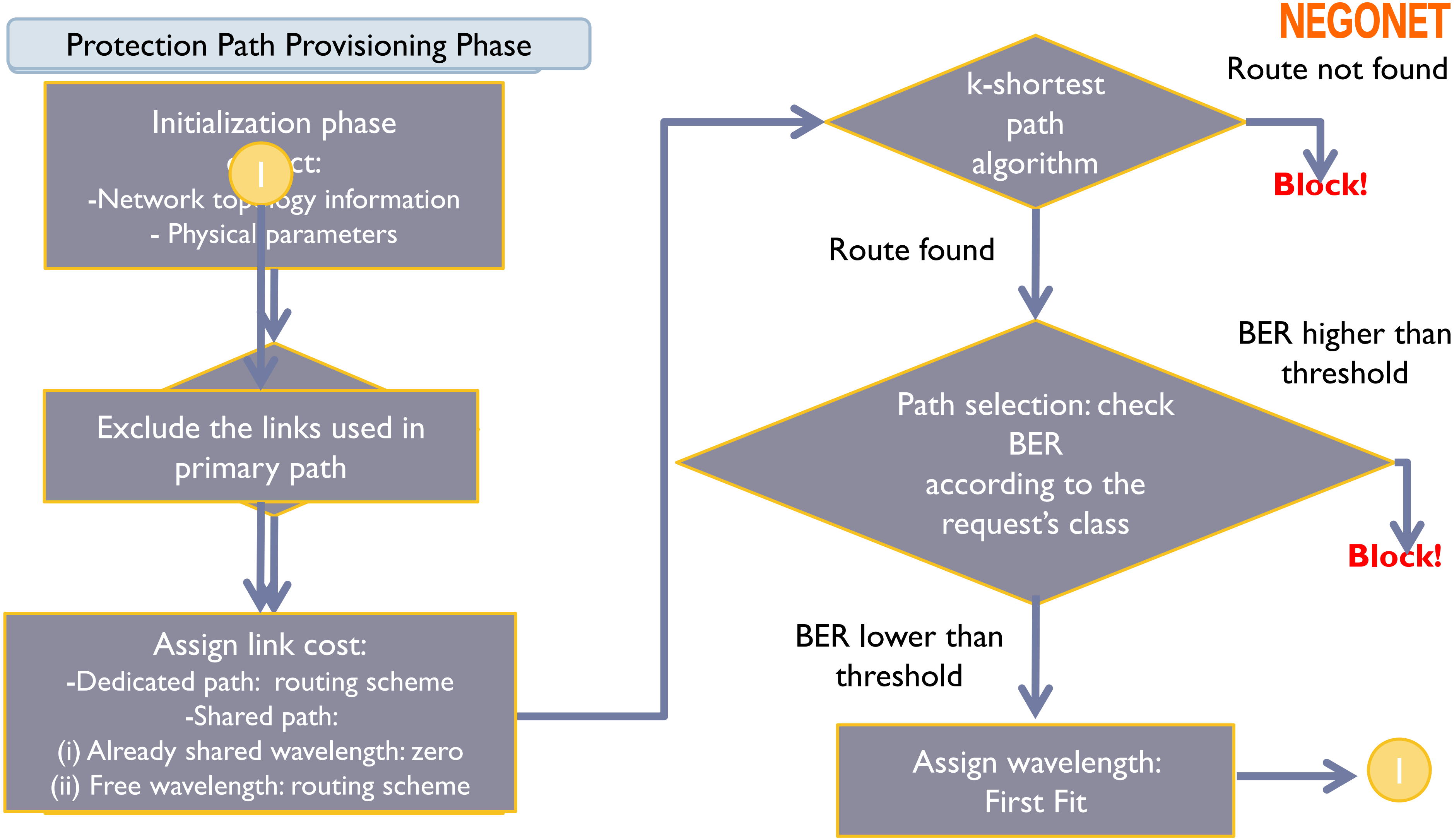

Dedicated path protection

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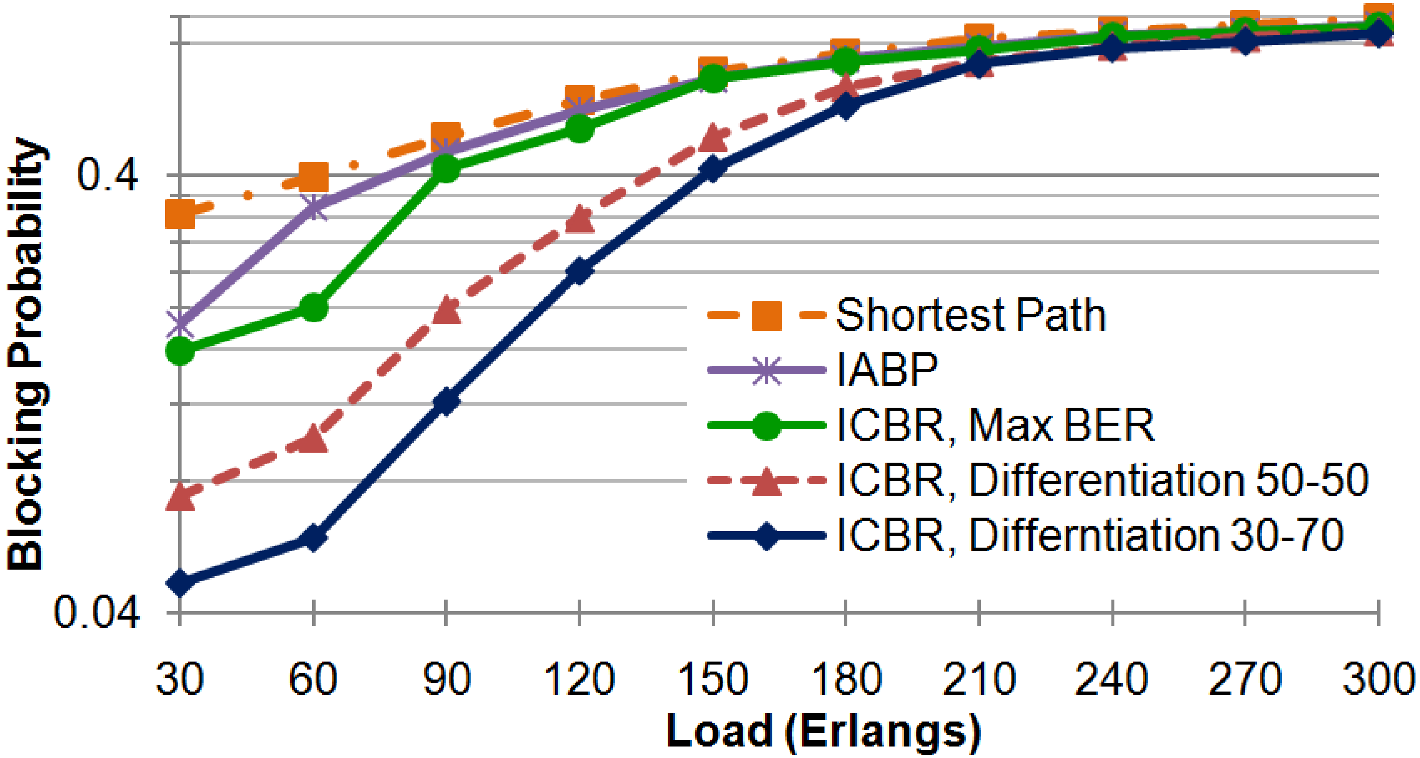

Traffic mixes	Shortest Path	IABP (10^{-15})
30/70	37%	33%

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Shared path protection

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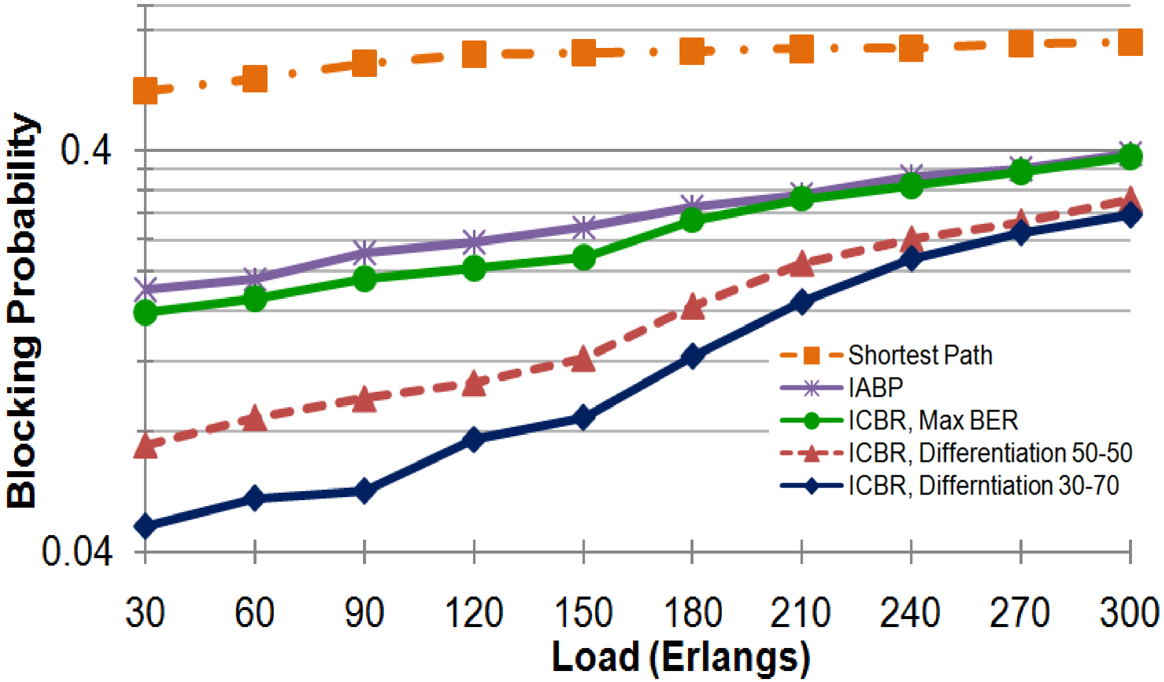

Traffic mixes	Shortest Path	IABP (10^{-15})
30/70	61%	17%

Provides a lightpath that has acceptable BER performance with respect to the signal quality requirement of each service class request

More efficient resource utilization

Avoid unnecessary blocking

A. Jirattigalachote, L. Wosinska, P. Monti, K. Katrinis, and A. Tzanakaki, "Impairment Constraint Based Routing (ICBR) with Service Differentiation in Survivable WDM Networks", *in Proc. of ECOC*, 2009.

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Physical layer impairments

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- Physical layer impairments classified into:
  - Affect each of the wavelengths individually
    - e.g., Attenuation, ASE noise, CD, PMD, SPM
  - Cause interference between wavelengths
    - e.g., XPM, FWM
- With interference between wavelength, lightpaths already established are also affected
- Distributed provisioning protocol has to account for this effect while deciding on whether to route a lightpath or not

Impairments estimation in a distributed scenario

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- Current state of the network: impairments computed and checked at each provisioning
  - **Current information, need to extend the GMPLS protocol set**
  - **Set-up times are long** for on-line Q-factor computation
- Worst case scenario: impairments fixed penalties for each link assuming that all wavelength are used
  - **Short lightpath set-up time** (the Q-factor can be pre-computed beforehand for each link)
  - **No need for GMPLS protocol extensions**
  - **Blocking probability** (might) unnecessarily **high**
- A probabilistic approach: a prediction on the maximum number of used wavelengths in every link in the network

Probabilistic Model

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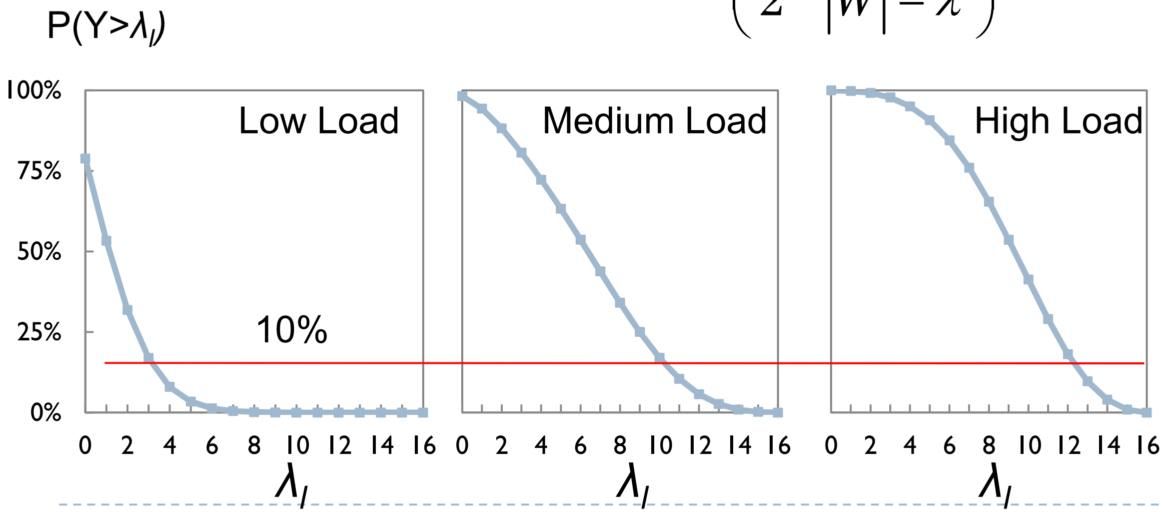
- $G(N, E, W)$ optical network graph
  - δ: the average nodal degree
  - H : the average hop length of a lightpath. $H \sim ((|N|-2)/(\delta-1))^{1/2}$
  - C: the average number of established lightpaths for a given offered load
  - λ: the average number of used wavelengths in a link, $\lambda = C \cdot H / |E|$
- Cumulative distribution of maximum number of used wavelengths in every link

$$P(Y > \lambda_l) = \alpha \cdot \left(\frac{1}{2} \cdot \frac{|W| - \lambda_l}{|W| - \lambda} \right) + (1-\alpha) \cdot [1 - P(X \le \lambda_l)]$$



Load (E)	8	16	24	32	40	48
Max wav. (λ_l)	3	5	7	9	10	11

Load (E)	56	64	72	80	88	96
Max wav. (λ_l)	12	13	14	14	15	16

ASE, XPM and FWM noise variance

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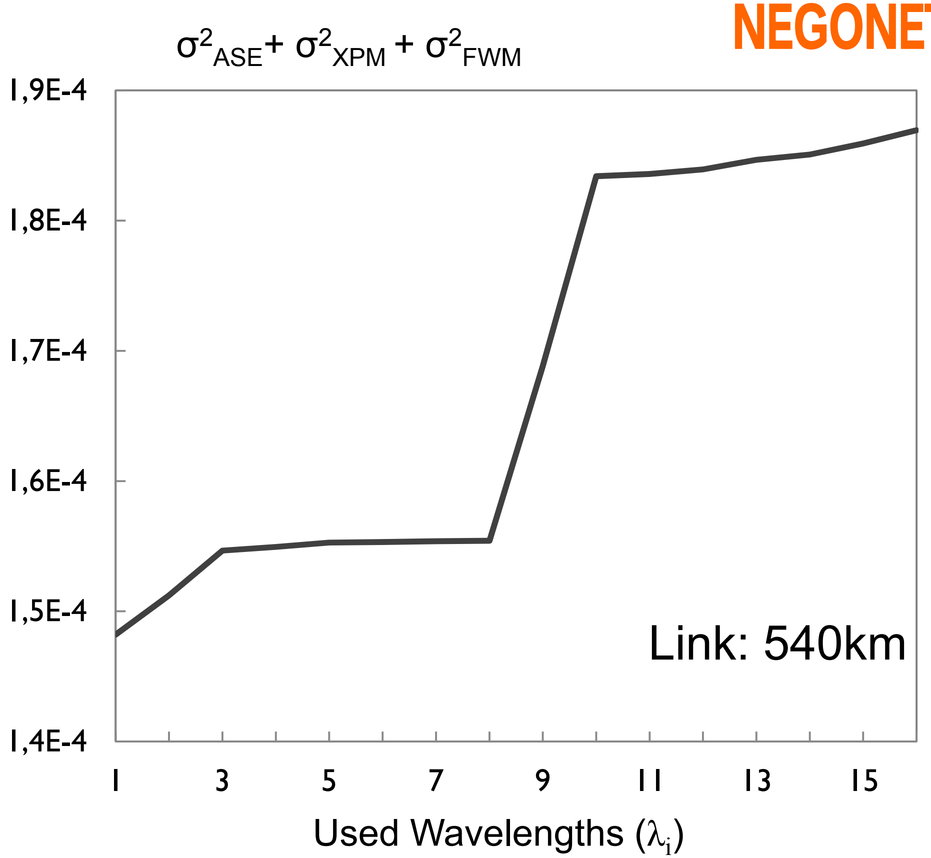
- Search order which spreads the used wavelengths as much as possible
- Minimal total variance and better lightpath Q-factor value
- Q-factor estimation is based on the impairments over the central wavelength (worst case)



Wavelength #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Search order	6	11	13	4	15	2	9	1	10	3	16	5	14	7	12	8

Blocking Probability (*Pb*)

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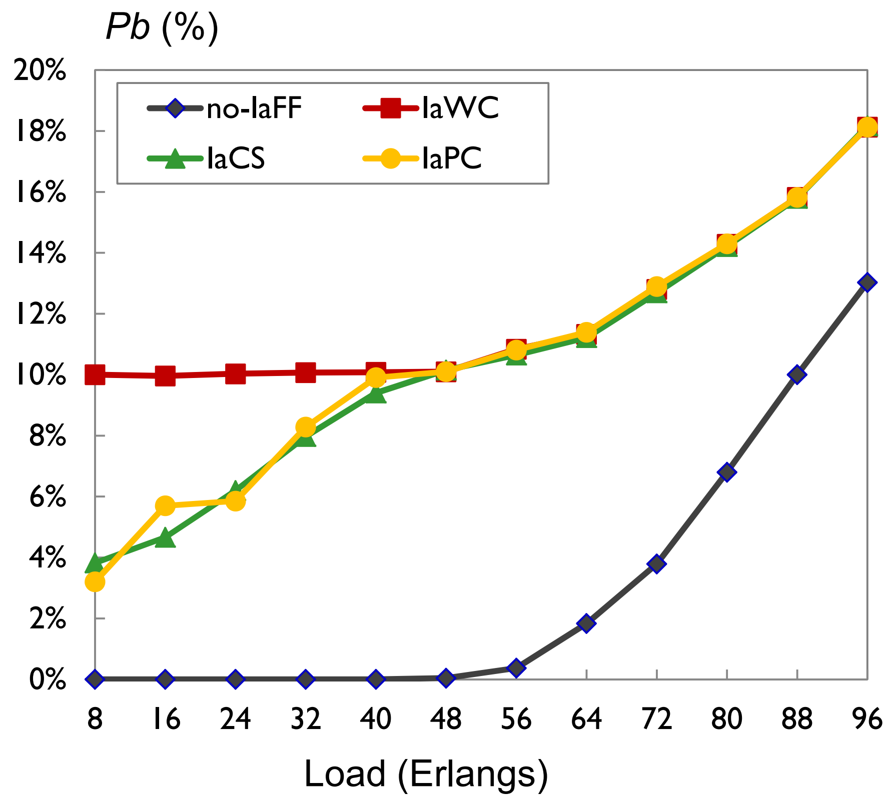
- Simulations with 16 node EON COST266 reference network) every link with 16 wavelengths
- Q threshold = 7.4 ⇔ BER ≈ 6.8 10^{-14}



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Impairments Availability

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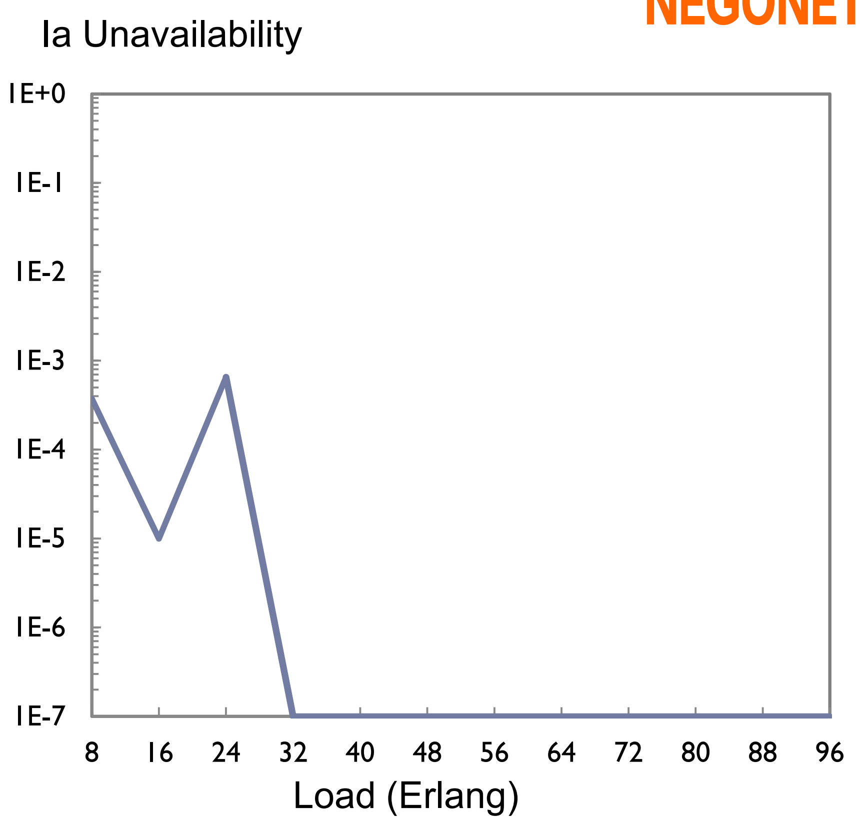
- With *Ia-CS* and *Ia-WC* each established lightpath with BER better than or equal to the threshold
- The constraint relaxed with *Ia-PC* approach
- Unavailability: ratio between lightpath experience BER>threshold and the total time the lightpath is established in the network



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Conclusions

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- ICBR routing with QoS levels
  - ICBR-Diff approach where path with maximum acceptable BER (good enough) is selected (both primary and secondary)
  - Significant blocking probability improvement against conventional ICBR
- ICBR routing in a distributed scenario
  - ICBR-PC approach with a contained set-up time and with no extensions for GMPLS protocol
  - Blocking probability comparable with exact ICBR approaches with acceptable level of unavailability

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Thank you!!

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