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Nonlinearity Estimation for Efficient Resource Allocation in Elastic Optical Networks

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Outline

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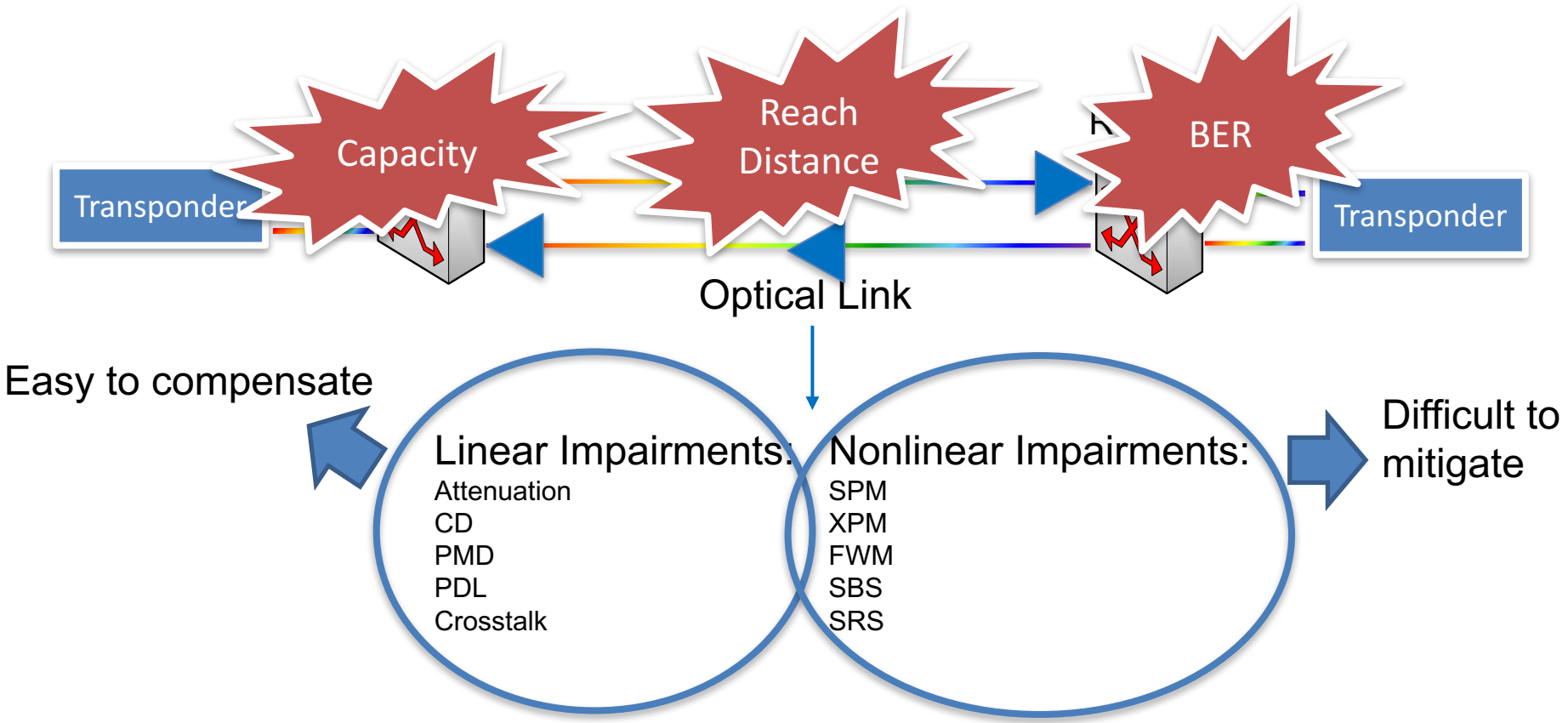
- Motivation
- Current solution of nonlinearity analysis
- Proposed hybrid nonlinearity model
- Nonlinearity aware resource allocation algorithm
- Results
- Conclusion

Motivation

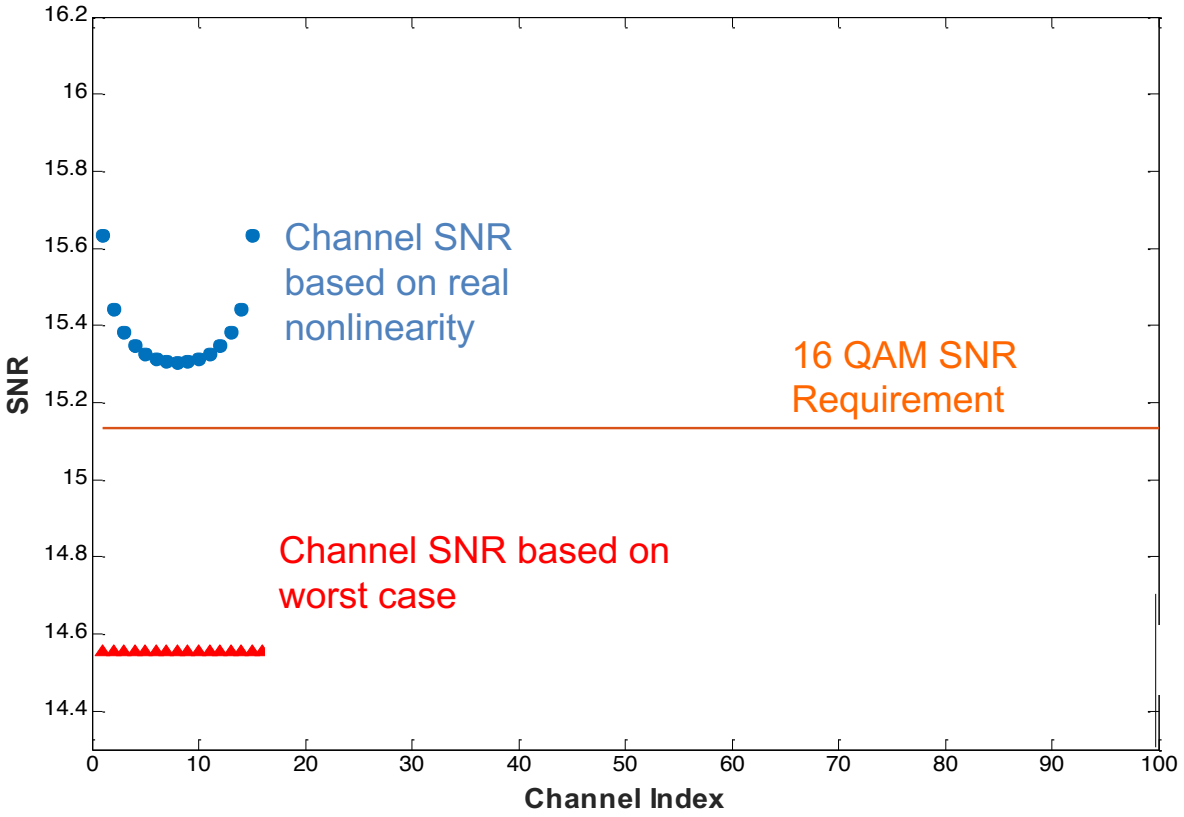
- Optical link introduce penalties which affect connections quality.



Existing Method to Use Nonlinearity Information

Worst-case or known as reference margin (RM) method

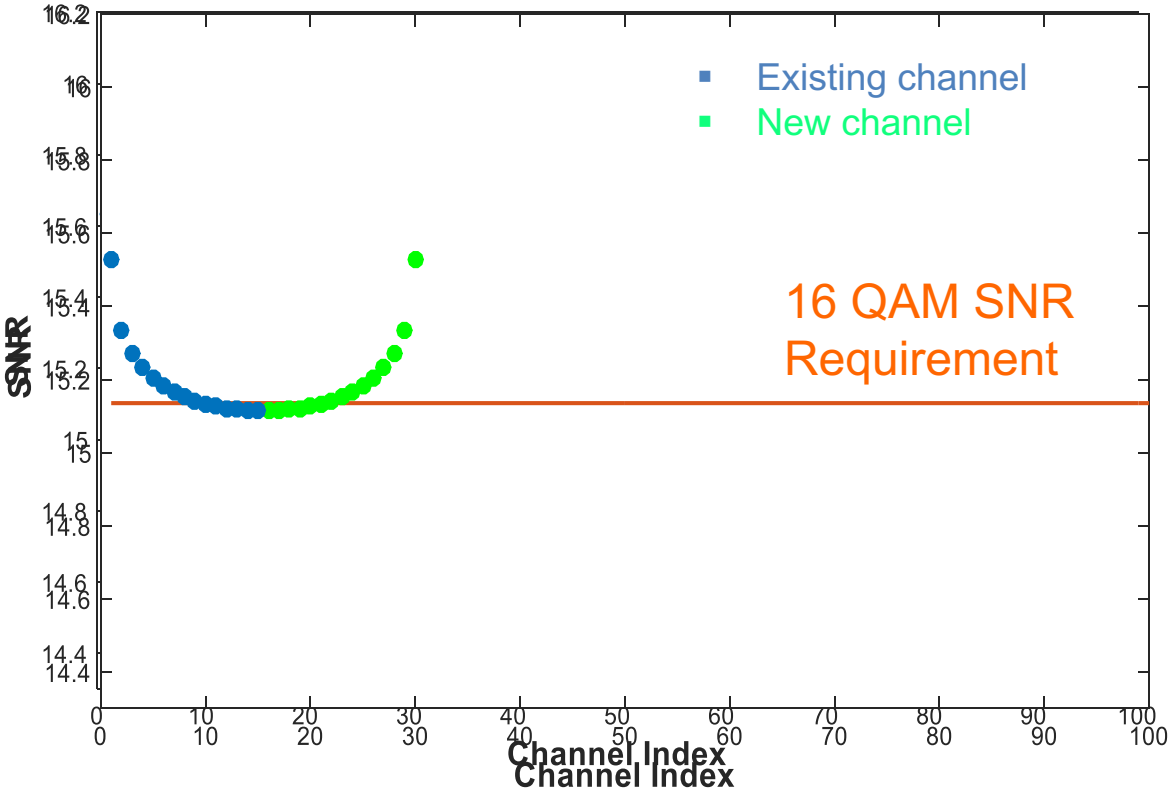
- ✓ Pros: Easy to implement/calculate. Does not require complex model or expensive nonlinear impairments monitoring techniques.
- ✗ Cons: Sacrifice network performance when the network not in worst case.



Existing Method to Use Nonlinearity Information

Accurate nonlinearity information

- ✔ Pros: More accurate information, improve network performance if traffic matrix pre-known.
- ✖ Cons: Computational complex model, expensive monitoring hardware.
- ✖ May block the future requests when traffic matrix unknown.



Effects of Two Nonlinearity Analysis Methods

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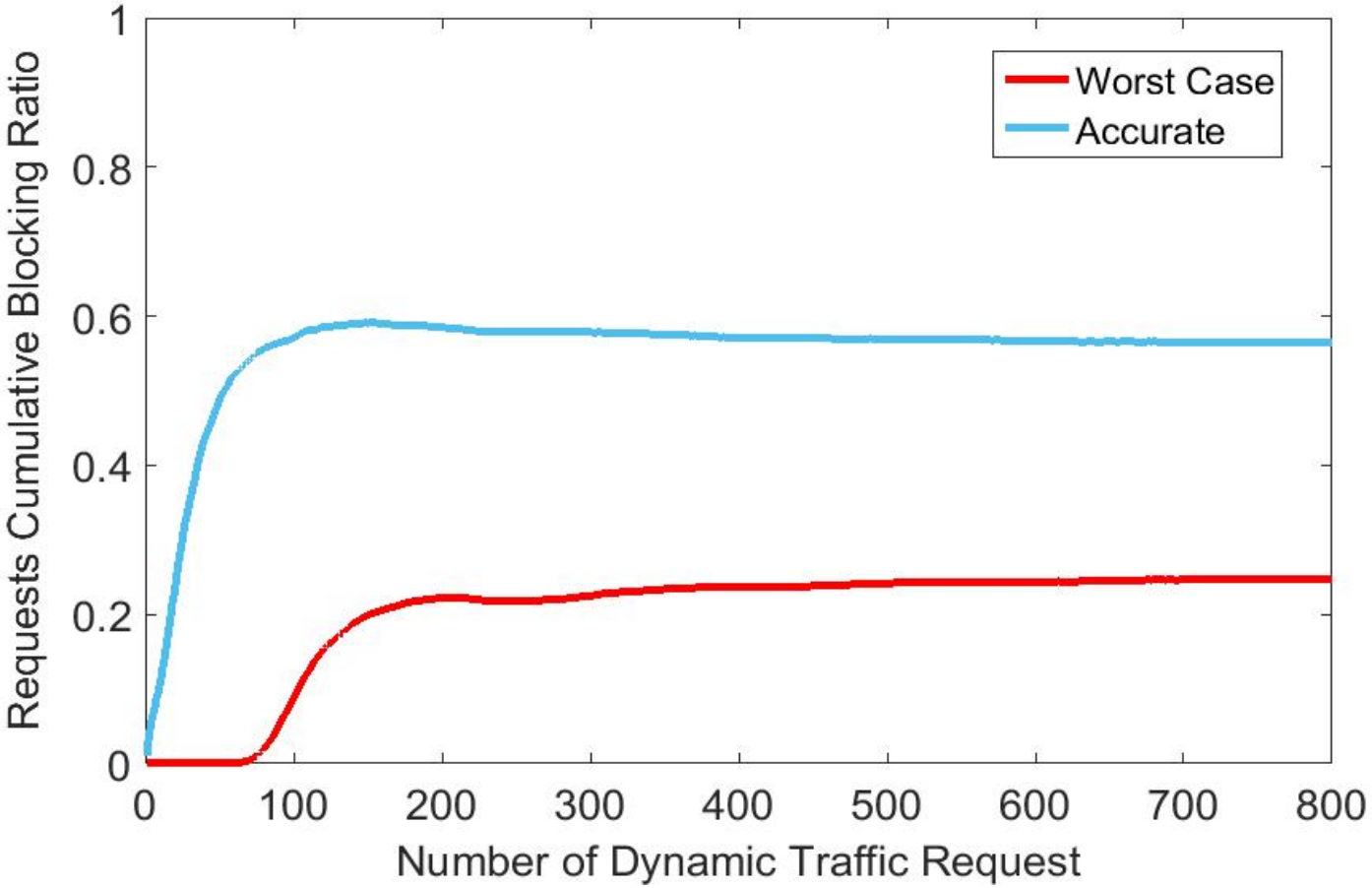
Worst-case/reference margin method has much better performance in terms of blocking ratio.
This is due to inter-channel blocking problem.



Hybrid Nonlinearity Model

- Hybrid nonlinearity model
  - Step-wise margin based on assigned spectrum index and link occupancy condition.
  - 5 loading states of continuous channel occupancy within an optical link as 20%, 40%, 60%, 80% or 100% occupied assumed in our work.
  - Nonlinearity are calculated based on above 5 loading states in advanced.
  - No inter-channel blocking for adding new lightpath when the link remains within same loading state.

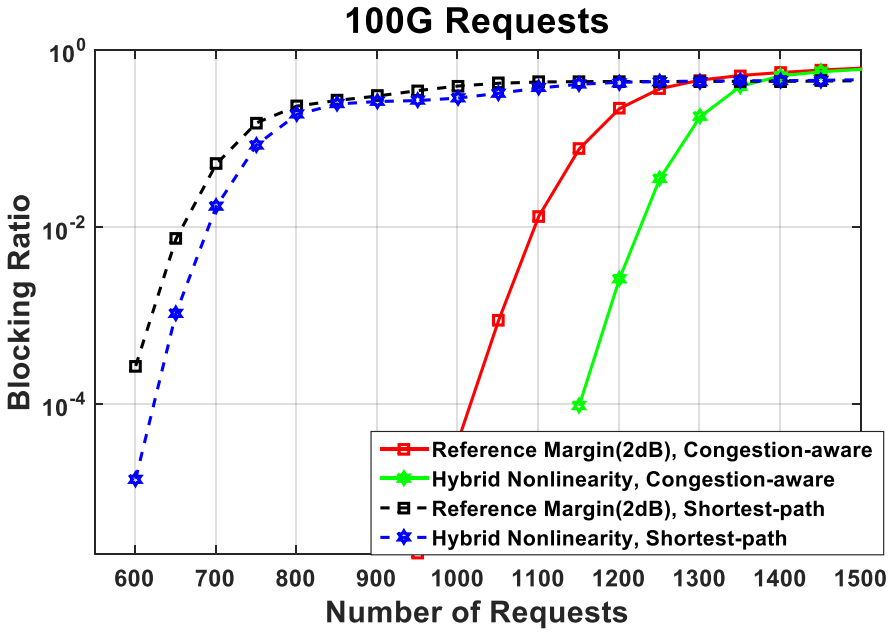
Thus $P_{NLI} = P_{ch}^3 \sum_{m,n,l} \beta_{m,n}^l$

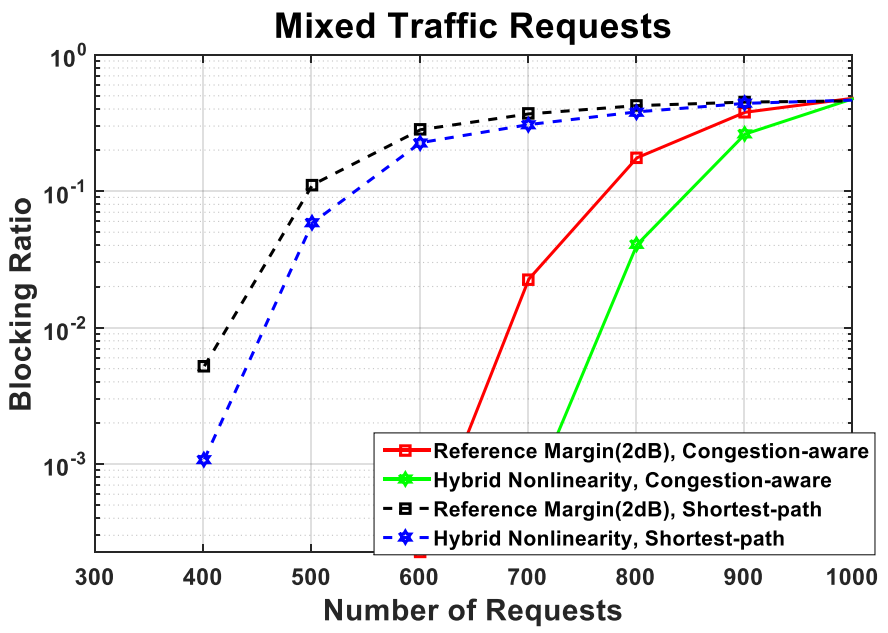
$\beta_{m,n}^l$: nonlinear coefficient of link l, frequency index m and loading state n

P_{ch}: lauch power of one frequency slot

Hybrid Nonlinearity Model Performance

- Sequential loaded EON:
  - Up to 130 more 100G requests using congestion-aware routing
  - Up to 100 more mixed traffic requests in congestion-aware routing
  - Still better performance under two traffic model using shortest path routing.





Hybrid Nonlinearity Model Performance

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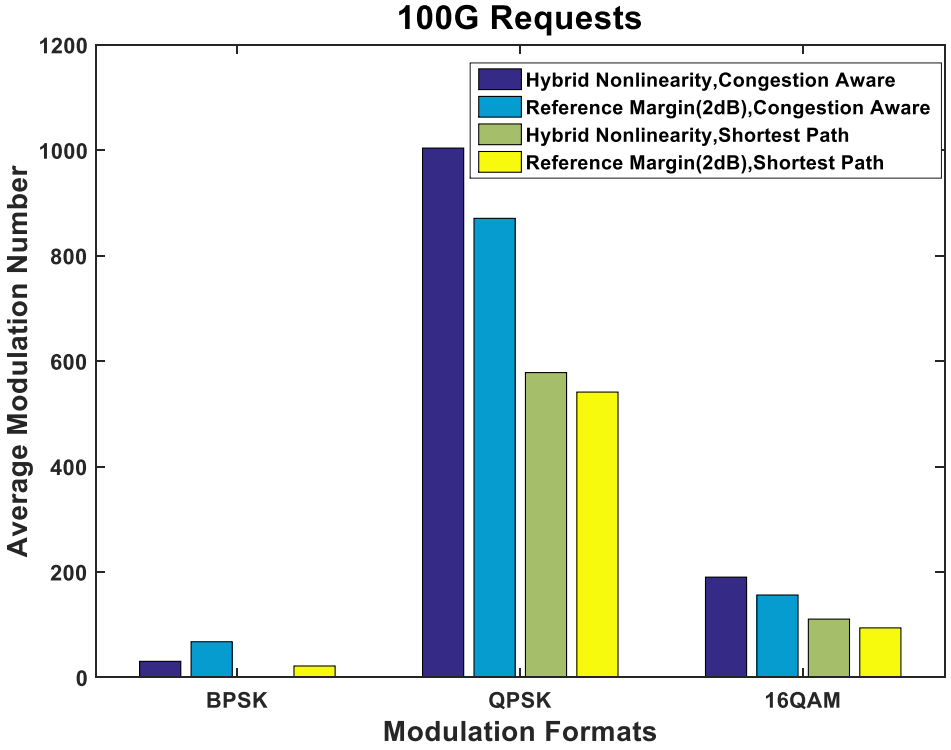
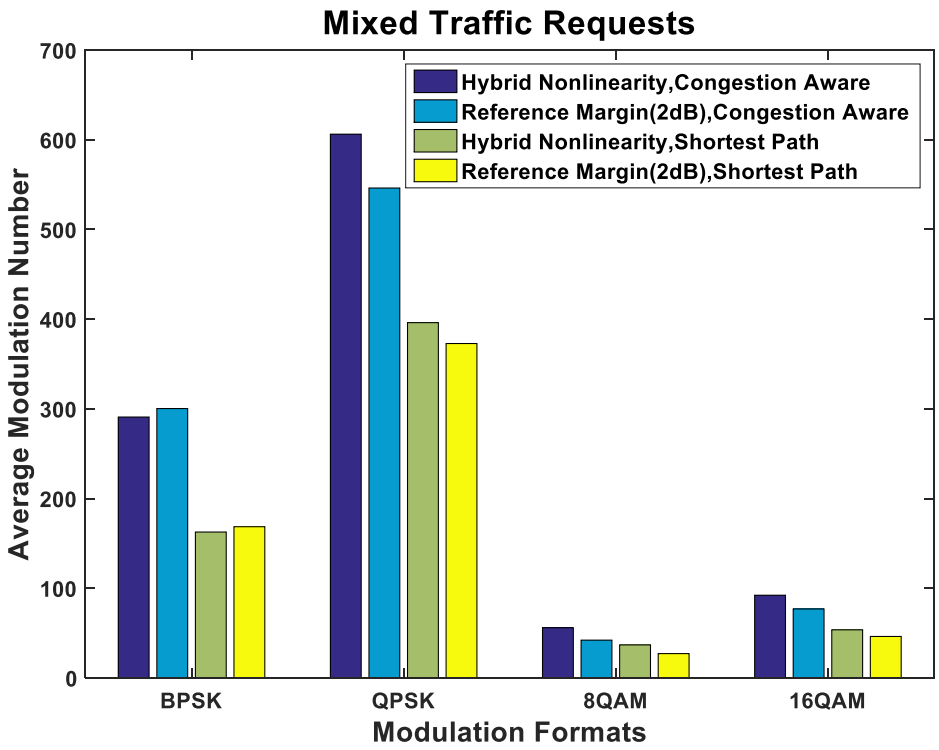
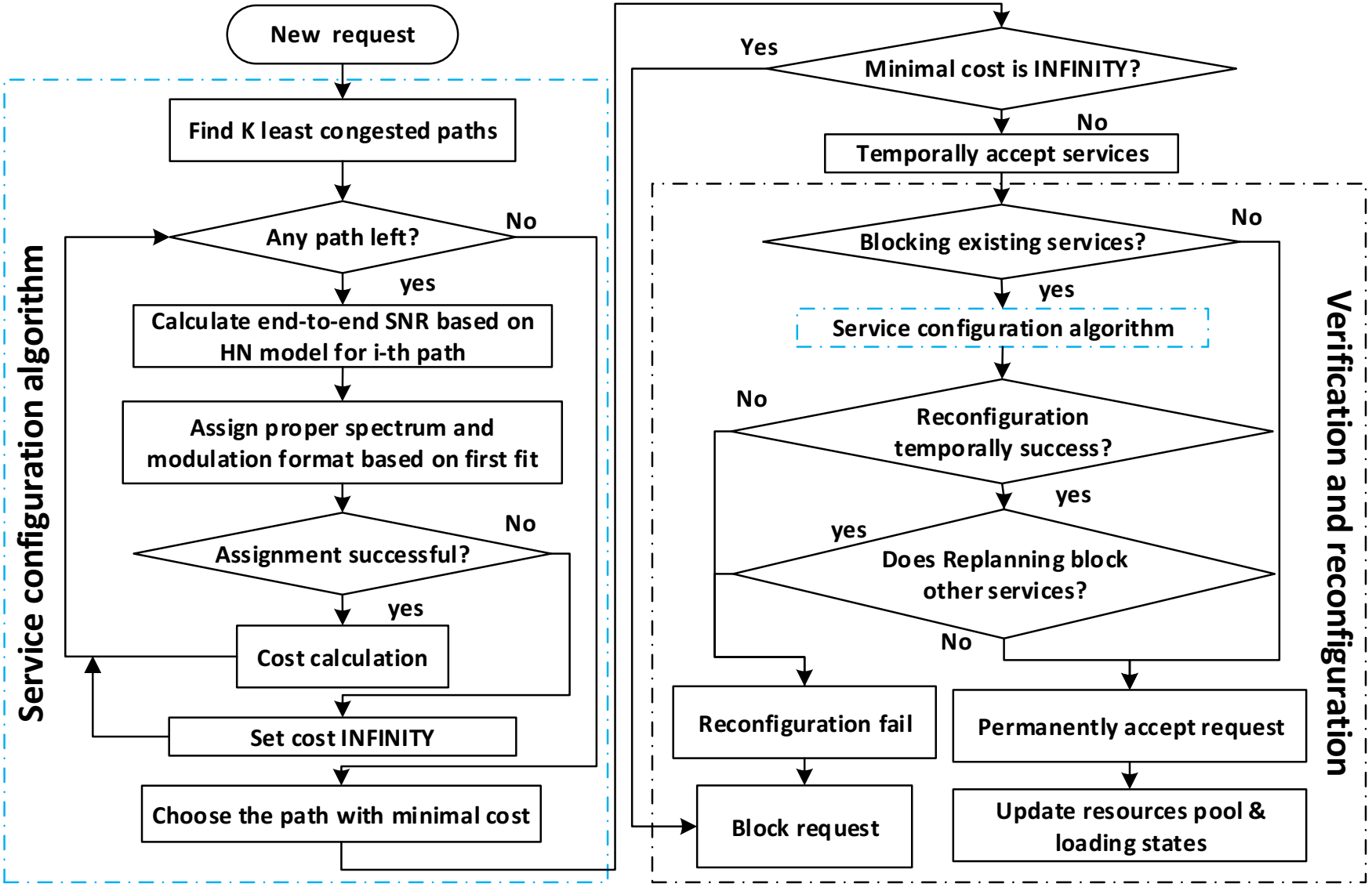
- Using hybrid nonlinearity model tends to utilize more high modulation formats than conservative reference margin (RM) method.





NARA Algorithm Flowchart



Assumption and Network Model

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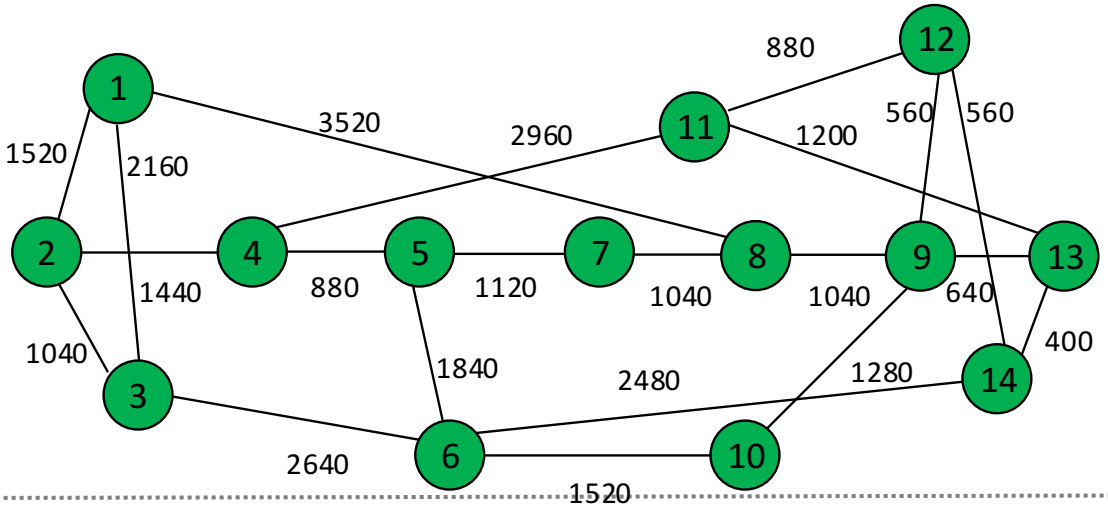
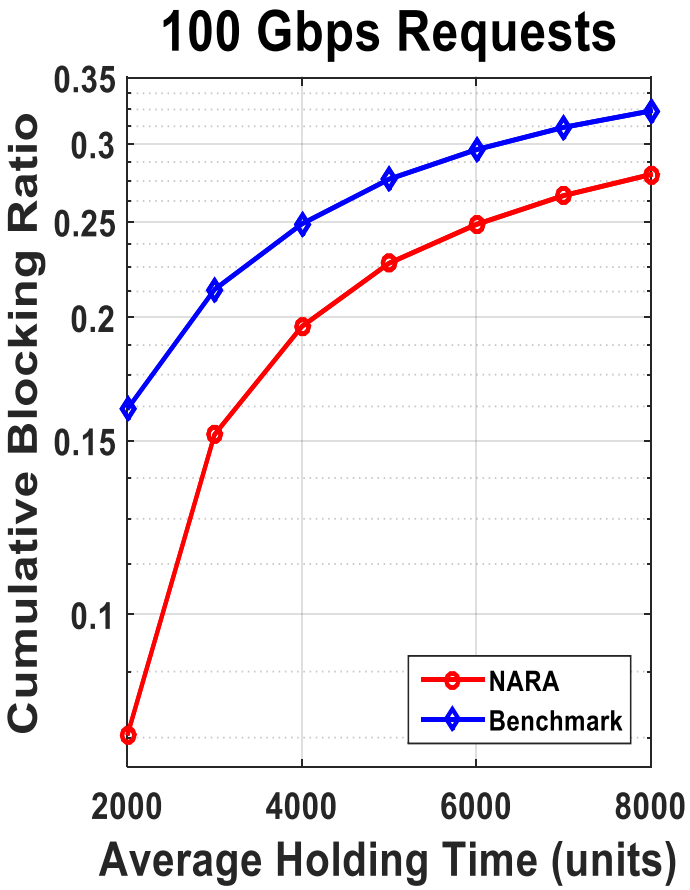
- Transparent dual-polarization optical system using coherent detection without inline compensation.
- Rectangle Nyquist spectrum shape and no guard band.
- Nonlinearity accumulates incoherently along spans.
- Equal transmission PSD among different channels.
- Power loss is completely compensated by EDFA.
- Bandwidth variable and modulation format adaptable transceivers being deployed.
- The traffic requests include FEC overhead.

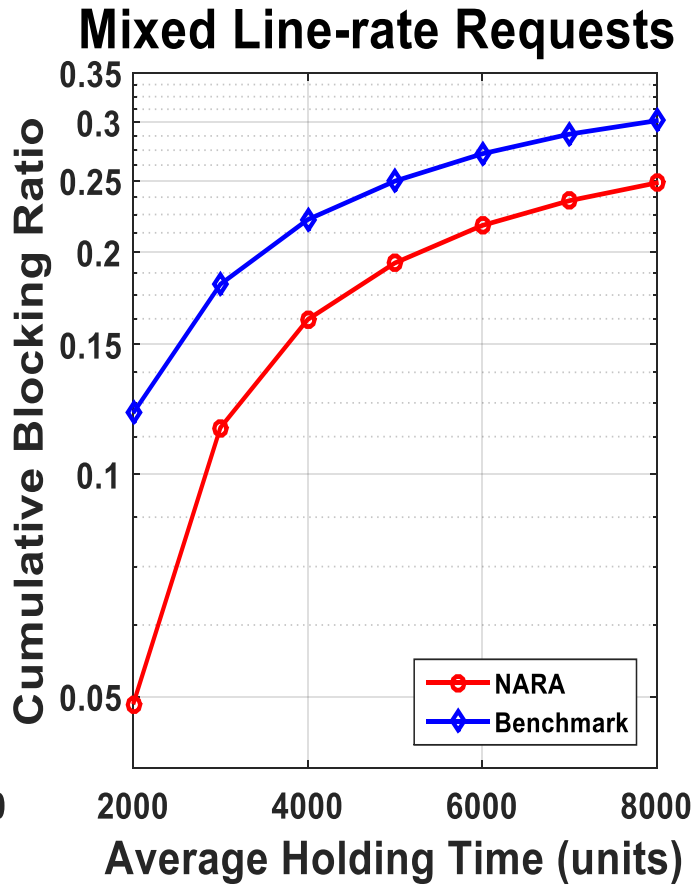
Simulation Environment

- 12.5 GHz grid optical system deployed SMF.
- NSFNET topology with 80 km/span
- 100 Gbps requests and mixed line-rate traffic requests (10 Gbps – 400 Gbps).
- Pre-FEC BER threshold: 4×10^{-3} .
- Interval time of traffic requests: Poisson distribution
- Service holding time: exponentially distributed



NARA Performance Results

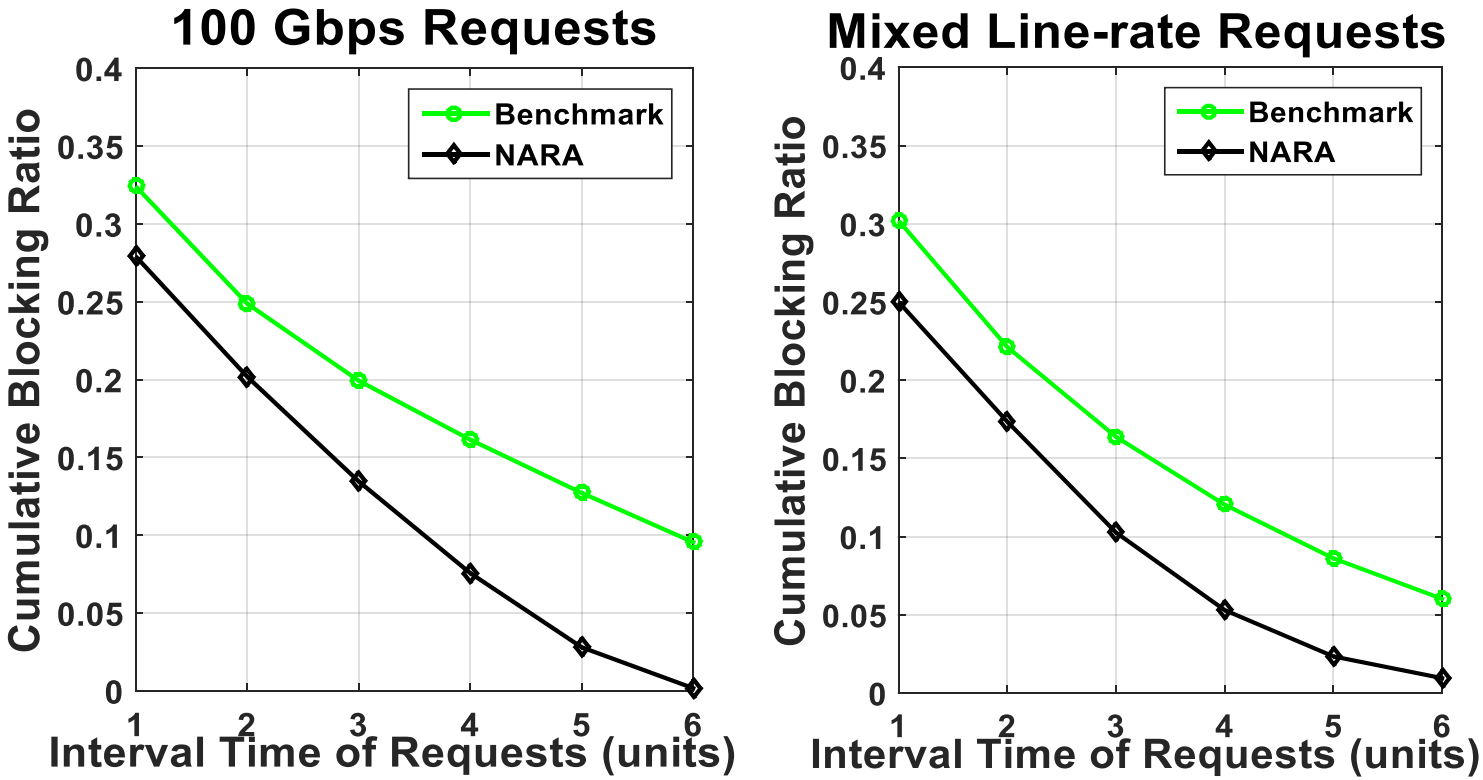




Benchmark: shortest path routing, first fit spectrum allocation and reference margin method for nonlinearity estimation.

NARA algorithm achieves between 5% to 15% higher service acceptance ratio than the benchmark method.

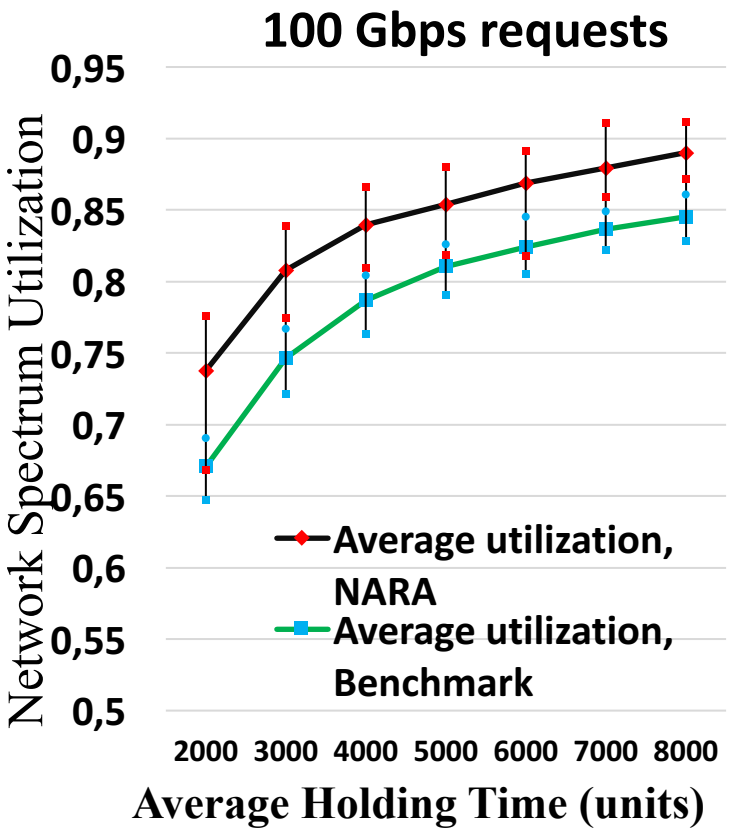
NARA Performance Results

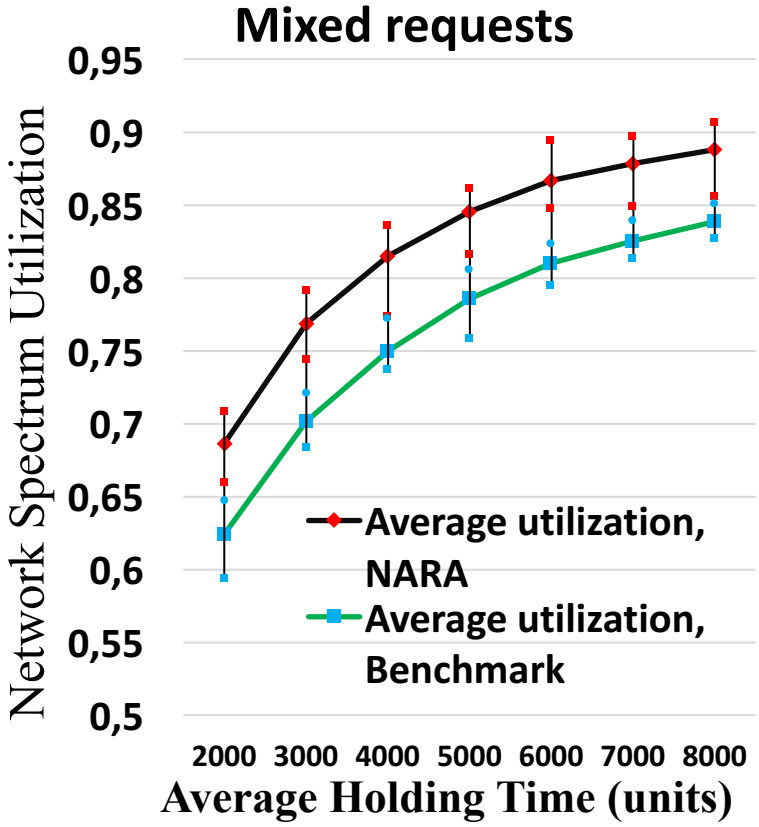


Service average holding time to be 8000 time units

NARA experiences 5-10% less blocking compared to benchmark for 100 Gbps traffic request and approximate 5% improvement for mixed line-rate requests.

NARA Performance Results





Spectrum utilization after 10000 service demands.

NARA is able to achieve:
4% to 7% more network spectrum utilization for 100 Gbps requests.
Approximate 6% more network spectrum utilization for mixed requests.

NARA Performance Results

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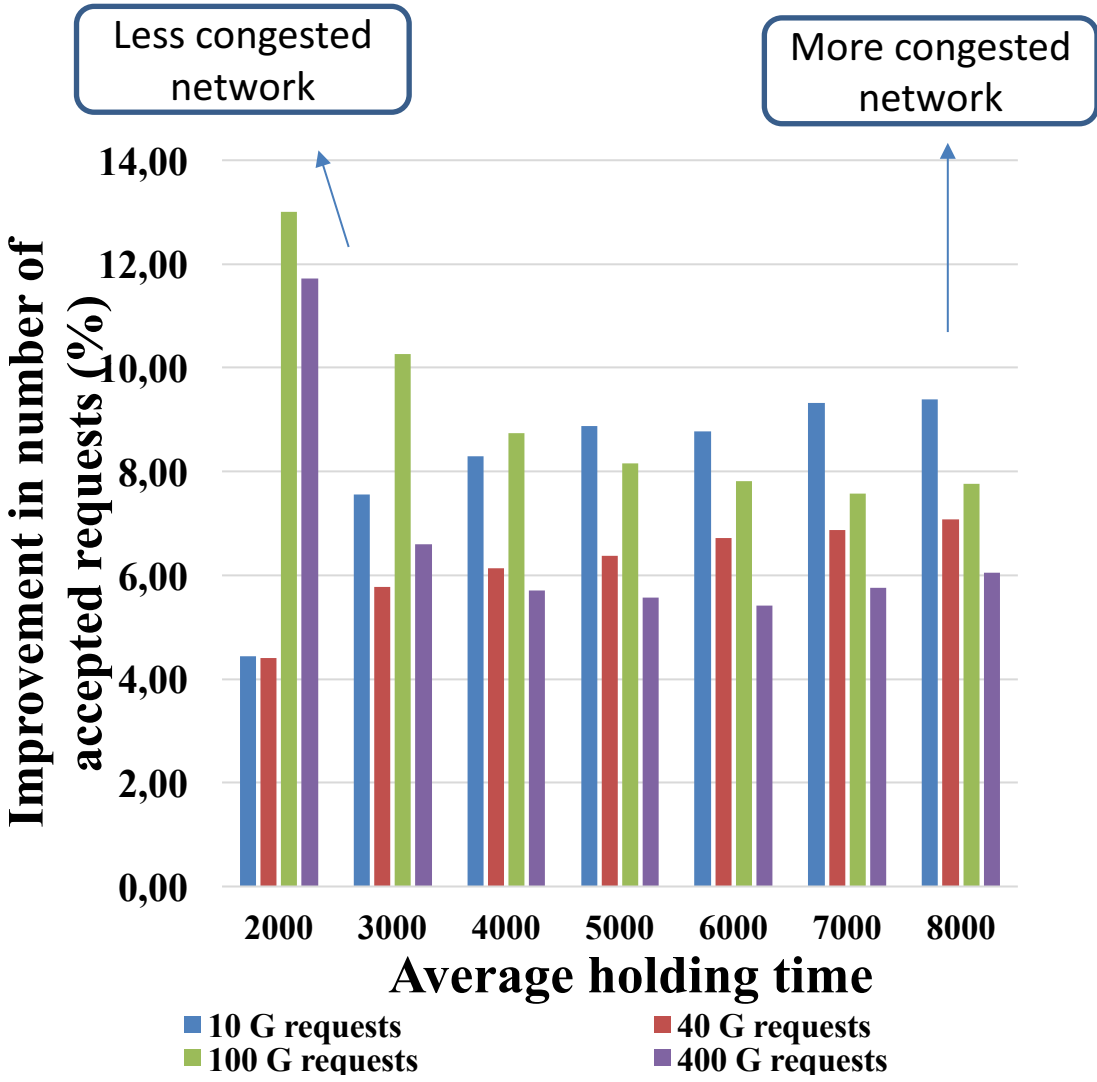
Mixed traffic request:

- At least 4% improvement for all scenarios.
- Small service holding time: more advantages for large traffic requests (100 Gbps and 400 Gbps), 11% - 13% higher
- Large service holding time: more advantages for small traffic requests (10 Gbps and 40 Gbps), 7% - 9%.



Conclusion

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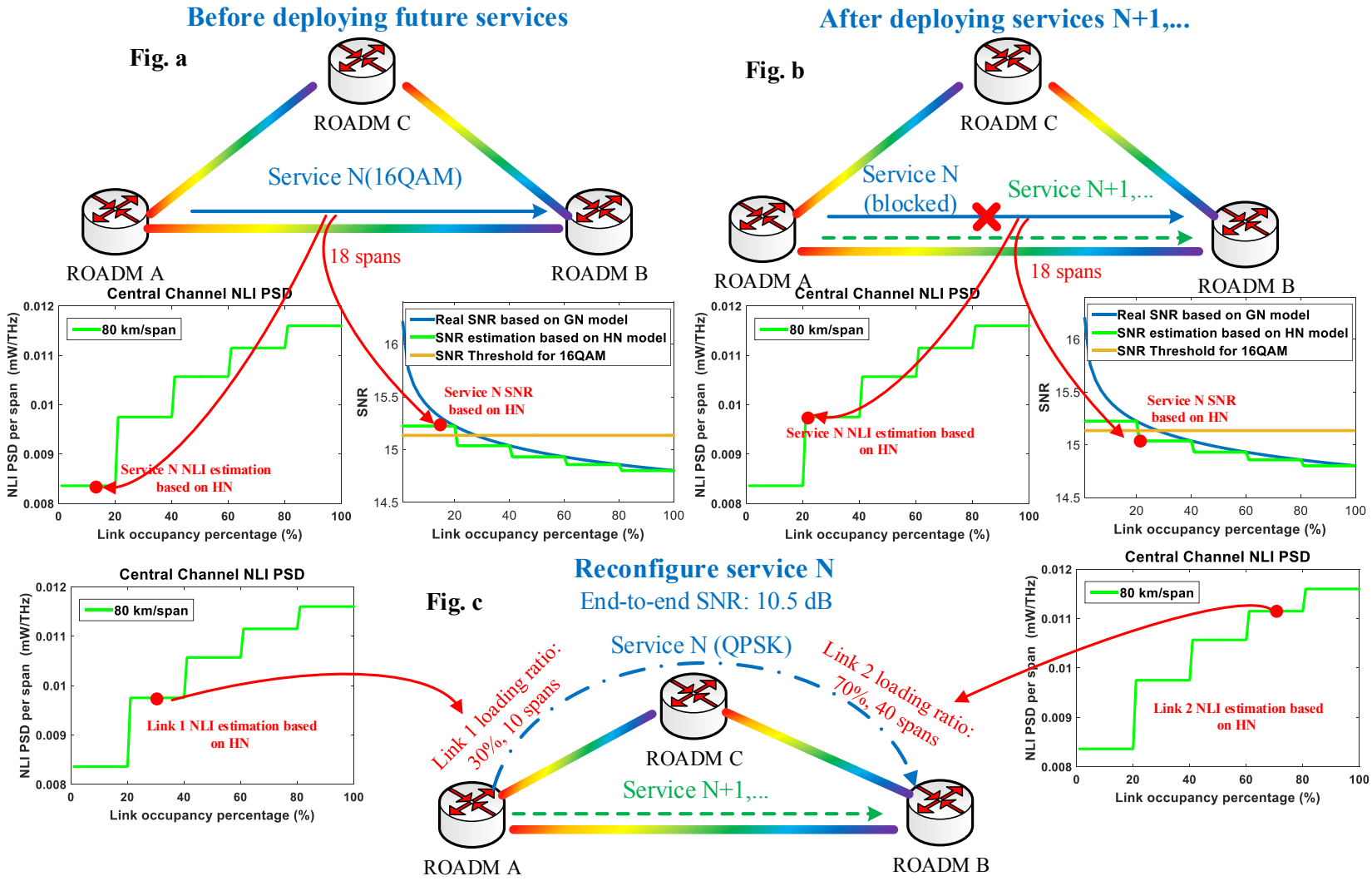
- Hybrid nonlinearity model is simple and accurate.
- The NARA algorithm using hybrid nonlinearity model significantly improves network service acceptance ratio.
- NARA using hybrid nonlinearity model achieves higher spectral efficiency and higher network utilization.
- NARA favours different traffic types depending on network congestion status.

Thank you.

Any question?

LARA Solution Showcase



Contribution

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- We develop a step-wise load-aware nonlinearity model.
  - More accurate than the worst-case/reference margin scenario.
  - Computational