Hybrid Machine Learning EDFA Model

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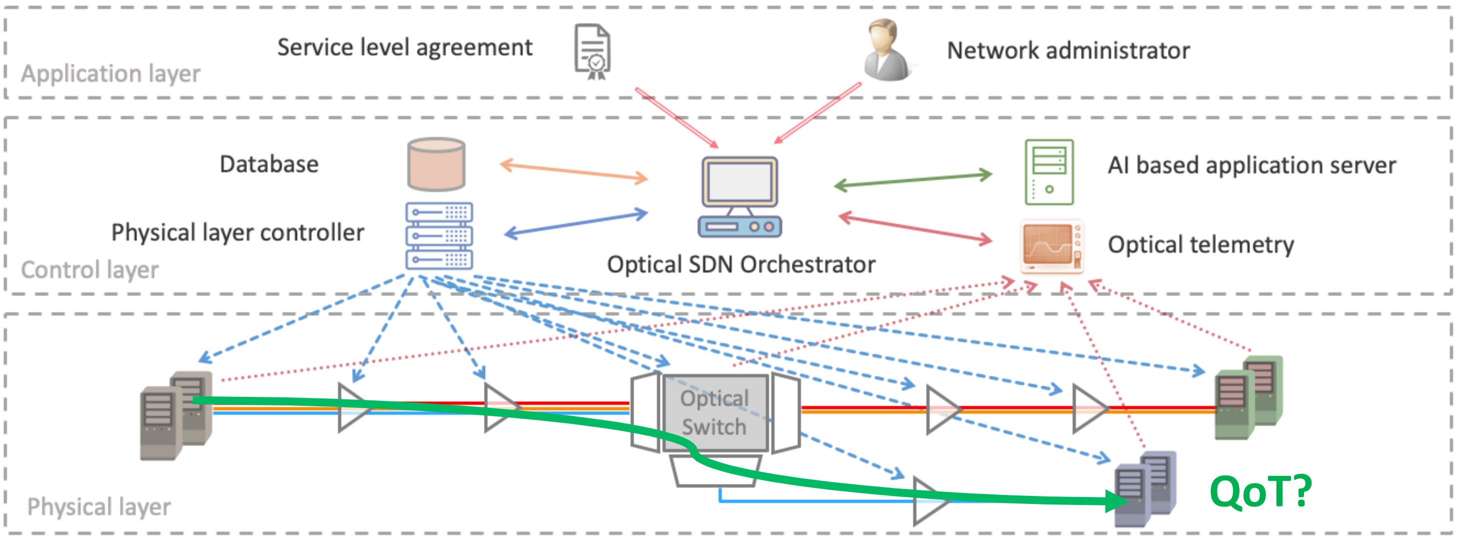
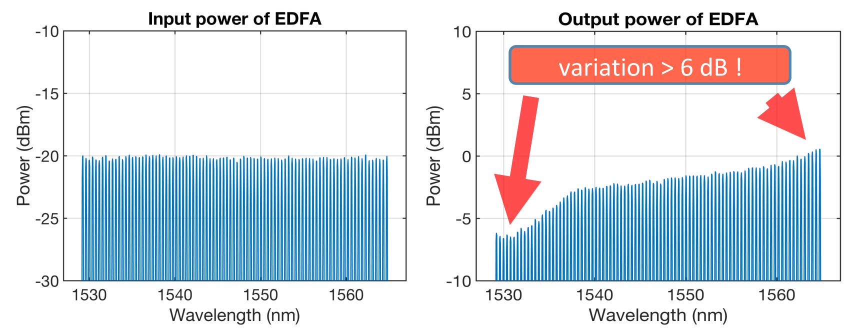
Why do we need an accurate EDFA model?



- Minimize Quality of Transmission (QoT) estimation error before channel provisioning.
  - Real time SDN control
  - Disaggregated systems



S. Zhu, et. al, OFC 2017

- EDFA gain spectrum dependent on input channel loading

- Tighter margins for less regeneration/higher spectral efficiency/lower cost

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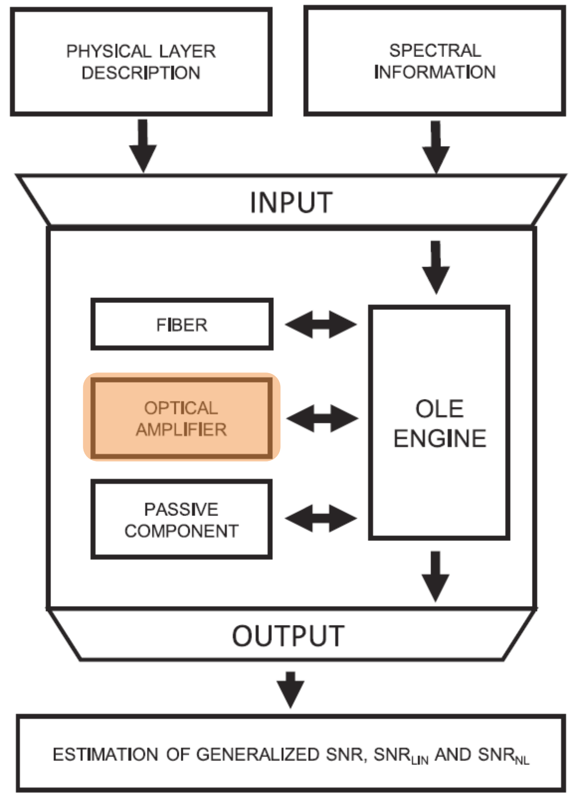
ML Model for SDN Controllers

In QoT estimation, amplifier model determines launch power and ASE noise



M. Filer, et. al, JLT 2018

- Accurate EDFA model
  -> improve the GN model accuracy
  -> better QoT estimation

Problem statement

- Purpose of having an accurate EDFA model:
  - Better predict optical channel power
  - Better **predict end-to-end Quality of Transmission**
  - Better network planning, e.g. improved Gaussian Noise (GN) model
- Difficulties of building an EDFA model:
  - Gain is dynamic: gain spectrum depends on input channel loading
  - Hard to find a pure mathematical formula based on physics
  - Empirical formula is not accurate
- Ideal EDFA model:
  - Given input power spectrum and EDFA settings (e.g. gain, tilt, middle stage loss, etc.), find output power spectrum
  - func edfa_model(input_spectrum: List[float], edfa_settings: Dict)

    -> output_spectrum: List[float]

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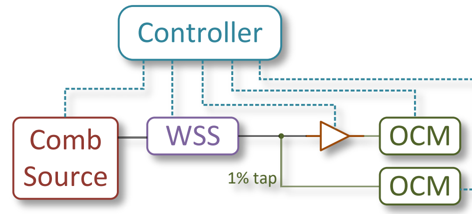
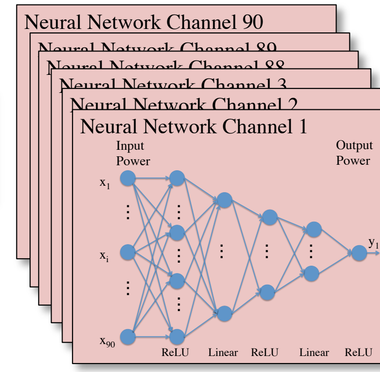
Two models: Analytical vs. ML

$$g(\lambda_i) = g(\lambda_i) + \sum_{j=1}^{n} [g_s(\lambda_j) - g(\lambda_j)]/n$$

K. Ishii, et al., OFC 2014





S. Zhu, et al., ECOC 2018

Analytical

- Simple model 👍
- Fast characterization 👍
- Quick calculation 👍
- Dynamic range is limited
- Accuracy is limited

ML

- Slow data capture process(~20k)
- Complex training process
- Quick calculation 👍
- Dynamic range is wide 👍
- Accuracy is highest 👍

🙋♂ Can we combine the pros of the two approaches?

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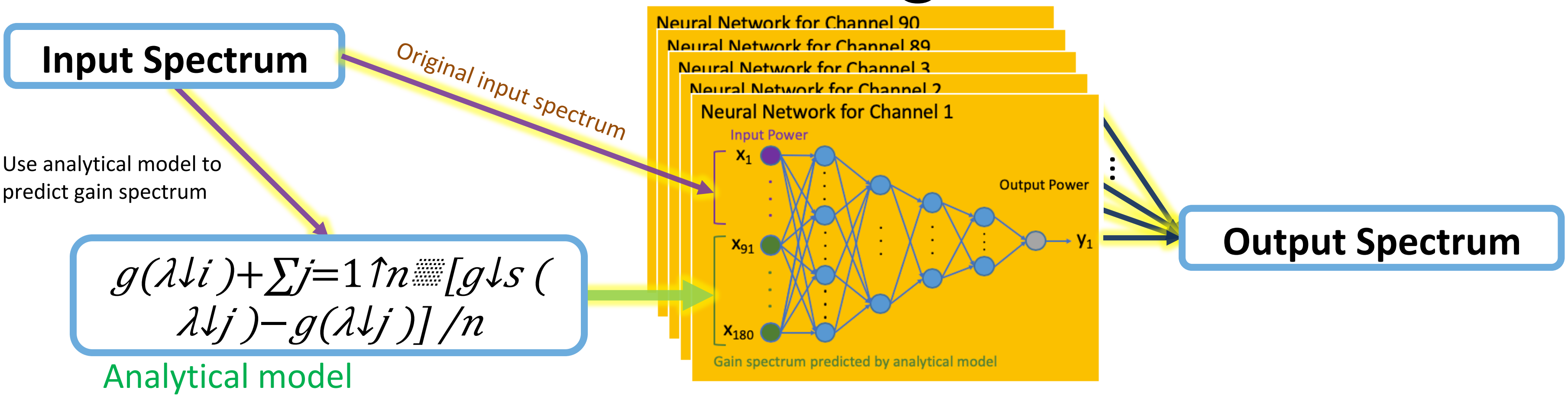
Hybrid Machine Learning (HML) Modeling



Input of model:

EDFA input spectrum,
Gain spectrum by analytical model

Output of model:

EDFA output spectrum
(or equivalently gain spectrum)

Parameter	Value
Input Vector	[P_{ch1}, … , P_{ch90}, **G_{ch1}, … , G_{ch90}**]
Output Vector	[P_{chi}] for *i* in [1, 90] # *i is index of the* 90 NNs
Transfer Func.	[ReLU, Linear, ReLU, Linear, ReLU]
Training Target	Min{MSE}
Training Method	Stochastic Gradient Descent (SGD)
Batch Size (m)	m = 60
Learning Rate (α)	α = 0.00025
Training Time	> 15000 iterations

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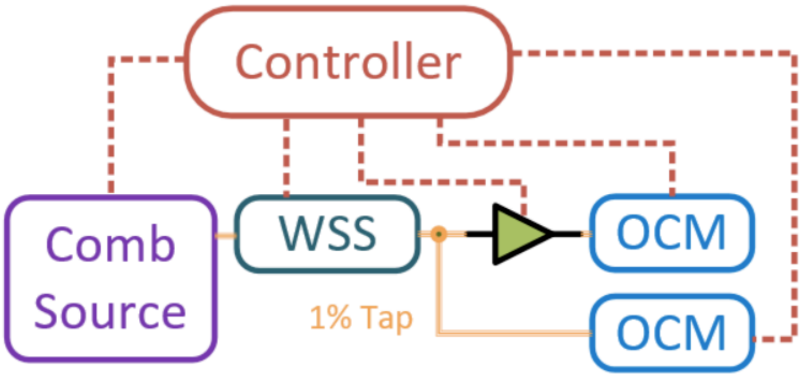
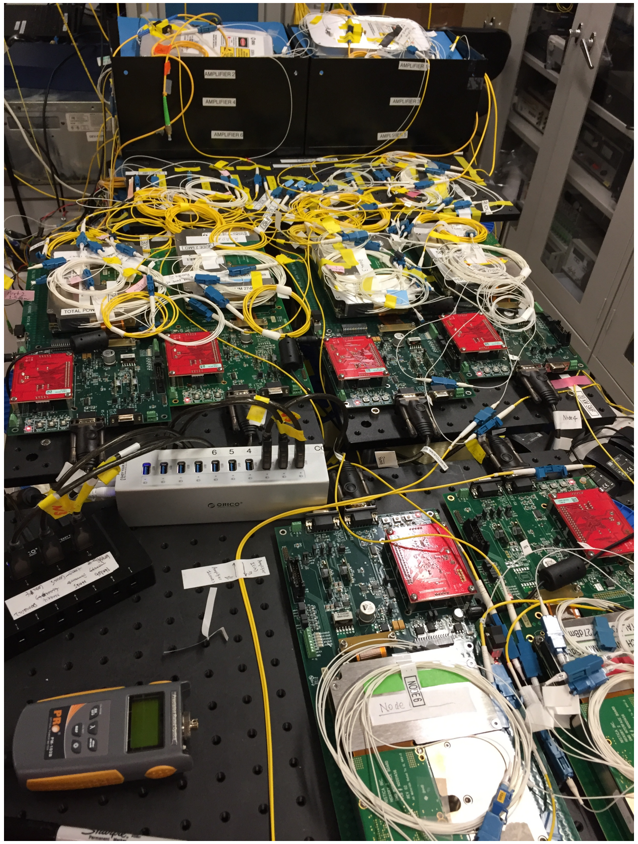
Experiment Setup

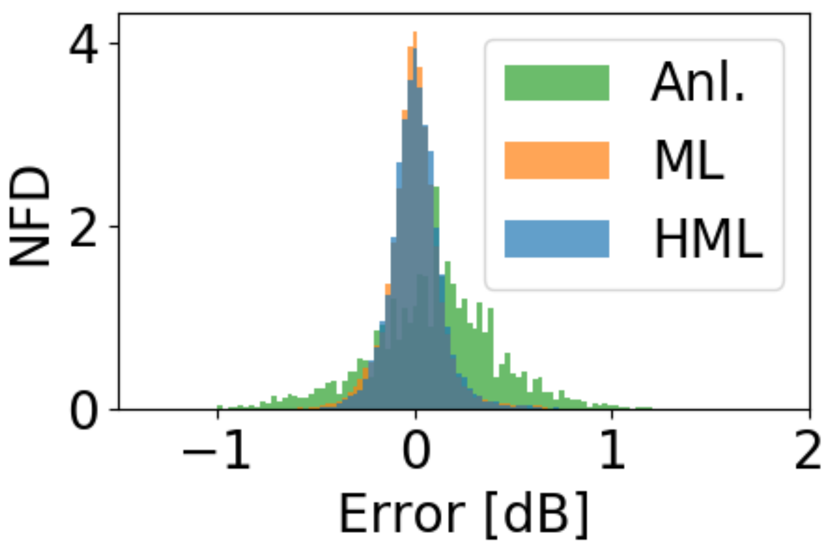
We take the data from previous results, as we reported in *S. Zhu, et al., ECOC 2018.*

- Characterize single channel and fully loaded gain profile for EDFA.
- Capture *true* value of input and output spectrum.
- Capture ML *training data*, *validation data*, *test data.*



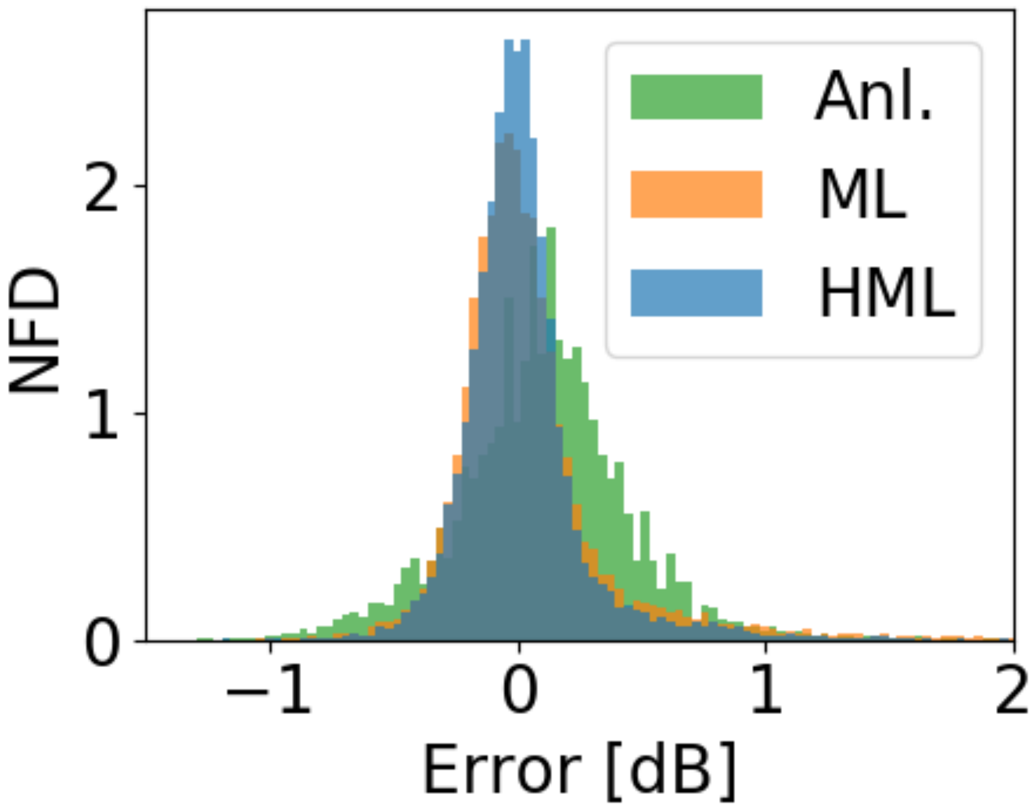


Accuracy of prediction given abundant training data and unlimited training time (12000 samples and 25000 iterations)



Model	MSE Error	Max Error
Analytical	0.36 dB	2.6 dB
ML	0.16 dB	2.6 dB
HML 👍	0.14 dB	1.6 dB

Accuracy of prediction given abundant training data and limited training time (12000 samples and 5000 iterations)



- HML has **much better accuracy** given limited training time.
- To achieve the same accuracy (e.g. 0.2 dB), HML takes **37% less** time than ML.

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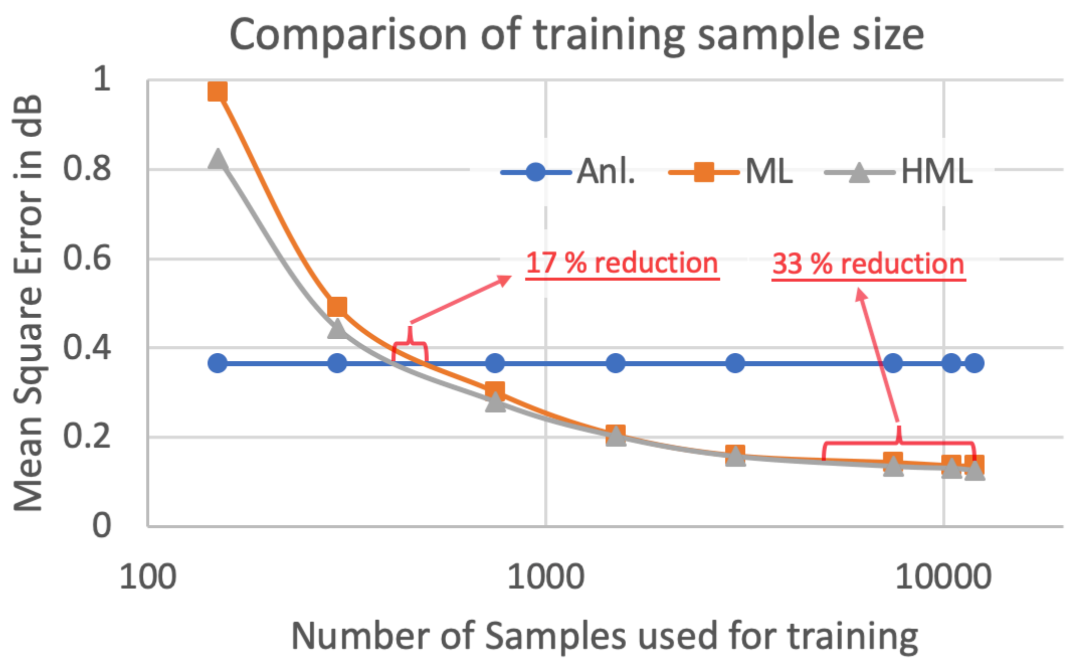
Prediction error vs. number of training samples



- HML shows ability of achieve same level of accuracy with <u>less training data.</u>
- In figure: 33 % reduction with target MSE of 0.134 dB / 3 % in linear scale).
- Note: The target MSE value of 0.134 dB is very close to measurement error of typical power reading device (0.1 ~ 0.2 dB).

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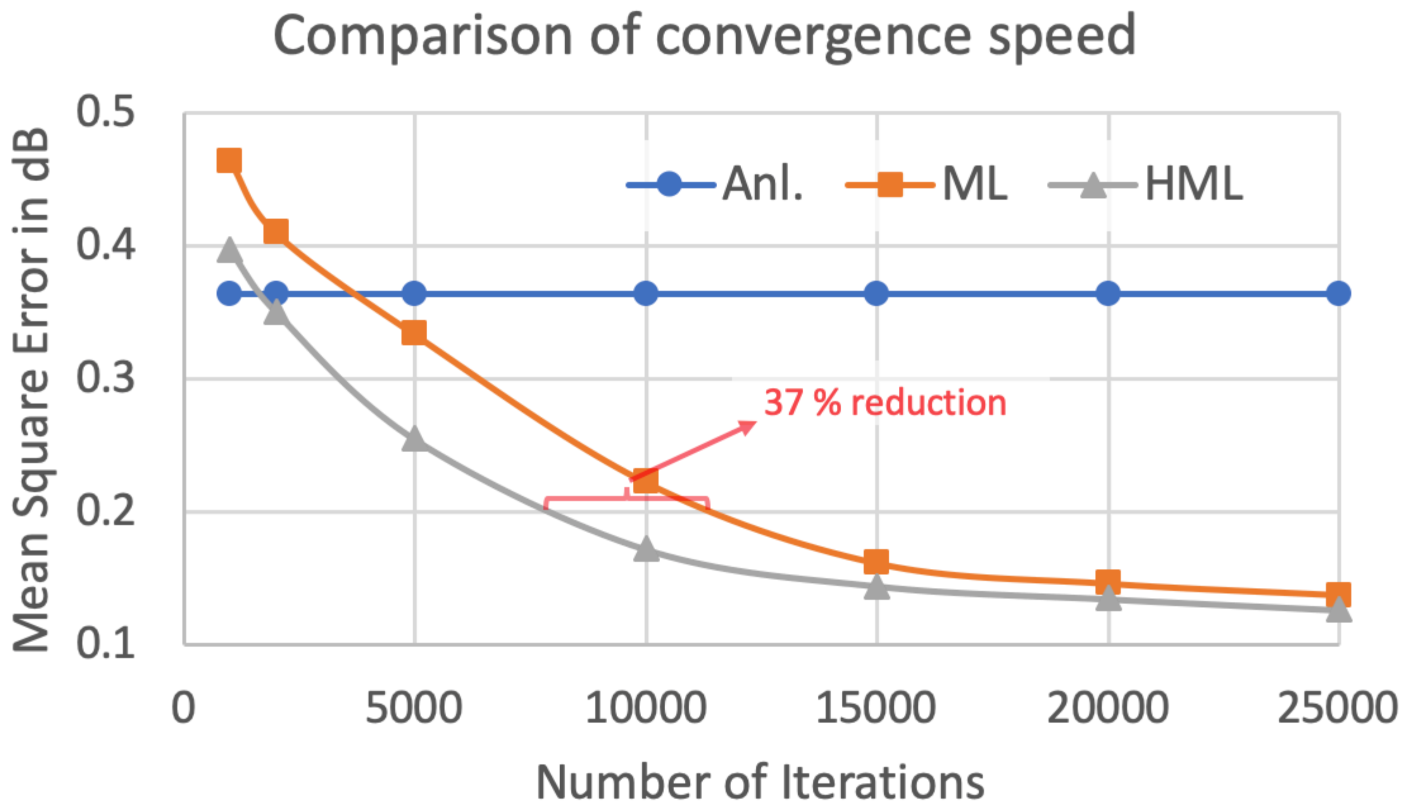
Comparison: error convergence speed



- HML shows ability of achieve same level of accuracy with <u>less time</u>.
  (37 % reduction with target MSE of 0.2 dB / 5 % in linear scale)

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Conclusion

1. HML has the following advantages:
   a. Quicker convergence and use less training data
   b. Reduce max prediction error

2. Both HML and ML can achieve a good prediction accuracy. Both have MSE error below 0.2 dB, which is close to typical error of optical power measurement. HML accelerates the training process and reduces the size of training data.

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Thank you!

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