Institut Mines-Télécom

Machine Learning Based Localization in 5G

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Journée Futur & Ruptures

Date: 7/4/2021

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Summary

1. **Introduction**
   - Localization, Machine Learning and 5G
   - Applications
2. **Indoor Localization**
   - Indoor Localization (IEEE CTW 2019)
   - Noise and Dimensionality Reduction
   - Deep NN & KNN
3. **Conclusion**

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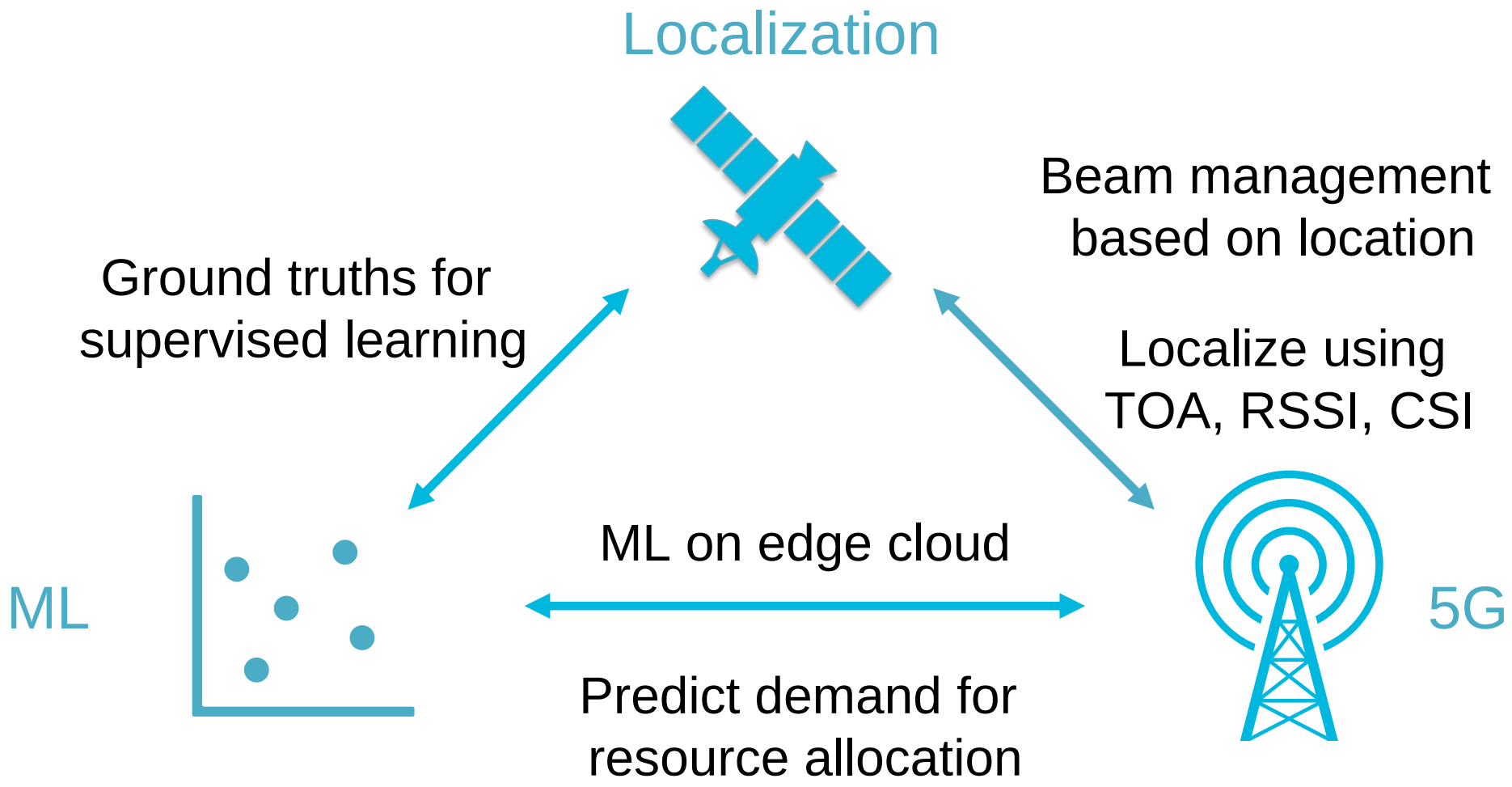
Introduction

- Localization: the process of determining the position of an entity in a local or global coordinate system.

- 5G:
  - Enhanced Mobile Broadband (10 Gbits/s)
  - Ultra-Reliable Low-Latency Communication (<1 ms)
  - Massive Machine-Type Communication (1M dev/km)

- Machine Learning: Modelling from data for prediction.

Introduction



Introduction

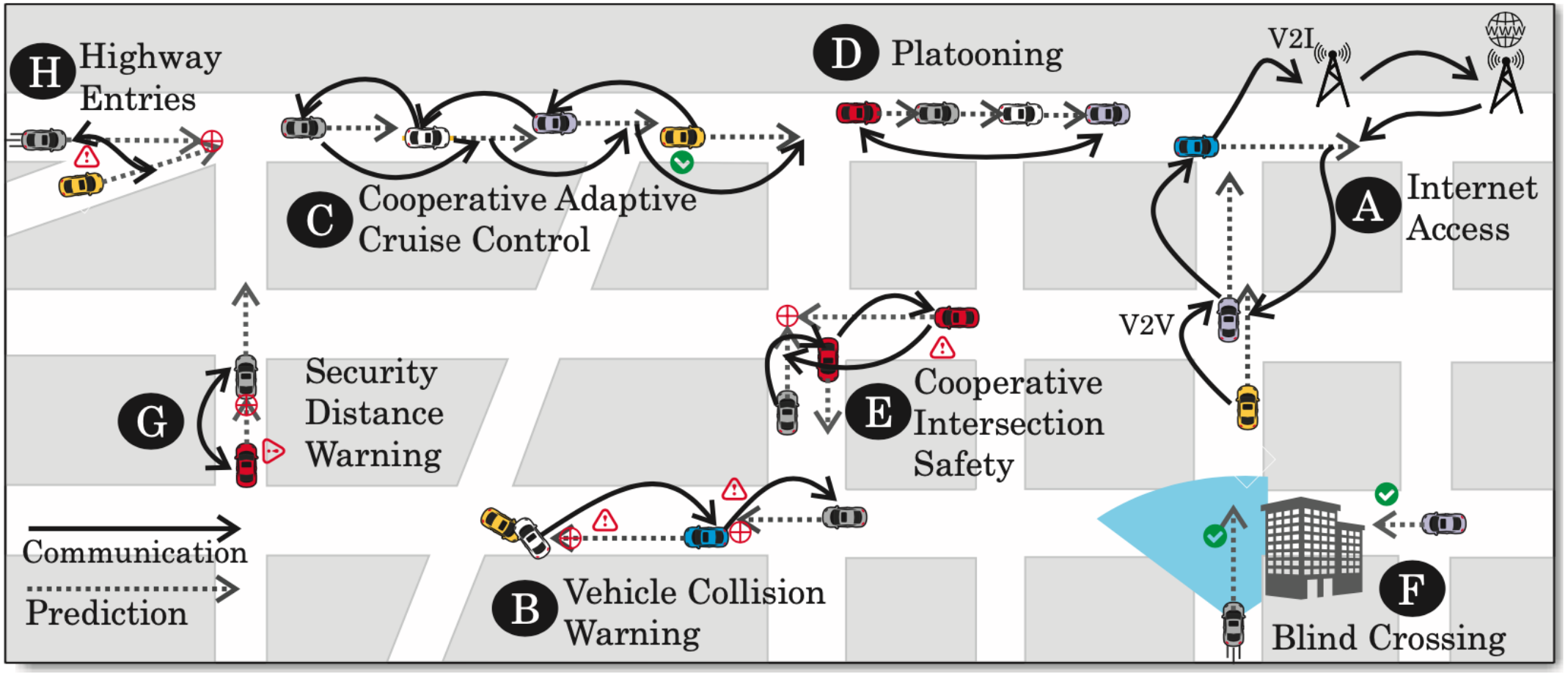
- Localization depends on different sensors:
  - Visual: cameras, LiDARs
  - Communication: RSSI, TOA, AoA, CSI
  - Satellite: GPS
- Localization is not a solved problem *.

* D. Lymberopoulos and J. Liu, “The microsoft indoor localization competition: Experiences and lessons learned”, IEEE Signal Processing Magazine, vol. 34, no. 5, pp. 125–140, 2017.

Applications: Industrial Automation *

* Amazon warehouse: https://www.youtube.com/watch?v=Ox05Bks2Q3s

Applications: Autonomous Driving *



* Balico, Leandro N., et al. "Localization prediction in vehicular ad hoc networks." IEEE Communications Surveys & Tutorials 20.4 (2018): 2784-2803.

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Indoor localization using MIMO CSI

- MIMO (Multiple Input Multiple Output) Antenna is a main driver for the 5G intended throughput: 10 Gb/s.

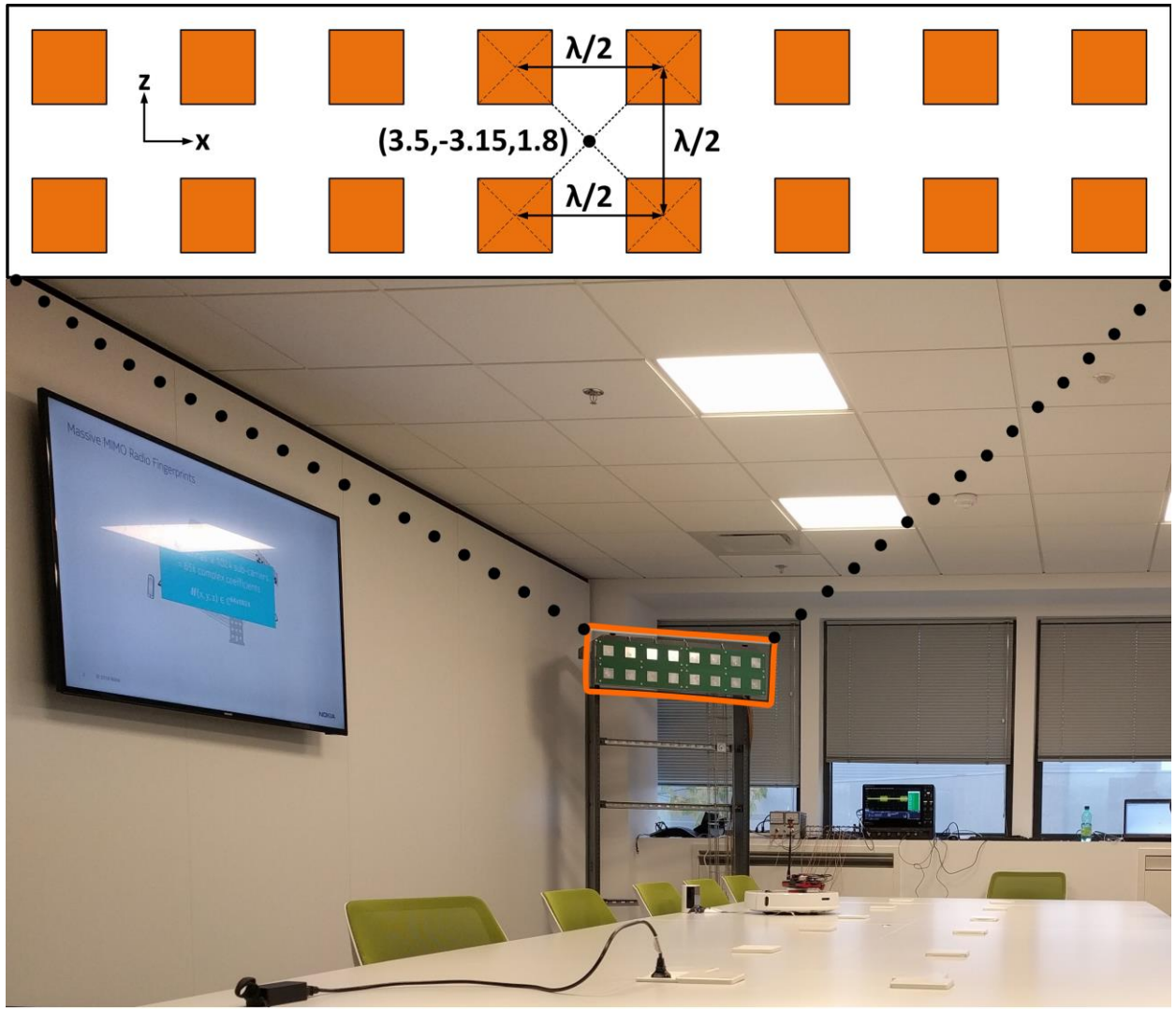
- Signals are transmitted on multiple subcarrier frequencies to multiple antennas.

- CSI (Channel State Information): Represent channel's effect on the signal e.g. scattering, fading etc.

$$\vec{Y} = \mathrm{CSI} \cdot \vec{X} + \vec{N}$$

IEEE CTW 2019 Competition

- Antenna Array 8x2.
- 924 subcarriers.
- Carrier Freq/ Bandwidth: 1.25 GHz / 20 MHz.
- Table area 4x2 m.
- CSI file: 17k x 16 x 924 x 2
- Pos file: 17k x 3



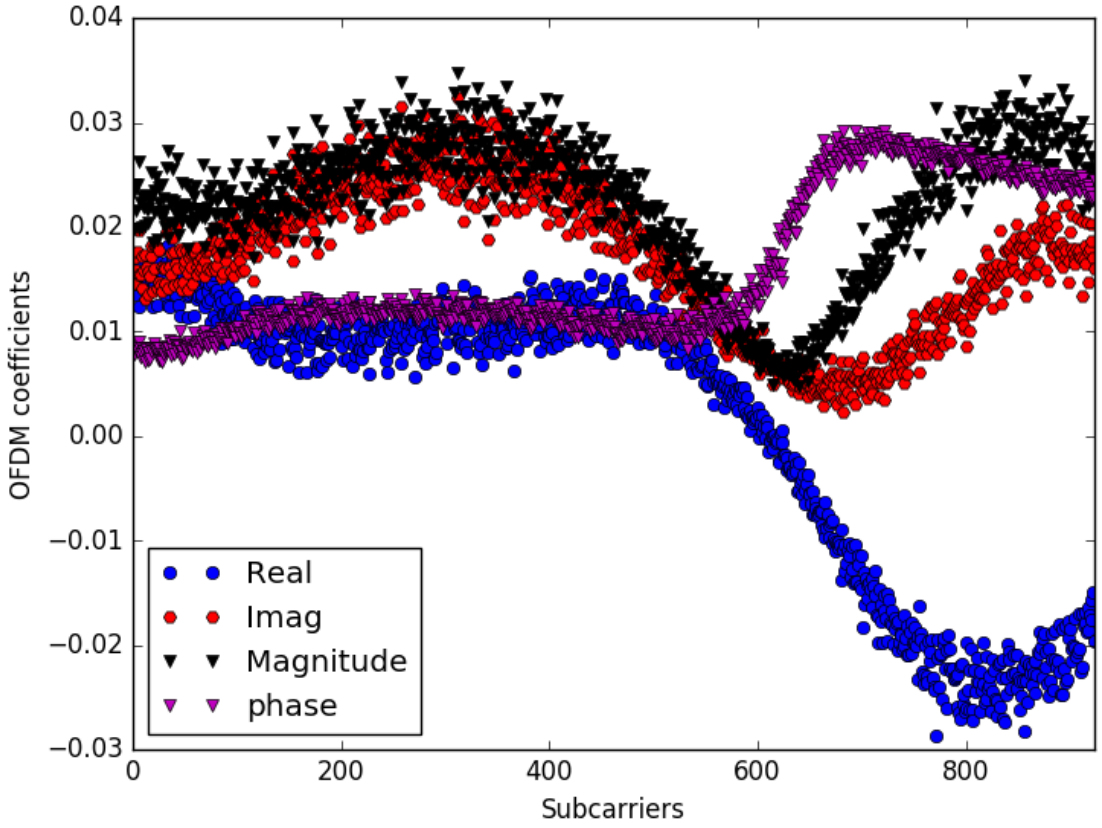
IEEE CTW 2019 Competition

- CSI is a complex number.

$$CSI_{i,j} = |Mag|\angle\phi$$

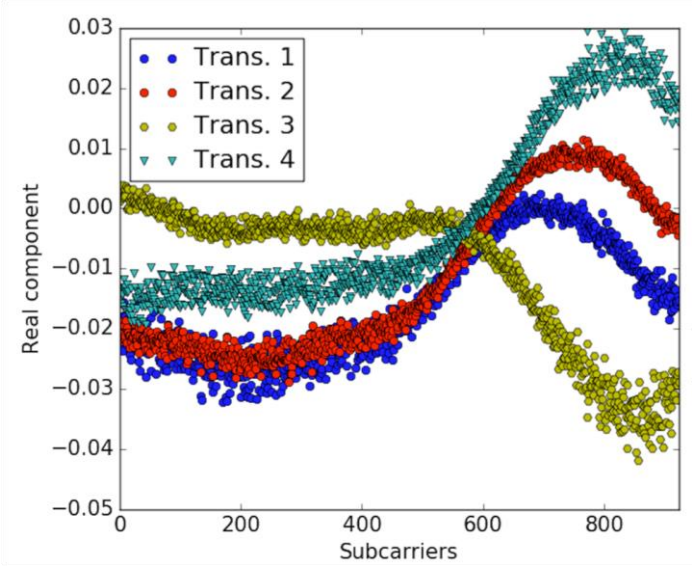
$$CSI_{i,j} = Re + iIm$$

- Orthogonal frequency-division multiplexing (OFDM).

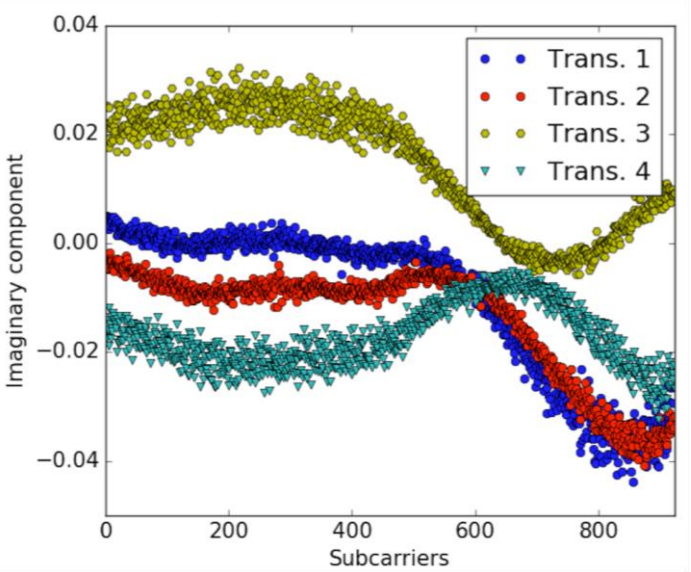


Primary Data Analysis

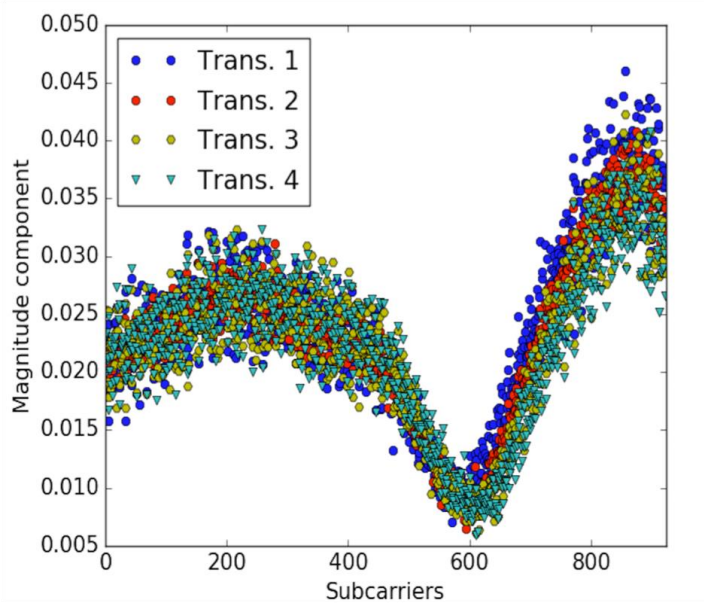
Real



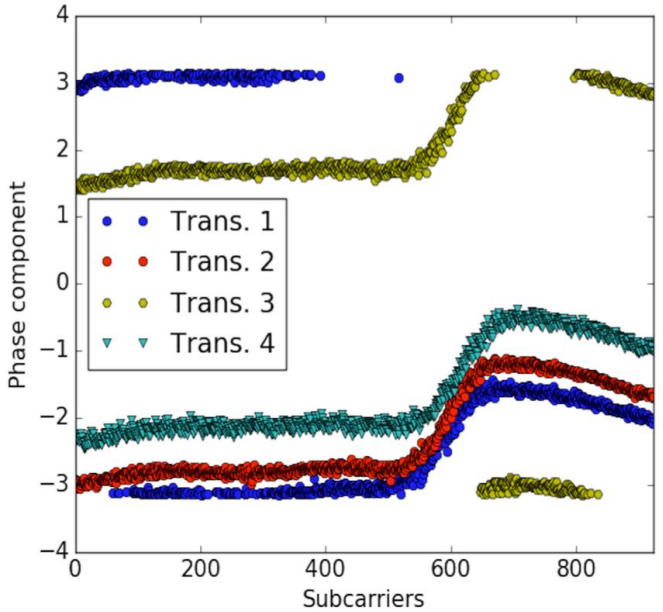
Imaginary



Magnitude



Phase

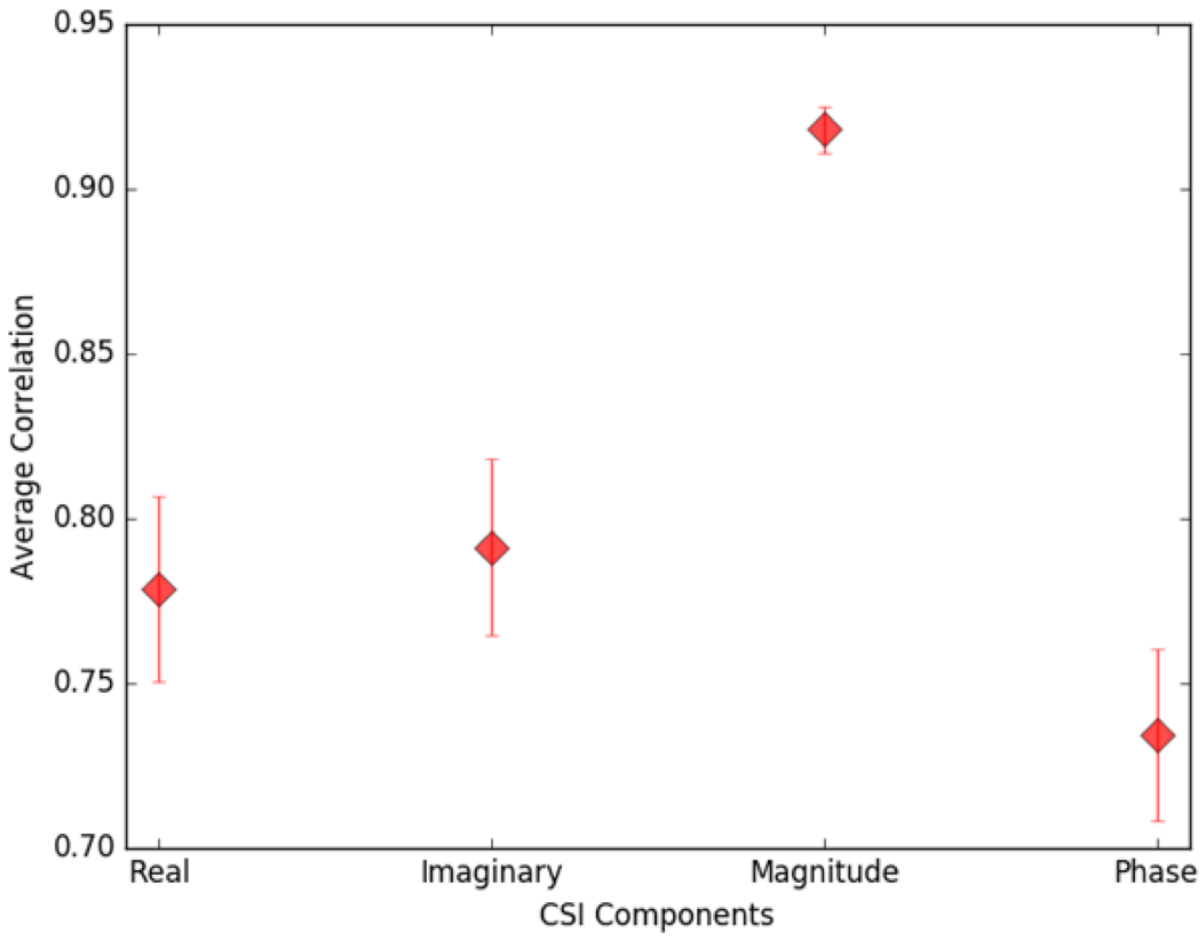


Primary Data Analysis

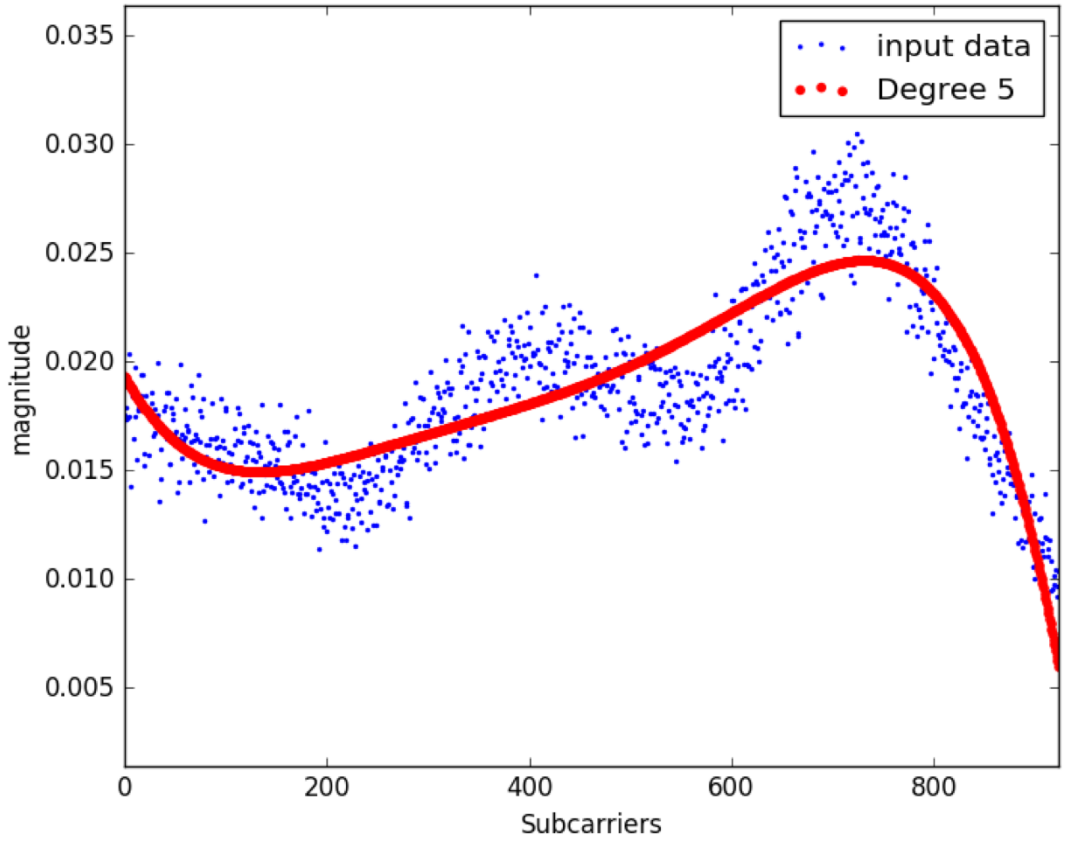
- Mean Correlation Coefficient for reference and closest sample over 1000 pairs.

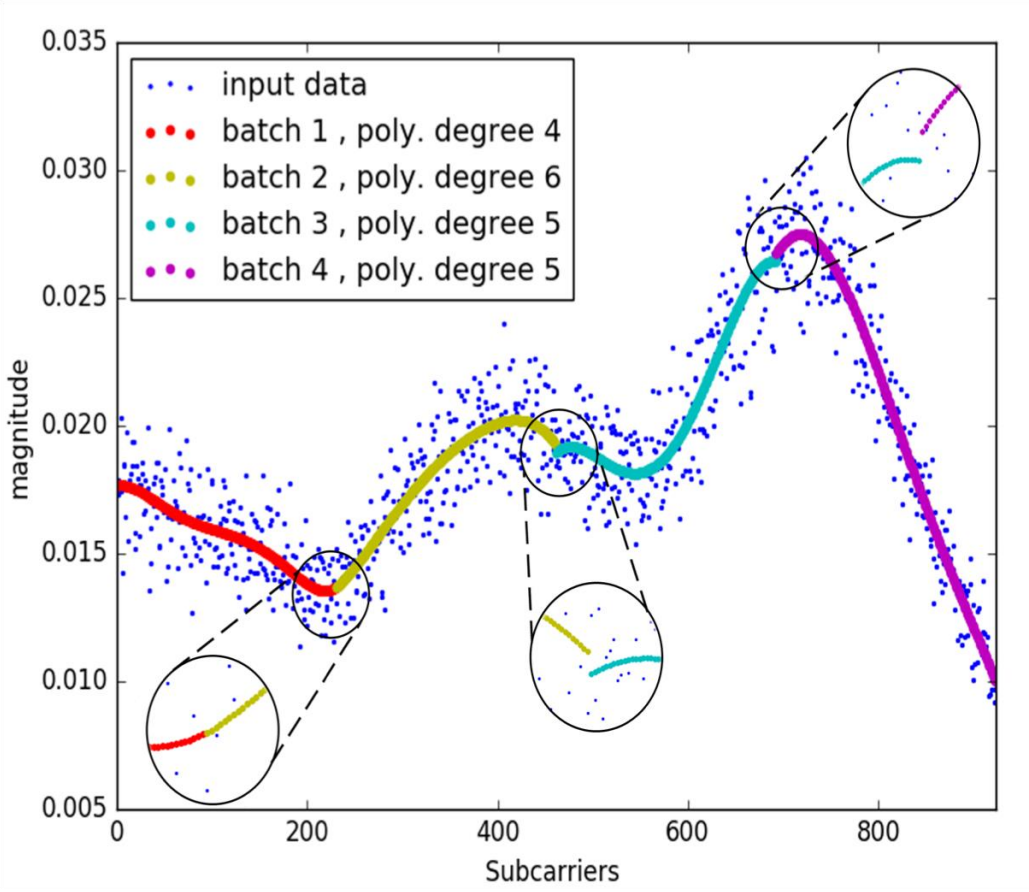
$$Corr_{p_1,p_2} = \frac{Cov\left(CSI_{p1}, CSI_{p2}\right)}{\alpha_{p_1} \times \alpha_{p_2}}$$

- Magnitude shows the highest stability.



Noise and Dimensionality Reduction with Polynomial Regression





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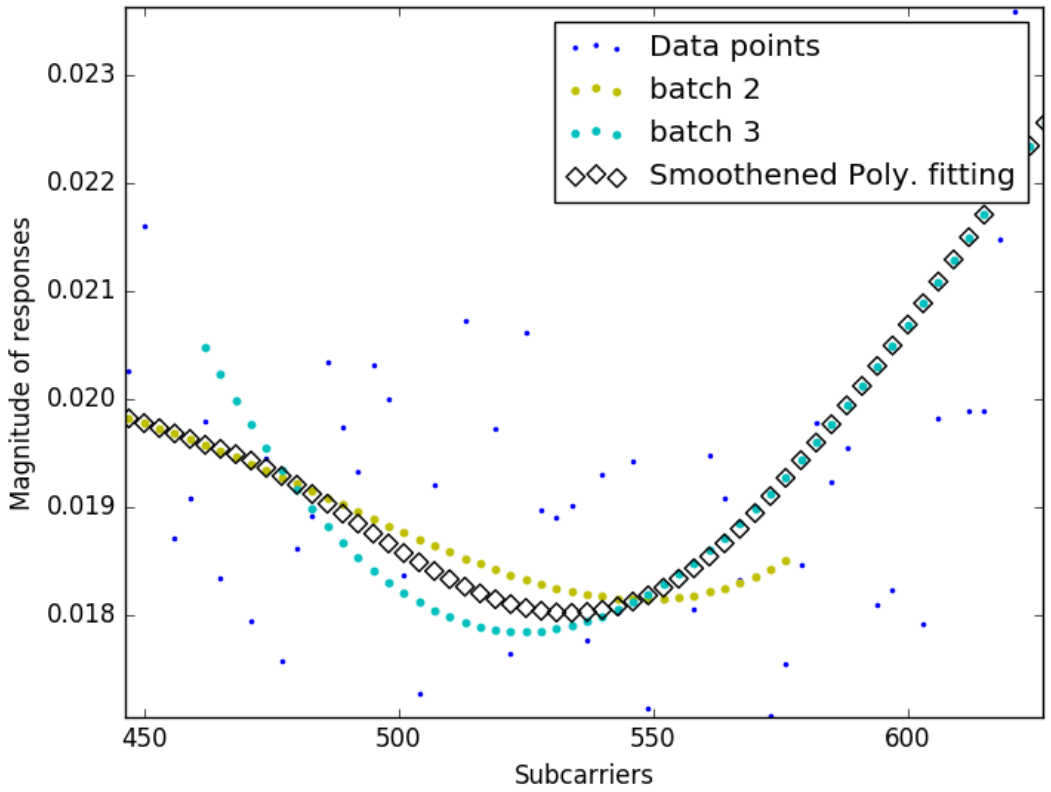
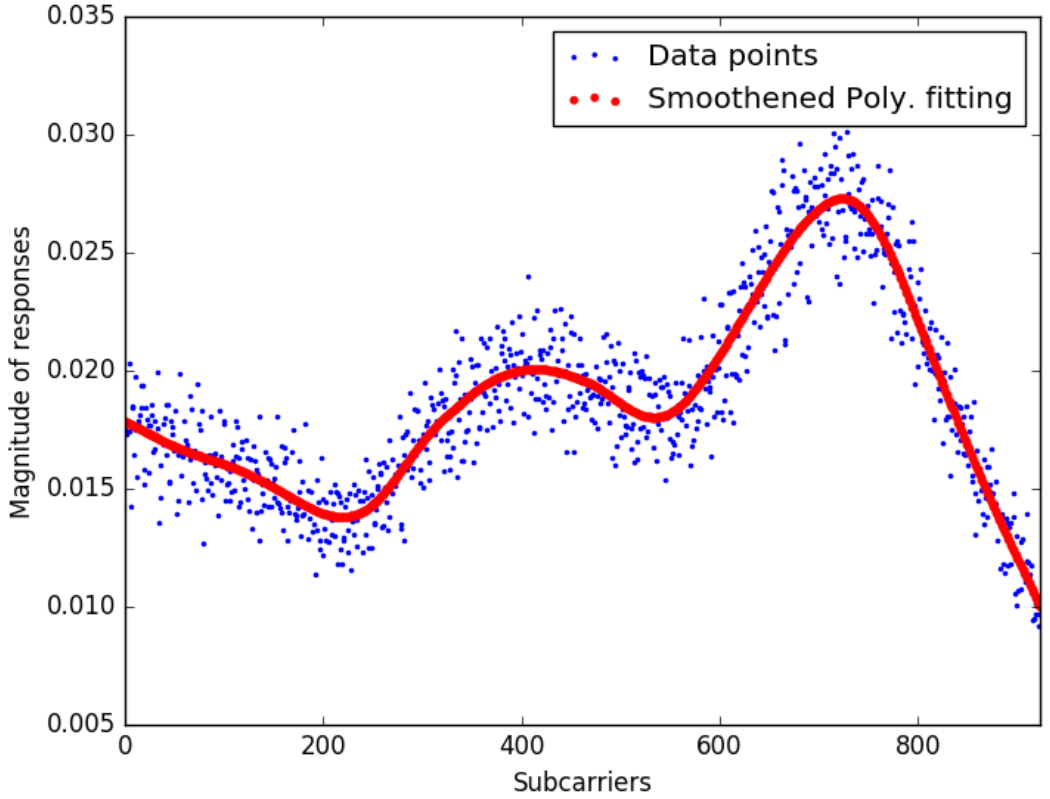
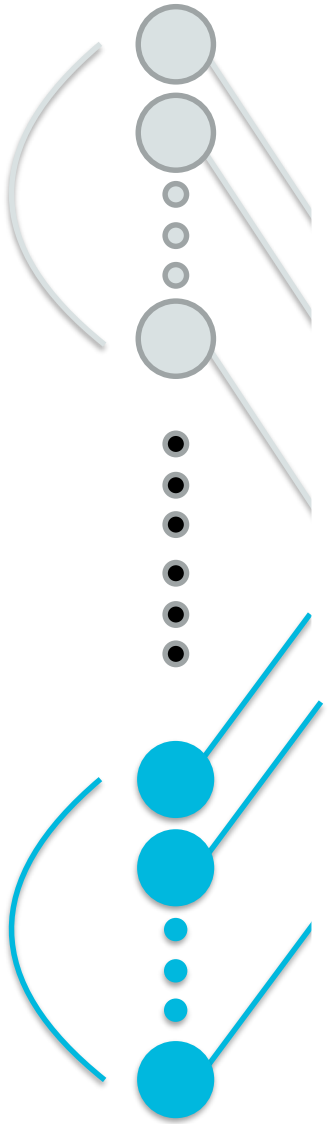




- Select 66 equidistant points on the red line to be the input for the deep learning model.

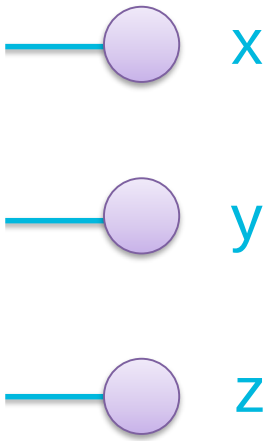
NDR - Multi Layer Perceptron NN

Ant. 1
66 Mag.

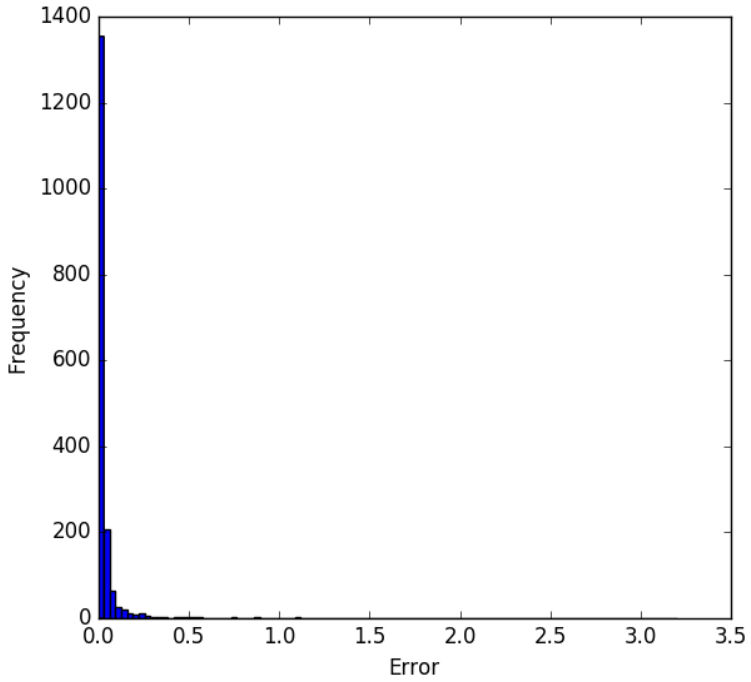


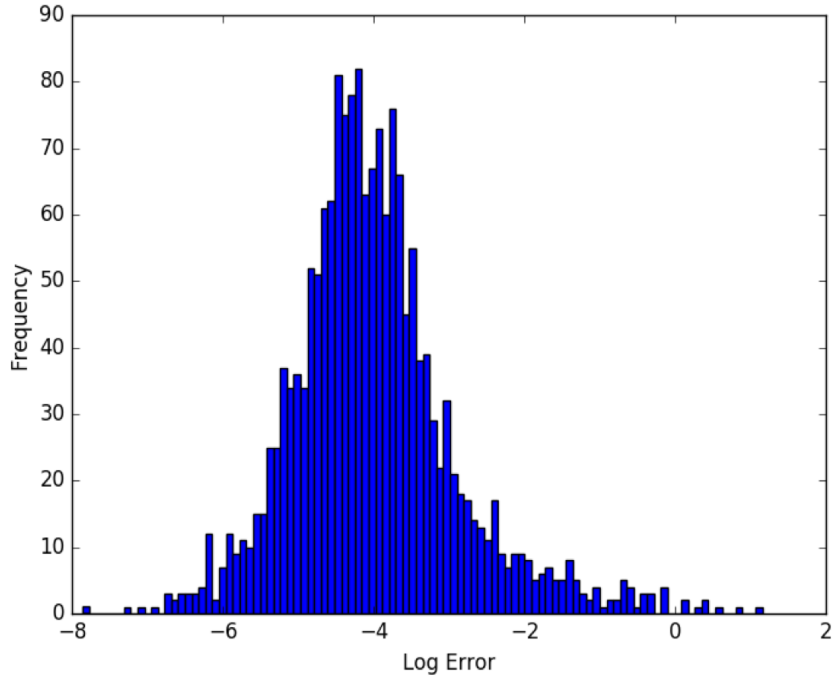
Ant. 16
66 Mag.

Hyperparameter	Tested values	Best found
Number of layers	[4,5,6,7,8]	7
Units per layer	[128,256,512,1024,1200]	1024
Epochs	[50,100,150,200]	150
Activation functions	[relu, selu, tanh, softmax]	relu
Learning rate	$[25 \times 10^{-5}, 5 \times 10^{-4}, 1 \times 10^{-3}]$	5×10^{-4}
Optimizers	[Adam, SGD, AdaDelta]	Adam
L2 regularization	$[\text{without}, 1 \times 10^{-4}, 1 \times 10^{-5}, 1 \times 10^{-6}]$	without L2
Dropout percent	[1%, 2%, ..., 10%]	3%



Distribution of Errors





Mean Square Error

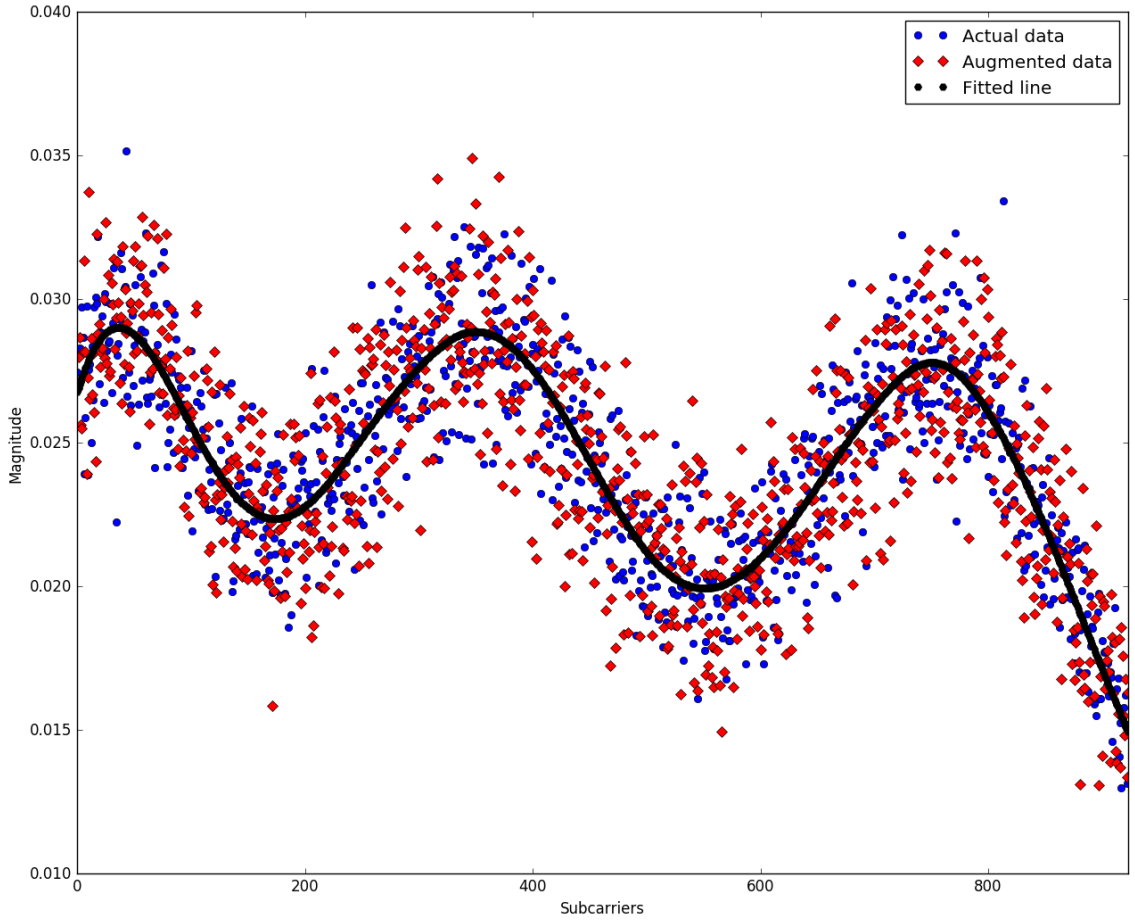
4.5 cm

Log-Error Distribution

with 1.8 cm Mean

Enhancements: Data Augmentation

- Scatter points around the estimated Polynomial Line.
- Use Gaussian Noise with twice the α.
- Corresponding Position is changed using a Gaussian noise with 1/3 cm α.

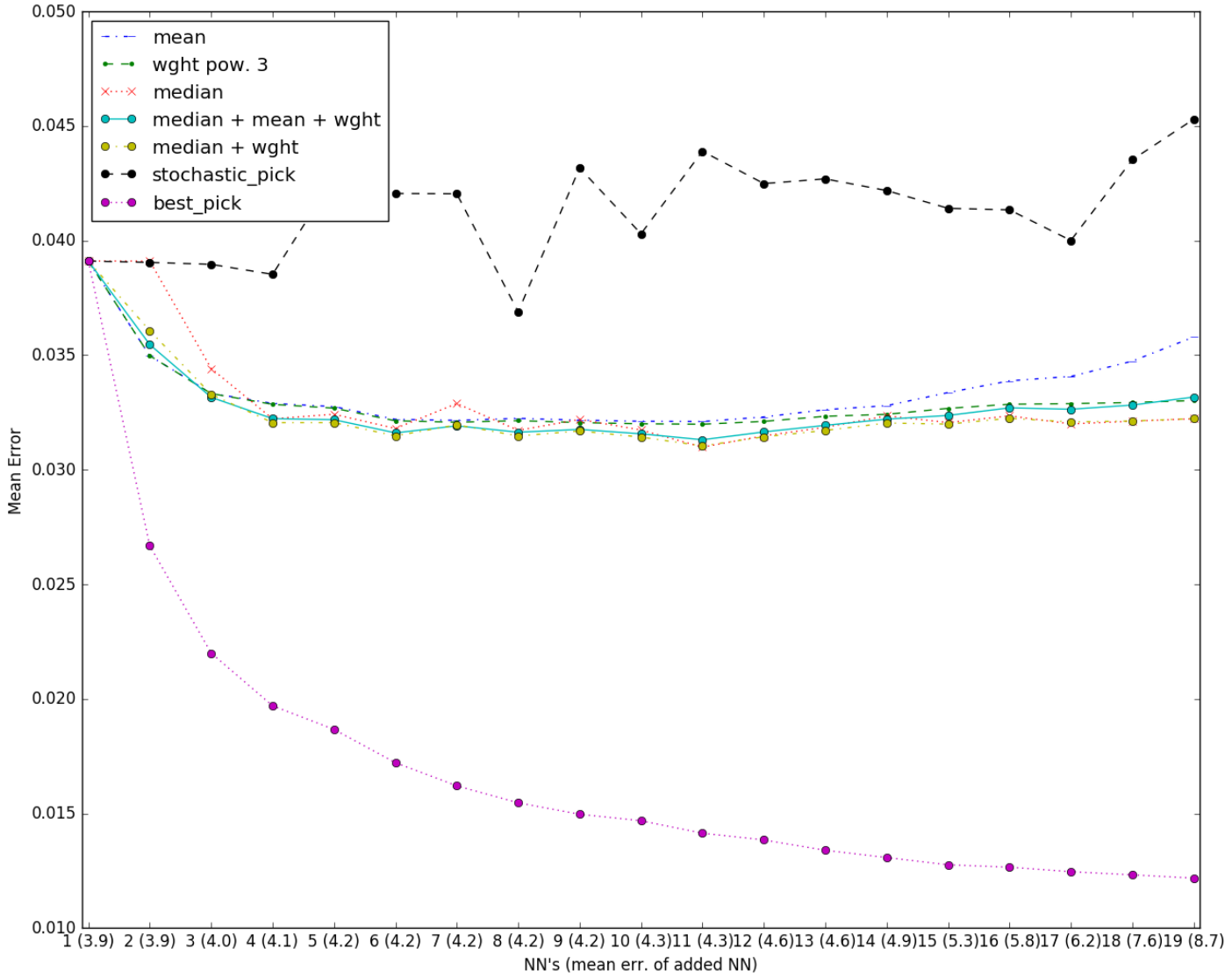


Enhancements: Ensemble Learning

- Building MLP NN’s with different hyper parameters and training data.

- Estimation is a combination of individual predictions:
  - Mean, weighted mean
  - Median
  - Random selection
  - Best selection

Enhancements: Ensemble Learning

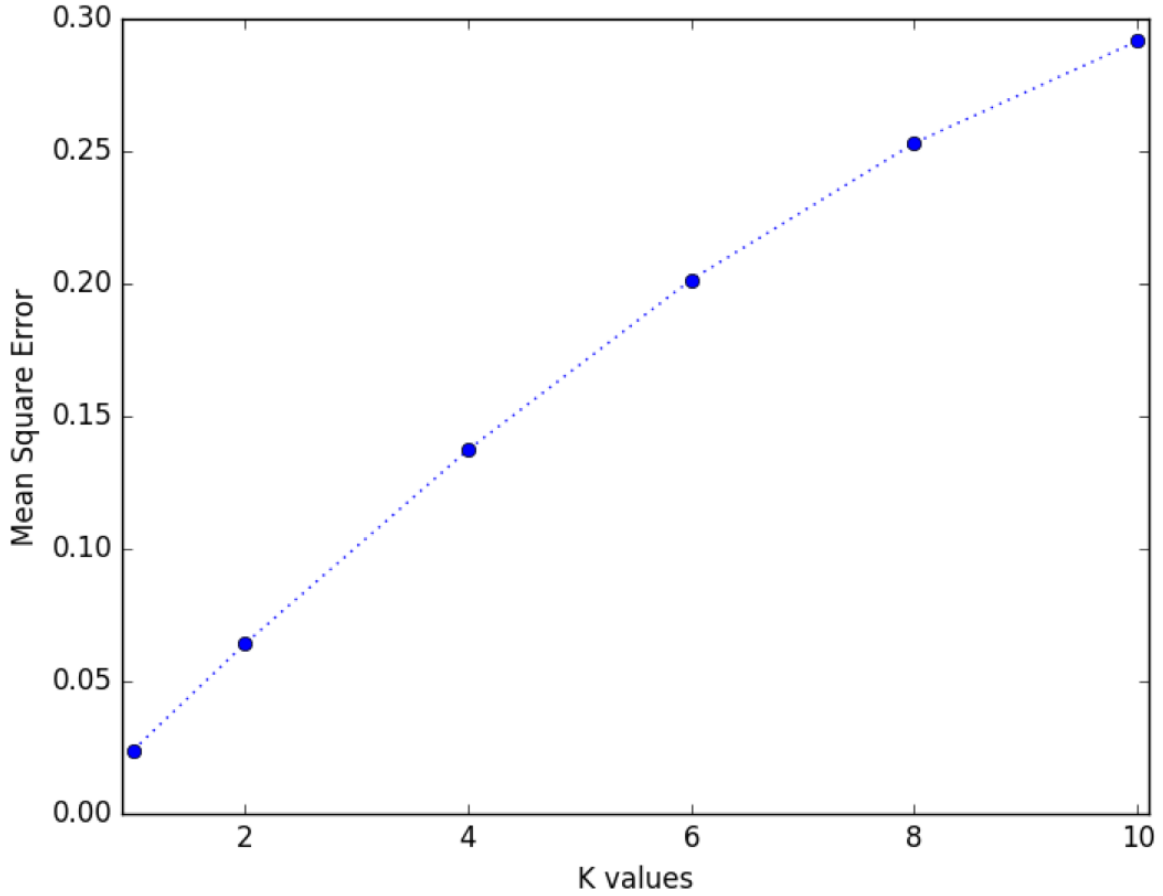


K-Nearest Neighbours

- Neighboring Criterion:
  Euclidean Distance

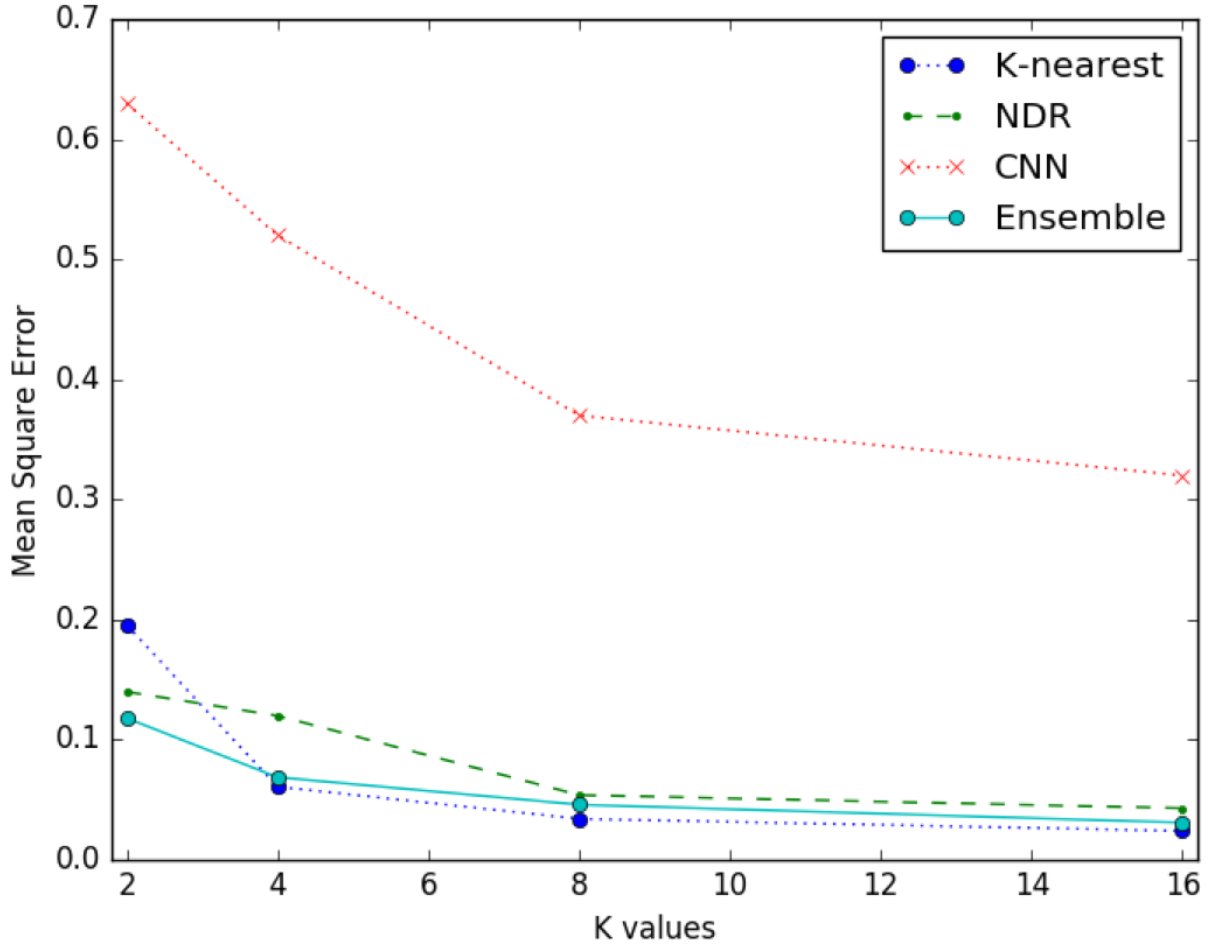
$$dist_{M^1,M^2} = \frac{1}{16}\sum_{a=1}^{16}\sqrt{\sum_{n=1}^{33}\left(M^1_{a,n} - M^2_{a,n}\right)^2}$$

- Number of neighbours: k = 1



Comparing different Methods

- CNN [*]: Convolutional NN with Re and Im components.
- NDR: Using MLP NN.
- Ensemble of MLP NN's.
- K-nearest: 2.4 cm MSE



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* M. Arnold, J. Hoydis, and S. ten Brink, "Novel massive mimo channel sounding data applied to deep learning-based indoor positioning", in SCC 2019; 12th International ITG Conf. on Systems, Communications and Coding

Experimental Summary

- Best Deep MLP (with param. tuning): 4.5 cm MSE.
- Ensemble Neural Networks with difference between adjacent carrier values: 3.1 cm MSE.
- K-nearest neighbour: 2.3 cm error.
- 1st Place among 8 teams from universities across the world: University of Toronto (Canada), Ruhr University Bochum (Germany), Heriot-Watt University (UK) …

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Contributions Summary

- CSI-based Indoor Localization (IEEE CTW 2019).
- Study the generalisation behaviour of the applied ML models.
- CSI-based Outdoor Localization (IEEE CTW 2020).
- Range-based Localization using Triangulation.
- 6 Publications: GlobeCom 2019 and ICC 2020.
- 14 external citations.

Conclusion

- Localization service is essential for many applications and shall thrive more with the 5G.
- CSI is a fine-grain measurement that allows cm level localization.
- Generalization of ML modelling is an essential evaluation criteria.
- Relational learning by biasing Deep Learning model architecture enforces extraction of more general features e.g. GNN

Thank you

Happy to answer your questions