An Efficient Machine Learning-based Channel Prediction Technique for OFDM Sub-Bands

Pedro E. Gória Silva, Jules M. Moualeu, Pedro H. Nardelli, Yonghui Li, and **Rausley A. A. de Souza**

National Institute of Telecommunications
(*Instituto Nacional de Telecomunicações* - Inatel)

2024 IEEE 99th Vehicular Technology Conference: VTC2024-Spring, 24-27 June 2024, Singapore

June 24, 2024

Summary

Inatel
Instituto Nacional de Telecomunicações

Motivation and novelty

Inatel
Instituto Nacional de Telecomunicações

- Channel state information (CSI)
- Channel estimation or channel prediction

To propose an efficient machine learning-based technique for channel prediction in OFDM sub-bands

Channel Characteristics and Assumptions

- To deal separately with relevant aspects of wave propagation and antenna characteristics
- To evaluate the channel on a two-dimensional plane through which the mobile radio channel simulator consists of reflection points of the signal transmitted in the 2-D plane
- To address the birth and death problem of multipath clusters by allowing some reflecting points to move randomly during the channel simulation
- The simulated environment is such that there are multipaths;
- The free space attenuation is assumed for each multipath;

- The relative position of the transmitter $\boldsymbol{P}_{\mathrm{tx}}$ and receiver $\boldsymbol{P}_{\mathrm{rx}}$, and initial position of the reflection points $\boldsymbol{P}_{\mathrm{r}}$ (randomly generated) in Cartesian coordinates;
- The speed vector of the receiver $\boldsymbol{S}_{\mathrm{rx}}$ and reflection points $\boldsymbol{S}$;
- The total number of reflection points N_{r} and mobile reflection points N_{m};
- The carrier frequency f_{c}, the sampling frequency f_{s}, the bandwidth of the transmitted signal B, and the sampling time window p;

1. $\boldsymbol{P}_{\mathrm{r}}$, $\boldsymbol{S}_{\mathrm{rx}}$, and $\boldsymbol{S}$ are generated according to a Gaussian distribution
2. The length of a multipath $l_i = |\boldsymbol{P}_i - \boldsymbol{P}_{\mathrm{rx}}| + |\boldsymbol{P}_i - \boldsymbol{P}_{\mathrm{tx}}|$
3. The delay and phase of the multipath i are calculated as $\tau_i = l_i/c$ and $\phi_i = -l_i f_{\mathrm{c}}/c \mod 2\pi$, respectively,
4. The channel impulse response

$$I = \sum_{i=1}^{N} \frac{c}{4\pi f_{\mathrm{c}} l_i} \exp\left(\phi_i + 2\pi D_i l_i\right)\delta(\tau_i - t) \tag{1}$$

5. Obtain the frequency response of the channel by the DFT
6. The positions of the receiver and other mobile points are updated

$$\boldsymbol{P}_{\mathrm{rx}} \leftarrow \boldsymbol{P}_{\mathrm{rx}} + \boldsymbol{S}_{\mathrm{rx}}\Delta t \tag{2}$$

$$\boldsymbol{P}_{\mathrm{r}} \leftarrow \boldsymbol{P}_{\mathrm{r}} + \boldsymbol{S}\Delta t, \tag{3}$$

Inatel
Instituto Nacional de Telecomunicações

Table 1: Summary of Channel Simulation Settings.

Symbol	Value	Description
$\boldsymbol{P}_{\mathrm{tx}}$	$(-200, 0)$	Transmitter's relative starting position
$\boldsymbol{P}_{\mathrm{rx}}$	$(200, 0)$	Receiver's relative starting position
N_{r}	256	Number of reflection points
N_{m}	63	Number of mobile reflection points
f_{c}	900 MHz	Carrier frequency
f_{s}	51.2 MHz	Sampling frequency
B	12.8 MHz	Bandwidth of the transmitted signal
p	10 μs	Sampling time window
SNR	12 dB	Signal-to-Noise ratio at receiver
Δt	500 μs	Time between two consecutive simulations of the channel

Channel simulation: results

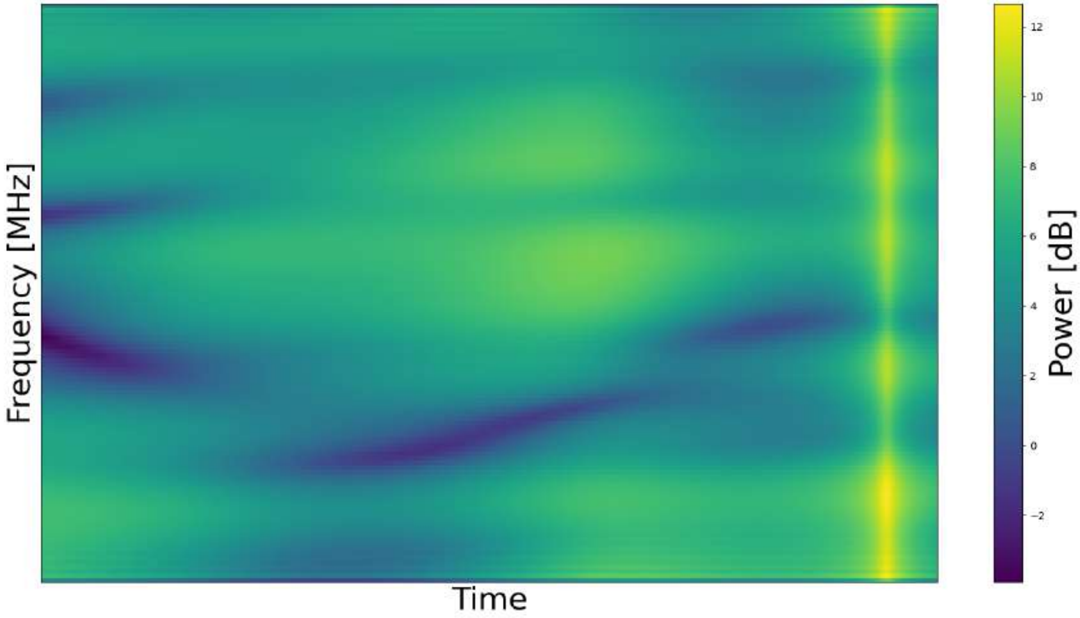

Figure 1: Frequency response of the channel over time.

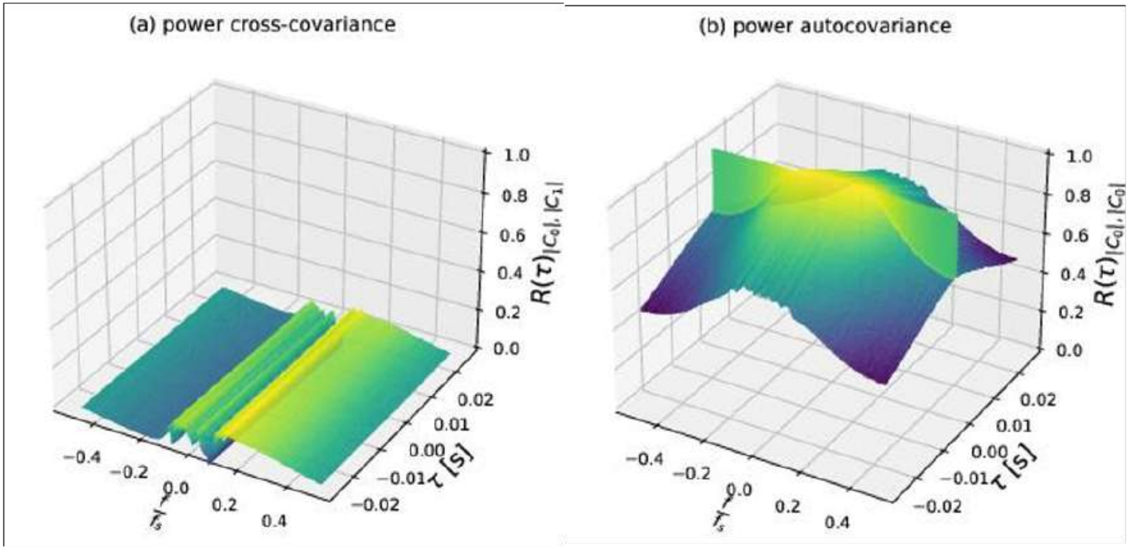

Figure 2: (a) Cross-covariance and (b) autocovariance over τ for the frequency band of interest.

Channel prediction: Goal

- Predict D steps ahead of the channel frequency response (CNN Predictor)
- Predict whether the channel intensity will be below a threshold D steps ahead (CNN Classifier).

Inatel
Instituto Nacional de Telecomunicações

Table 2: Summary of the Characteristics of the Predictor Layers.

#	Channels	Kernel size	Dilation rate	Activation function
1	2	(3×10)	(1×1)	$\tanh(\cdot)$
2	3	(10×10)	(1×16)	$\tanh(\cdot)$
3	3	(10×10)	(10×1)	$\tanh(\cdot)$
4	2	(10×3)	(1×64)	$\tanh(\cdot)$
5	D	(1×64)	(1×1)	exponential

Inatel
Instituto Nacional de Telecomunicações

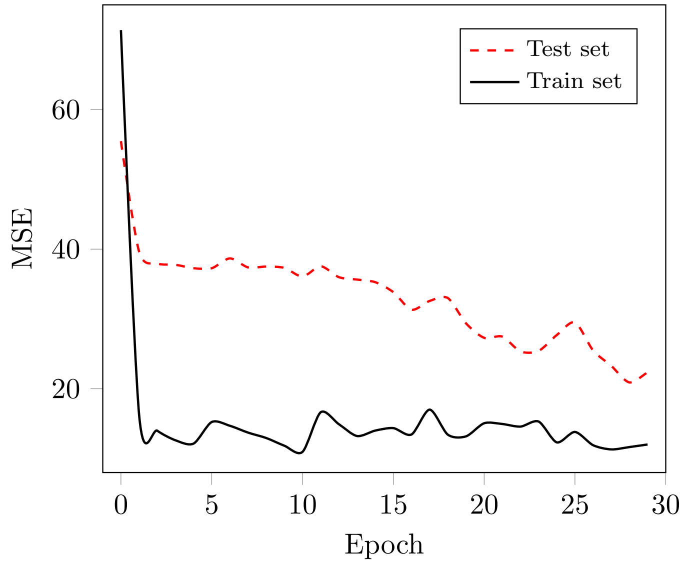

Figure 3: Mean Squared Error during training.

Predictor has smoother training and converges (≈ 8 training epochs)

Numerical Results: ROC

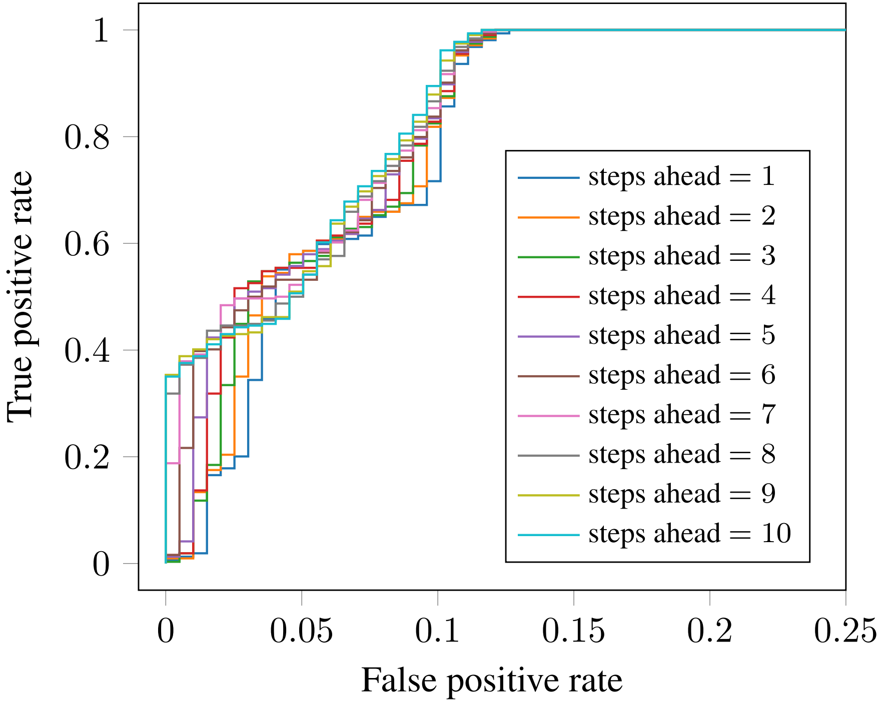

Figure 4: ROC curves for a single sub-band and for the different steps ahead.

Inatel
Instituto Nacional de Telecomunicações

Table 3: Mean Squared Error over the 4096 samples from a new and uncorrelated channel.

Step ahead	MSE
1	24.455336
2	22.610251
3	26.049115
4	24.488873
5	23.515360
6	23.826602
7	25.350836
8	25.708386
9	25.830940
10	26.221350

Conclusions

- A simplified way to simulate a mobile radio channel with fading has been proposed
- A CNN predictor and classifier have been successfully employed to predict the multi-step fading channel in wireless broadband systems
- Both the predictor and the classifier performed adequately when training and testing were performed on uncorrelated physical scenarios

Next Steps

Inatel
Instituto Nacional de Telecomunicações

- Include the antenna parameters
- Different channels, like Rician
- Find a better CNN

Thank you!

This work is supported in part by the Academy of Finland via: (a) FIREMAN consortium n.326270 as part of CHIST-ERA-17-BDSI-003, (b) EnergyNet Fellowship n.321265/n.328869/n.352654, and (c) X-SDEN project n.349965; by Jane and Aatos Erkko Foundation via STREAM project; by CNPq (Grant Nos. 403612/2020-9, 311470/2021-1, and 403827/2021-3), by Minas Gerais Research Foundation (FAPEMIG) (Grant Nos. APQ-00810-21 and PPE-00124-23), and by the projects XGM-AFCCT-2024-2-5-1 and XGM-FCRH-2024-2-1-1 supported by xGMobile – EMBRAPII-Inatel Competence Center on 5G and 6G Networks, with financial resources from the PPI IoT/Manufatura 4.0 from MCTI grant number 052/2023, signed with EMBRAPII, and by the South African National Research Foundation (NRF) under the BRICS Multilateral Research and Development Project (Grant No. 116018).