Machine Learning LTE RF Fingerprinter

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GMU CYSE 640 Wireless Network Security

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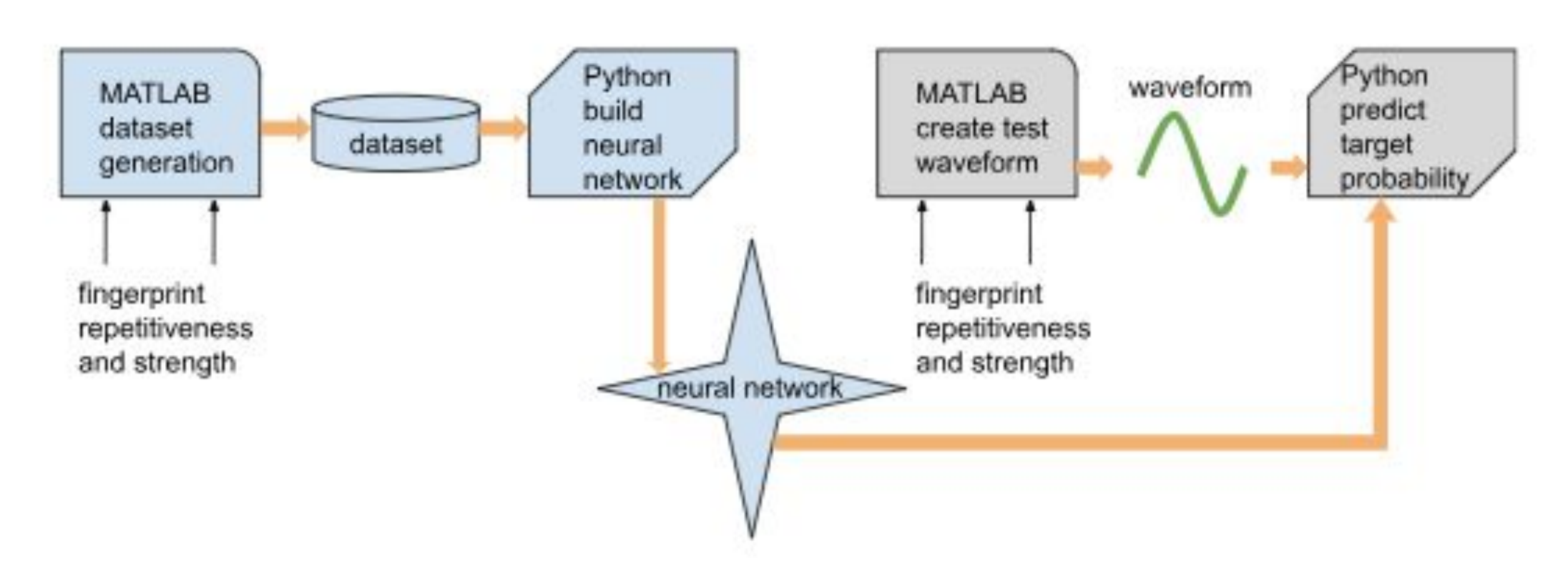
Project Objectives

- MATLAB
  - LTE Toolbox
- LTE
  - Standards Compliance
  - Simulation
- Radio Fingerprinting
  - Theory
  - Integration
- Community Standards
  - SigMF
  - curl HTTP Web API Service
- Further Development

Investigative Tools



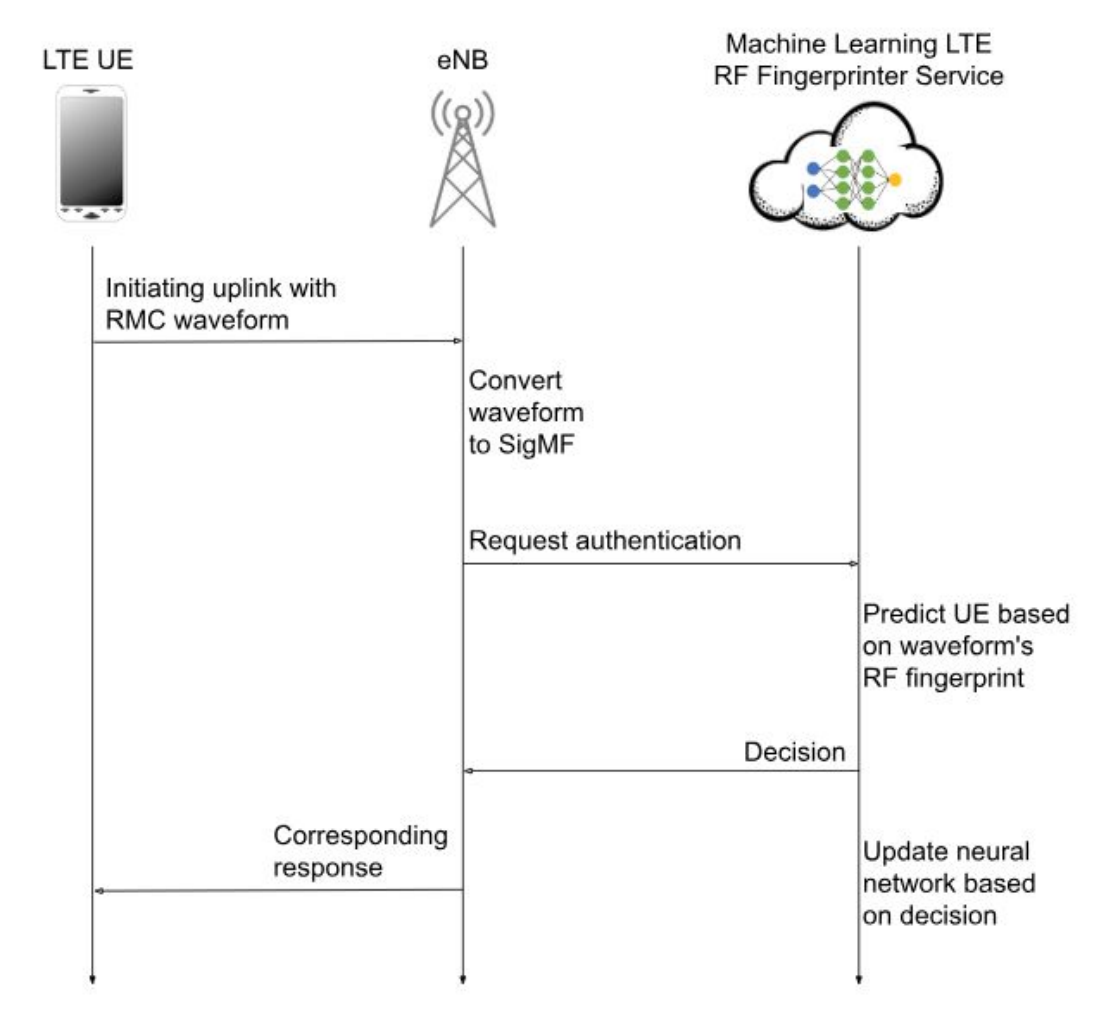
Tools Demo

chrimson.github.io/ML-LTE-RFF

Tools Result

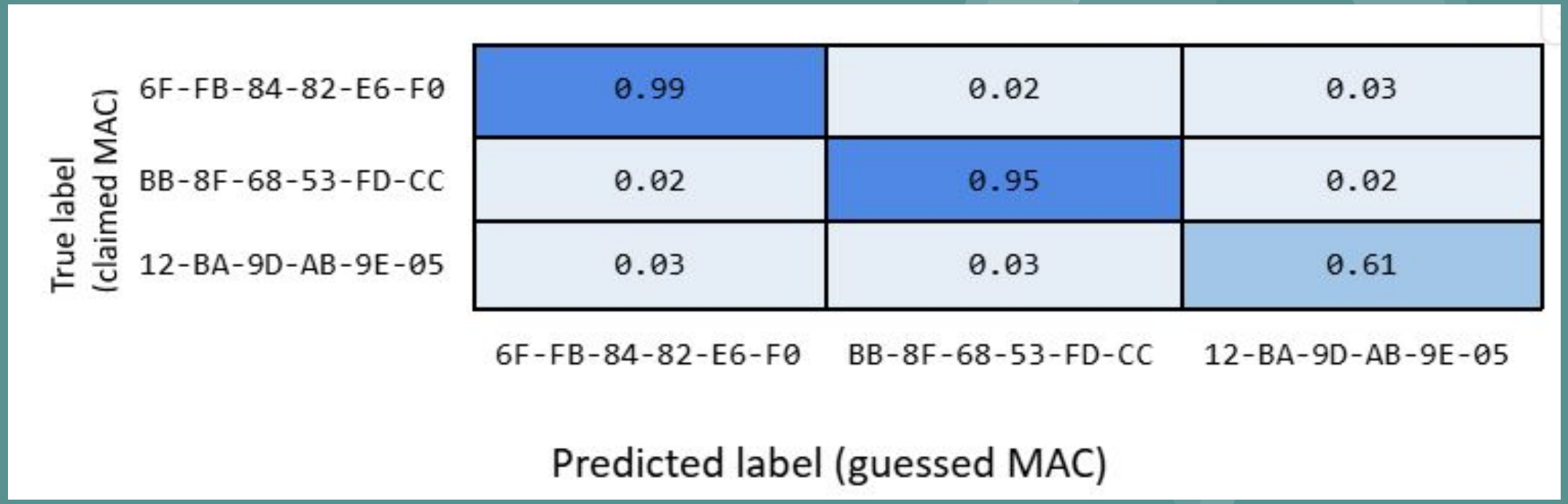
Strength \ Repetition	10	15	20	25	30	35
10%	33%	2%	4%	3%	2%	2%
15%	2%	2%	2%	2%	99%	9%
20%	2%	22%	59%	**99%**	90%	2%
25%	99%	99%	99%	95%	12%	99%
30%	99%	99%	99%	99%	99%	99%
35%	70%	99%	99%	99%	15%	2%

Service Architecture



Service Demo

Service Result



Further Work

- Hardware feasibility
- Full signal length
- Address catastrophic forgetting
- HTTPS, certificate hardening
- IP port standardization

References

(Summary only, details in report)

Deep Learning Convolutional Neural Networks for Radio Identification, S. Riyaz

Improving security of the Internet of Things via RF fingerprinting based device identification system, S. Abbas

Reference measurement channel RMC parameters of LTE downlink waveforms, F. Azzawi

Data classification with deep learning using TensorFlow, F. Ertam

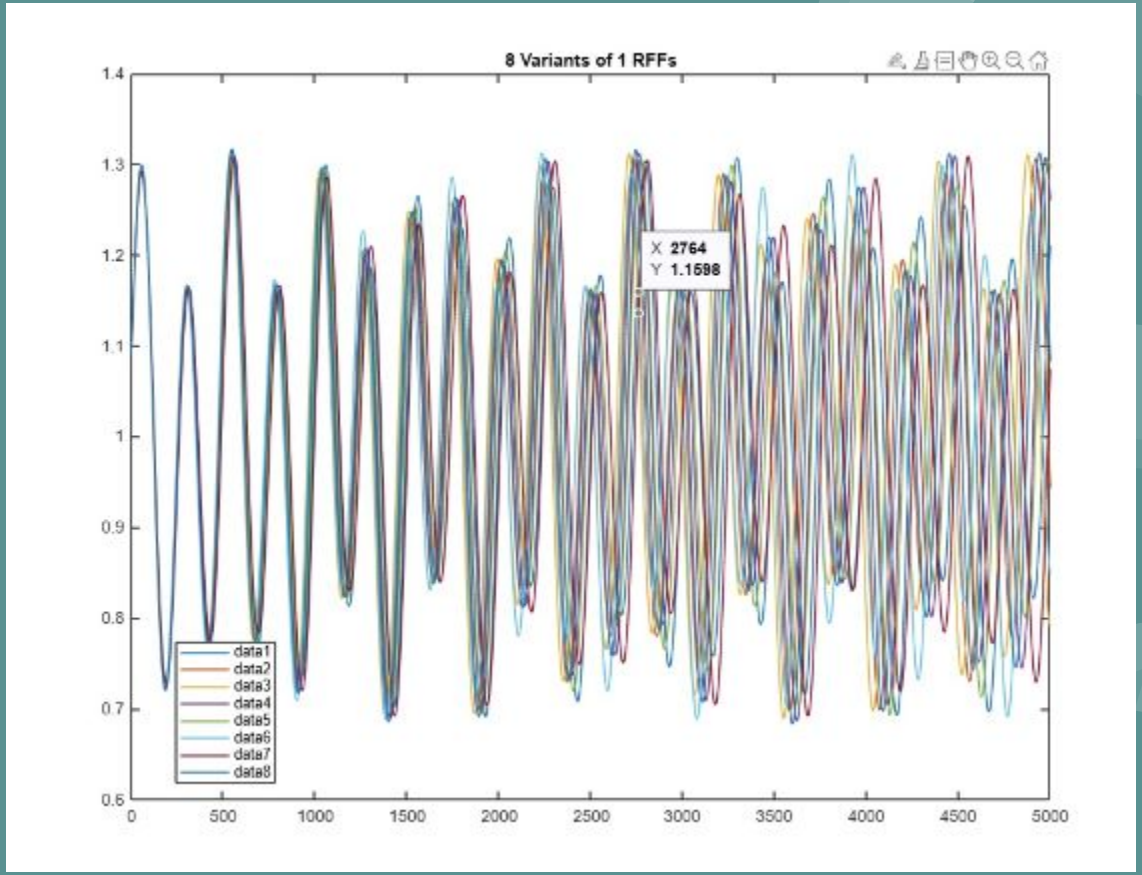
Web Application Implementation with Machine Learning, A. Verma

Implementation of Automated Annotation through Mask RCNN Object Detection model in CVAT using AWS EC2 Instance, M. Guillermo

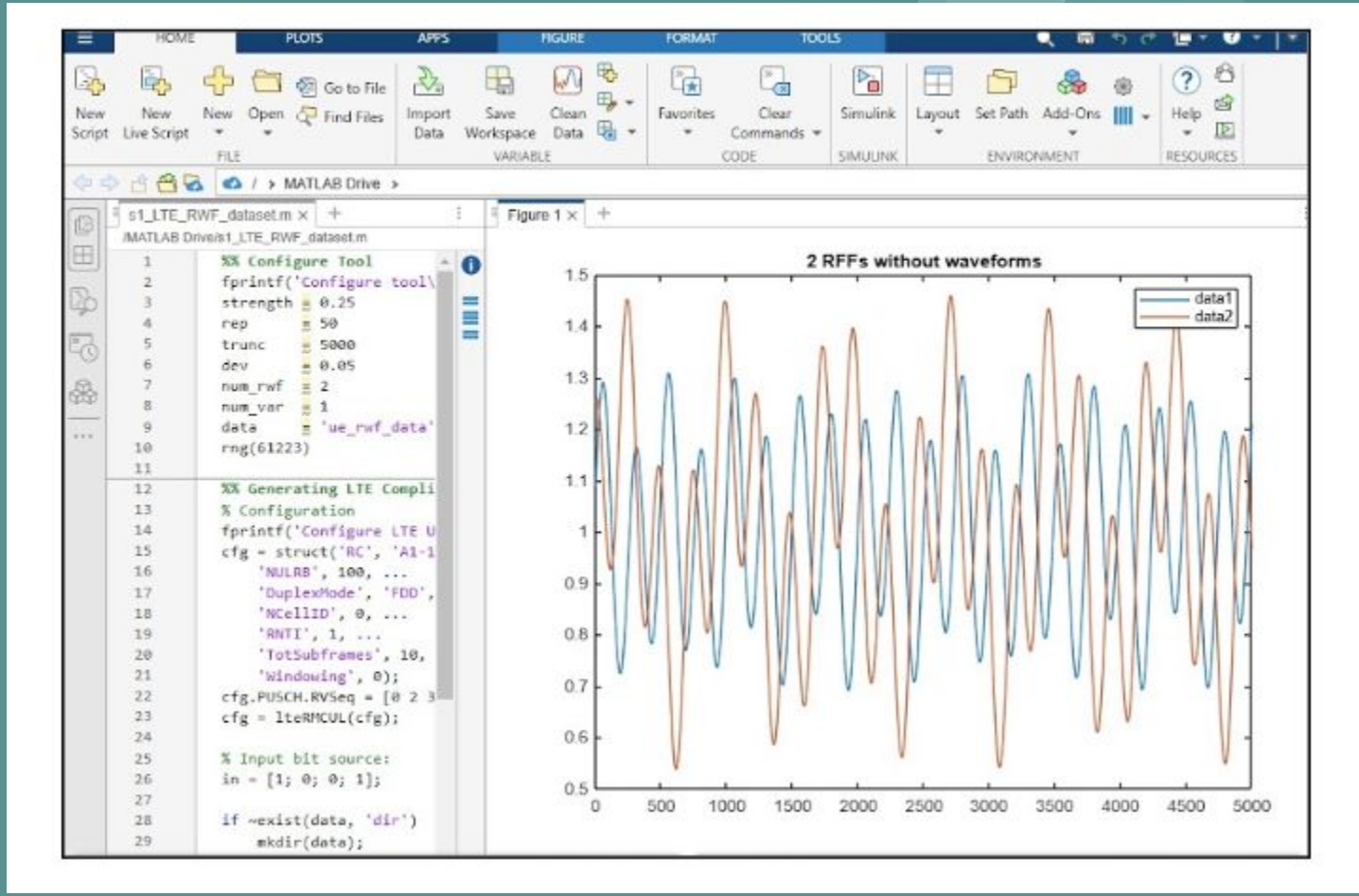
Understanding LTE with MATLAB: From Mathematical Modeling to Simulation and Prototyping, H. Zarrinkoub

SigMF: The Signal Metadata Format, B. Hilburn

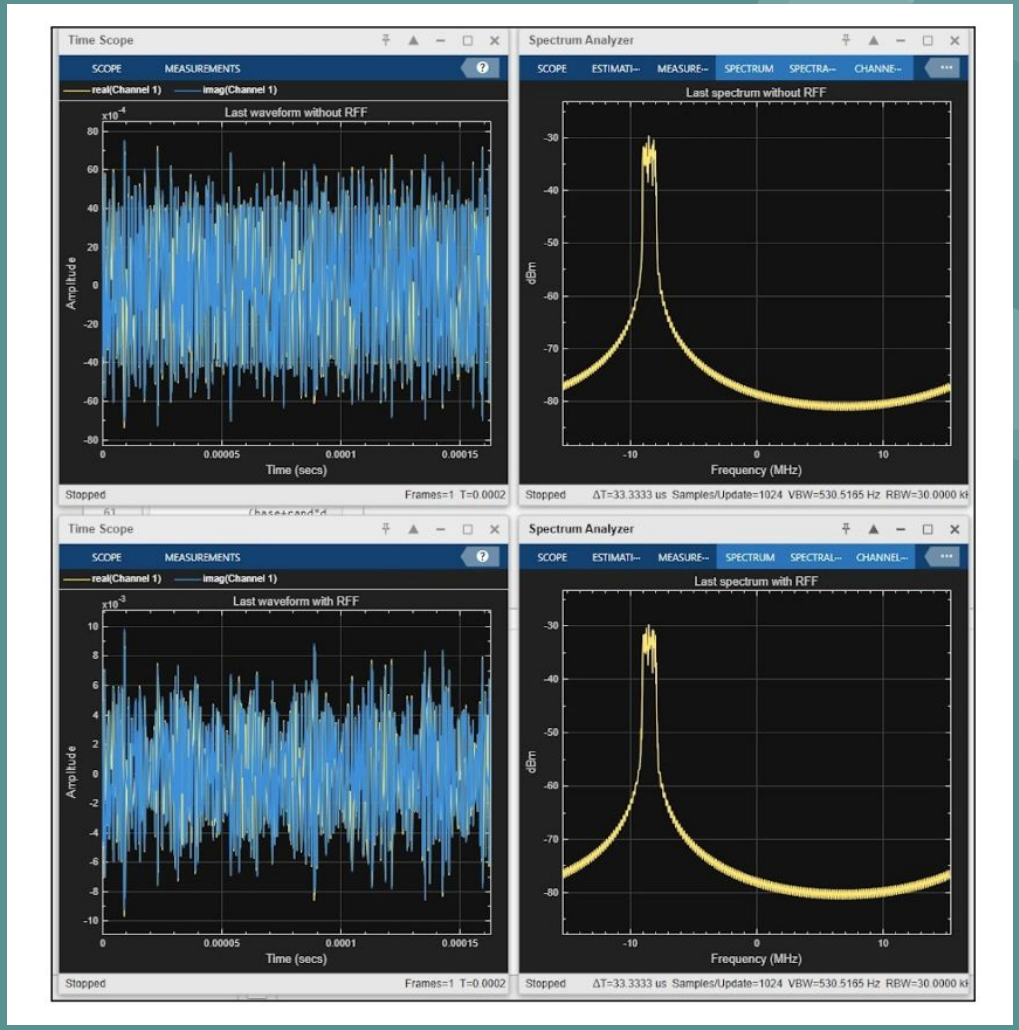
Backup


8 Variants of 1 RFFs
X 2764
Y 1.1598
data1
data2
data3
data4
data5
data6
data7
data8
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

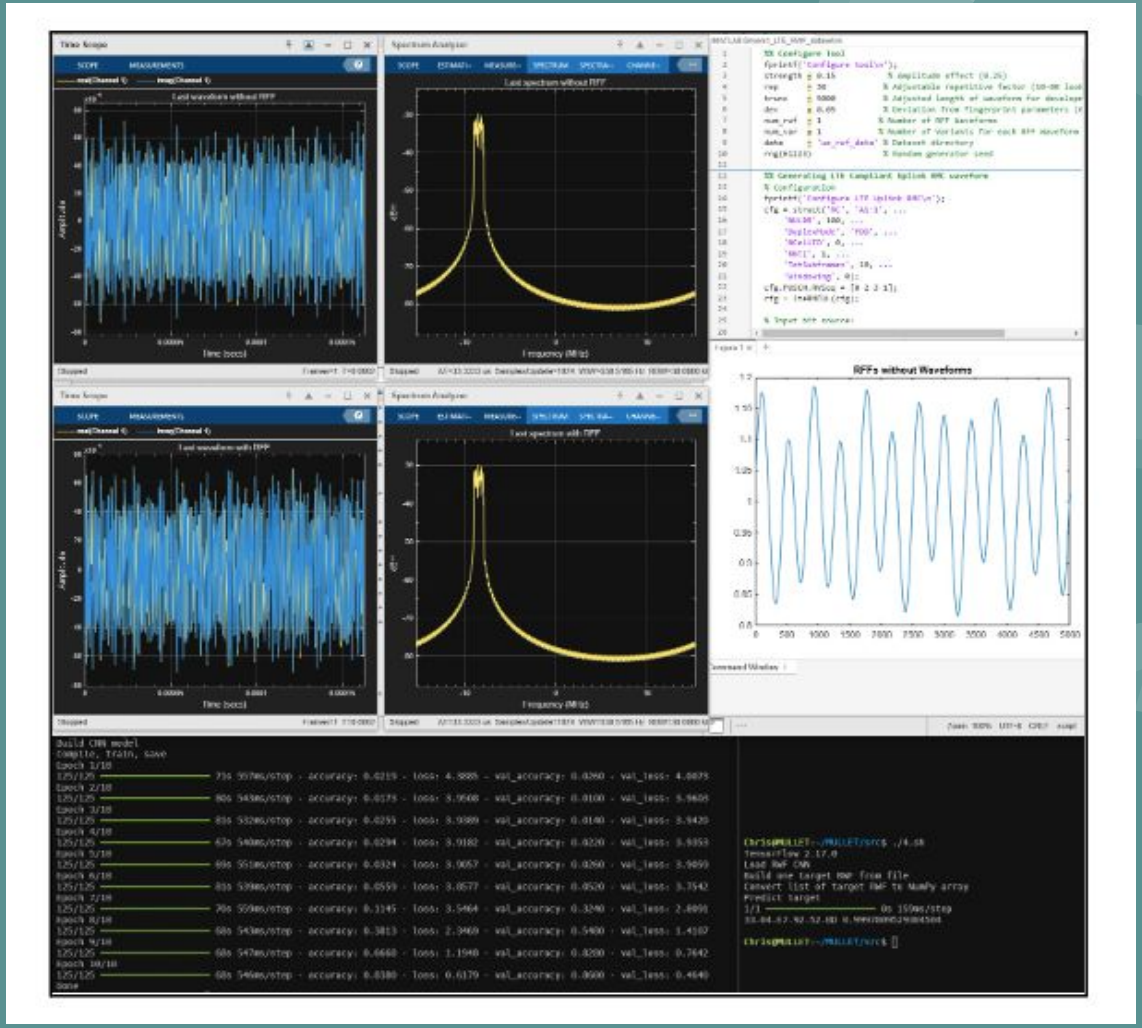
Backup


HOME
PLOTS
APPS
FIGURE
FORMAT
TOOLS
New Script
New Live Script
New
Open
Go to File
Find Files
Import Data
Save Workspace
Clean Data
Favorites
Clear Commands
Simulink
Layout
Set Path
Add-Ons
Help
FILE
VARIABLE
CODE
SIMULINK
ENVIRONMENT
RESOURCES
MATLAB Drive
s1_LTE_RWF_dataset.m
/MATLAB Drive/s1_LTE_RWF_dataset.m
%% Configure Tool
fprintf('Configure tool\
strength = 0.25
rep = 50
trunc = 5000
dev = 0.05
num_rwf = 2
num_var = 1
data = 'ue_rwf_data'
rng(61223)
%% Generating LTE Compli
% Configuration
fprintf('Configure LTE U
cfg = struct('RC', 'A1-1
'NULRB', 100, ...
'DuplexMode', 'FDD',
'NCellID', 0, ...
'RNTI', 1, ...
'TotSubframes', 10,
'Windowing', 0);
cfg.PUSCH.RVSeq = [0 2 3
cfg = lteRMCUL(cfg);
% Input bit source:
in = [1; 0; 0; 1];
if ~exist(data, 'dir')
mkdir(data);
Figure 1
2 RFFs without waveforms
data1
data2
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Backup


Time Scope
SCOPE
MEASUREMENTS
real(Channel 1)
imag(Channel 1)
Last waveform without RFF
Amplitude
Time (secs)
Stopped
Frames=1 T=0.0002
Spectrum Analyzer
SCOPE
ESTIMATI...
MEASURE...
SPECTRUM
SPECTRA...
CHANNE...
Last spectrum without RFF
dBm
Frequency (MHz)
Stopped
ΔT=33.3333 us Samples/Update=1024 VBW=530.5165 Hz RBW=30.0000 kH
Time Scope
SCOPE
MEASUREMENTS
real(Channel 1)
imag(Channel 1)
Last waveform with RFF
Amplitude
Time (secs)
Stopped
Frames=1 T=0.0002
Spectrum Analyzer
SCOPE
ESTIMATI...
MEASURE...
SPECTRUM
SPECTRAL...
CHANNEL...
Last spectrum with RFF
dBm
Frequency (MHz)
Stopped
ΔT=33.3333 us Samples/Update=1024 VBW=530.5165 Hz RBW=30.0000 kH

Backup



Backup

```
ubuntu@ip-172-31-35-3:~/ML-LTE-RFF/generate$ ./1.sh 25 20

                          < M A T L A B (R) >
                Copyright 1984-2024 The MathWorks, Inc.
             R2024b Update 1 (24.2.0.2740171) 64-bit (glnxa64)
                          September 20, 2024

Configure tool

trunc =
        5000

dev =
    0.0500

num_rwf =
    50

num_var_base =
    30

data =
    '25x20_ue_rwf_data'

Configure LTE Uplink RMC

RFF Waveform 1, MAC 33-04-E7-92-52-BD
Variant 1
Variant 2
...
Variant 43
Variant 44

...

RFF Waveform 50, MAC BB-8F-68-53-FD-CC
Variant 1
Variant 2
...
Variant 54
Variant 55
```

```
ubuntu@ip-172-31-35-3:~/ML-LTE-RFF/generate$ ./2.sh 25 20

TensorFlow 2.18.0
Build lists of RWFs and their MAC IDs from dataset
A6-0E-DF-53-2B-04
0025 0010 0031 0008 0002 0009 0022 0038 0004 0026 0020 0017 0000 0034 0018 0032 0016 0028 0033 0037 0013
0036 0024 0039 0027 0035 0029 0030 0015 0021 0001 0014 0011 0023 0003 0007 0005 0019 0006 0012
...
47-76-DC-B0-07-60
0025 0010 0031 0008 0002 0009 0022 0004 0026 0020 0017 0000 0018 0032 0016 0028 0033 0013 0024 0027 0029
0030 0015 0021 0001 0014 0011 0023 0003 0007 0005 0019 0006 0012

Convert lists to NumPy arrays
Label encoding
Shuffle arrays
Build CNN model

Compile, train, save
Epoch 1/12
116/116 ------- 9s 44ms/step - accuracy: 0.0263 - loss: 4.8441 - val_accuracy: 0.0238 - val_loss: 3.9601
Epoch 2/12
116/116 ------- 2s 17ms/step - accuracy: 0.0326 - loss: 3.9473 - val_accuracy: 0.0238 - val_loss: 3.9448

...

116/116 ------- 2s 17ms/step - accuracy: 0.0968 - loss: 3.5956 - val_accuracy: 0.1948 - val_loss: 2.8682
Epoch 11/12
116/116 ------- 2s 17ms/step - accuracy: 0.2694 - loss: 2.5664 - val_accuracy: 0.5325 - val_loss: 1.5733
Epoch 12/12
116/116 ------- 2s 17ms/step - accuracy: 0.6083 - loss: 1.3111 - val_accuracy: 0.7056 - val_loss: 0.9645

Done
```

```
ubuntu@ip-172-31-35-3:~/ML-LTE-RFF/generate$ ./4.sh 25 20
TensorFlow 2.18.0
Load RWF CNN
Build one target RWF from file
Convert list of one target RWF to NumPy array
Predict target
1/1 ------- 1s 1s/step

BB-8F-68-53-FD-CC 0.5671826601028442
```

Backup

```
ubuntu@ip-172-31-35-3:~/ML-LTE-RFF/service$ python3 ml_lte_rff.py
[2024-11-23 04:39:46,657] INFO in reader: Read 50 MACs and their variant RWFs from dataset
[2024-11-23 04:39:47,036] INFO in reader:   Read A6-0E-DF-53-2B-04 40 Variants
[2024-11-23 04:39:47,425] INFO in reader:   Read 47-76-DC-B0-07-60 34 Variants
...
[2024-11-23 04:40:00,241] INFO in reader:   Read 33-04-E7-92-52-BD 44 Variants
[2024-11-23 04:40:01,348] INFO in reader:   Read BB-8F-68-53-FD-CC 55 Variants
[2024-11-23 04:40:05,965] INFO in builder: Build and train


[2024-11-23 04:40:07,622] INFO in builder:   Epoch 1/12 Accuracy 1.68%
[2024-11-23 04:40:16,046] INFO in builder:   Epoch 2/12 Accuracy 2.60%
[2024-11-23 04:40:17,964] INFO in builder:   Epoch 3/12 Accuracy 2.60%
...
[2024-11-23 04:40:31,424] INFO in builder:   Epoch 10/12 Accuracy 2.33%
[2024-11-23 04:40:33,343] INFO in builder:   Epoch 11/12 Accuracy 2.60%
[2024-11-23 04:40:35,262] INFO in builder:   Epoch 12/12 Accuracy 2.33%

 * Serving Flask app 'ml_lte_rff_svc'
 * Debug mode: off
 * Running on all addresses (0.0.0.0)
 * Running on http://127.0.0.1:64024
 * Running on http://172.31.35.3:64024

[2024-11-23 04:44:21,094] INFO in ml_lte_rff_svc: Uploaded 12-BA-9D-AB-9E-05
[2024-11-23 04:44:21,095] INFO in predictor: Import target RWF from stage
[2024-11-23 04:44:21,250] INFO in predictor:   Guess 6F-FB-84-82-E6-F0 Probability 2.65%
[2024-11-23 04:44:21,251] INFO in predictor:   Claim 12-BA-9D-AB-9E-05 Probability 2.31%
[2024-11-23 04:44:21,255] INFO in ml_lte_rff_svc:   Diff MACs, RWF < 80% Learn claimed MAC

[2024-11-23 04:44:21,328] INFO in builder: Build and train
[2024-11-23 04:44:21,616] INFO in builder:   Epoch 1/12 Accuracy 1.84%
[2024-11-23 04:44:27,909] INFO in builder:   Epoch 2/12 Accuracy 1.73%
...
[2024-11-23 04:44:45,247] INFO in builder:   Epoch 11/12 Accuracy 15.87%
[2024-11-23 04:44:47,175] INFO in builder:   Epoch 12/12 Accuracy 19.45%
```

```
[2024-11-23 04:47:44,781] INFO in ml_lte_rff_svc: Uploaded 12-BA-9D-AB-9E-05
[2024-11-23 04:47:44,781] INFO in predictor: Import target RWF from stage
[2024-11-23 04:47:44,797] INFO in predictor:   Guess 12-BA-9D-AB-9E-05 Probability 60.65%
[2024-11-23 04:47:44,798] INFO in predictor:   Claim 12-BA-9D-AB-9E-05 Probability 60.65%
[2024-11-23 04:47:44,799] INFO in ml_lte_rff_svc:   Same MACs, RWF >= 50% Checks out

[2024-11-23 04:48:08,921] INFO in ml_lte_rff_svc: Uploaded BB-8F-68-53-FD-CC
[2024-11-23 04:48:08,921] INFO in predictor: Import target RWF from stage
[2024-11-23 04:48:08,936] INFO in predictor:   Guess BB-8F-68-53-FD-CC Probability 46.54%
[2024-11-23 04:48:08,937] INFO in predictor:   Claim BB-8F-68-53-FD-CC Probability 46.54%
[2024-11-23 04:48:08,938] INFO in ml_lte_rff_svc:   Same MACs, RWF < 50% Strengthen

[2024-11-23 04:48:09,013] INFO in builder: Build and train
[2024-11-23 04:48:09,280] INFO in builder:   Epoch 1/12 Accuracy 1.89%
[2024-11-23 04:48:15,581] INFO in builder:   Epoch 2/12 Accuracy 2.16%
...
[2024-11-23 04:48:32,962] INFO in builder:   Epoch 11/12 Accuracy 7.30%
[2024-11-23 04:48:34,898] INFO in builder:   Epoch 12/12 Accuracy 22.61%

[2024-11-23 04:51:25,116] INFO in ml_lte_rff_svc: Uploaded BB-8F-68-53-FD-XX
[2024-11-23 04:51:25,117] INFO in predictor: Import target RWF from stage
[2024-11-23 04:51:25,131] INFO in predictor:   Guess BB-8F-68-53-FD-CC Probability 94.62%
[2024-11-23 04:51:25,131] INFO in predictor:   Claim BB-8F-68-53-FD-XX Probability N/A
[2024-11-23 04:51:25,132] INFO in ml_lte_rff_svc:   Diff MACs, RWF > 80% Flag for examination
```

```
ubuntu@ip-172-31-35-3:~/ML-LTE-RFF/service$ ls flag
BB-8F-68-53-FD-XX_BB-8F-68-53-FD-CC
```

Backup

```
ubuntu@ip-172-31-35-3:~/ML-LTE-RFF$ curl -F "rwf=@12-BA-9D-AB-9E-05" http://35.153.176.133:64024
  Diff MACs, RWF < 80% Learn claimed MAC

ubuntu@ip-172-31-35-3:~/ML-LTE-RFF$ curl -F "rwf=@12-BA-9D-AB-9E-05" http://35.153.176.133:64024
  Same MACs, RWF >= 50% Checks out

ubuntu@ip-172-31-35-3:~/ML-LTE-RFF$ curl -F "rwf=@BB-8F-68-53-FD-CC" http://35.153.176.133:64024
  Same MACs, RWF < 50% Strengthen

ubuntu@ip-172-31-35-3:~/ML-LTE-RFF$ cp BB-8F-68-53-FD-CC BB-8F-68-53-FD-XX
ubuntu@ip-172-31-35-3:~/ML-LTE-RFF$ curl -F "rwf=@BB-8F-68-53-FD-XX" http://35.153.176.133:64024
  Diff MACs, RWF > 80% Flag for examination
```