ITU AI/ML in 5G Challenge: Applying Machine Learning in Communication Networks

A Real-time CQI Prediction Framework for Proactive Resource Scheduling in 5G Enabled Drones Using AI

Submitted by:

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॥ त्वं ज्ञानमयो विज्ञानमयोऽसि ॥

Introduction and Problem Statement

Challenges in enabling uRLLC use-cases in 5G

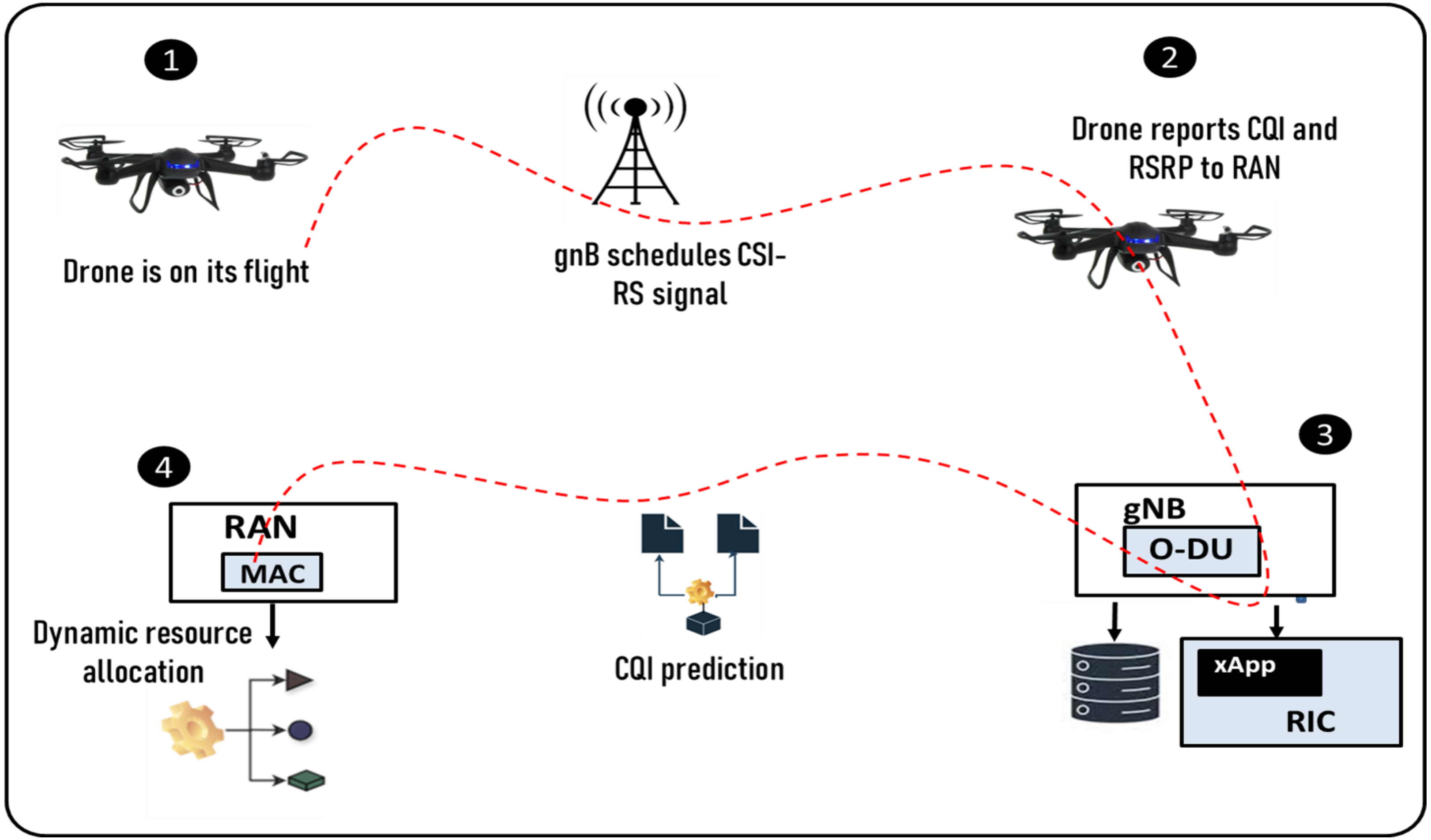
- Requires guaranteed QoS technologies
- Current telecom networks only support best-effort QoS where applications such as 5G-enabled drones, remotely operated vehicles, telesurgeries, etc., cannot be supported
- No guarantee on latency bounds leads to outages in latency-critical applications

Needed new technologies for enabling uRLLC use-cases in 5G

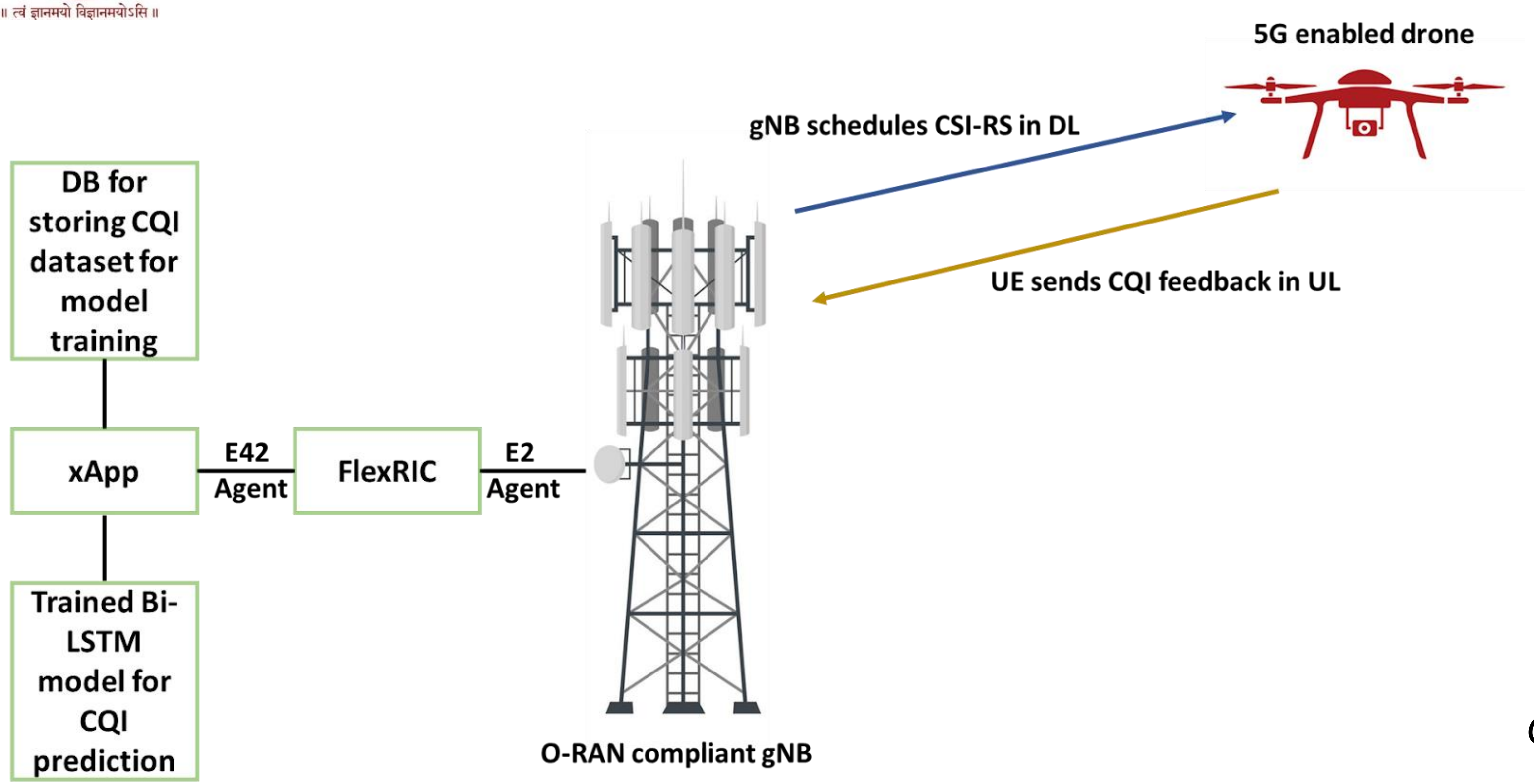
- Requires guaranteed QoS on 5G networks
- Key technologies that enable these include: Network Slicing and AI
- Emergence of O-RAN architecture made the AI integration integration simpler
- AI guided resource allocation strategies will play a key role in enabling the above use-cases

Use-case Flow Diagram

A Real-time CQI Prediction Framework for Proactive Resource Scheduling in 5G Enabled Drones Using AI



CQI Measurement Using CSI-RS in DL



CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	193	0.3770
3	QPSK	449	0.8770
4	16QAM	378	1.4766
5	16QAM	490	1.9141
6	16QAM	616	2.4063
7	64QAM	466	2.7305
8	64QAM	567	3.3223
9	64QAM	666	3.9023
10	64QAM	772	4.5234
11	64QAM	873	5.1152
12	256QAM	711	5.5547
13	256QAM	797	6.2266
14	256QAM	885	6.9141
15	256QAM	948	7.4063

CQI mapping table [3GPP 38.214, Release 15]

- A moderate channel condition will have CQI value between 7 to 10.
- Good channel condition will have a CQI value of 11 to 15 and can enhance transmission rate.
- A higher order modulation scheme like 64 QAM or 256 QAM will be used by a system with high CQI leading to higher data transmission with less allocated resources.

Objective & Activities Undertaken

A Real-Time CQI Prediction Framework for Proactive Resource Scheduling in 5G-Enabled Drones Using AI

Setting up a 5G O-RAN compliant network using Open Air Interface (gNB, UE, CN, and FlexRIC)

Development of xApp in Python 3 to aggregate and prepare a CQI dataset for AI model training and eventual prediction of the CQI by integrating the trained model.

Matlab and Linux-based Expect scripts (utilities) to induce automated channel variations into the OAI RF Simulator for CQI dataset collection and model validation.

Creation of novel CQI datasets for AI model training and testing in real-time

Developed a Bi-LSTM based model that takes the past CQI values (for the past 400 frames) and predicts the future CQI value for the upcoming frame for a UE

Real-time validation of the proposed model in integration with the xApp, FlexRIC, OAI gNB, and OAI UE to assess performance.

Sustainable Development Goals

SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

- Using 5G-enabled drones for surveillance, monitoring, etc.
- Enabling remotely operated vehicles in industry 5.0
- 5G-enabled remotely operated vehicles for industry automation

SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable

- Tele-surgeries and tele-medicine, especially for remote areas
- 5G-enabled air ambulances and medicinal payload delivery in rural areas
- Urban security and vigilance

Use-case Requirements

Requirement 1 (Critical)

- Monitoring real-time UE CQI information to prepare training dataset for AI model development and eventual prediction of CQI for next frame in real-time using the trained model.

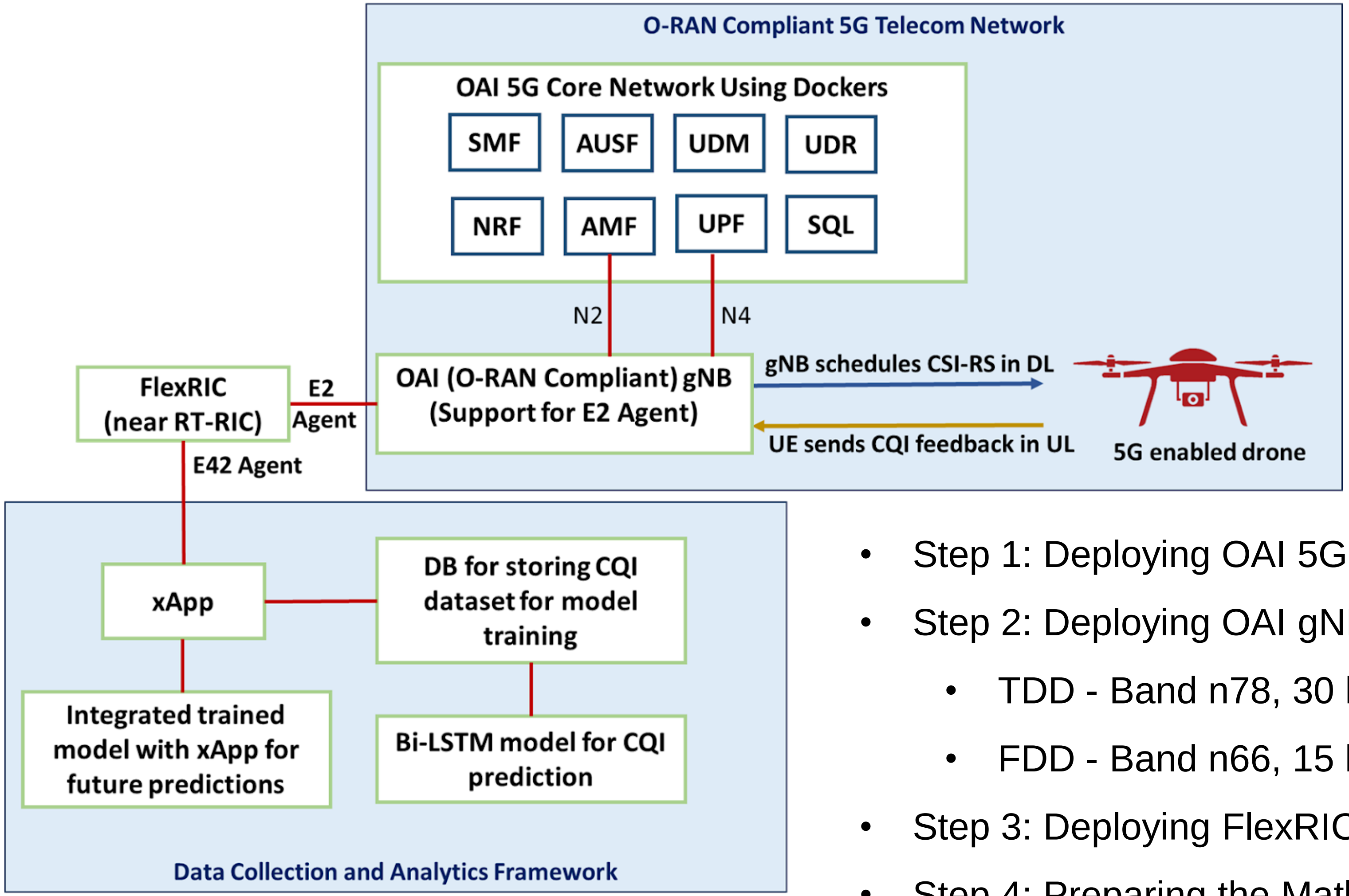
Requirement 2 (Critical)

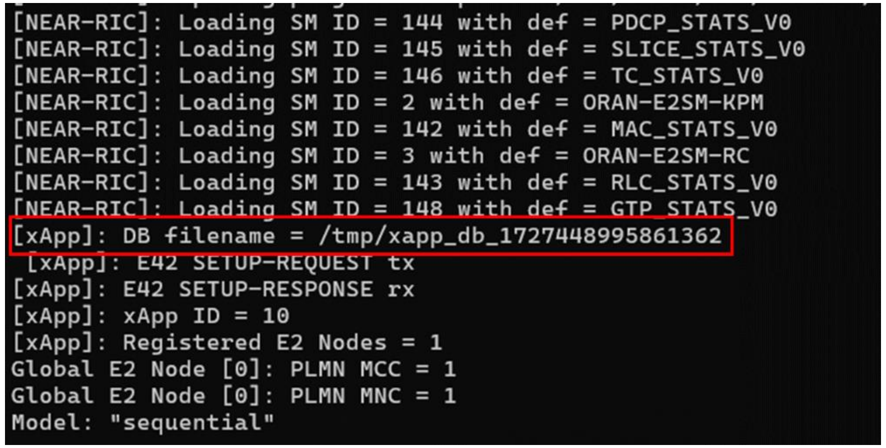
- Accurately predicting the CQI values considering the past CQI instances.

Requirement 3 (Work in Progress - With good commercialization potential)

- xApp will intimate RAN to allocate resources based on the proposed scheduling strategy using the predicted CQI value.
- NaaS (Network as a Service): 5G enabled drone for payload deliveries, Tele-surgeries, Network leasing for next generation connected applications (Smart cities, XR, etc.)

PS-1: Pipeline Design for the Use-case



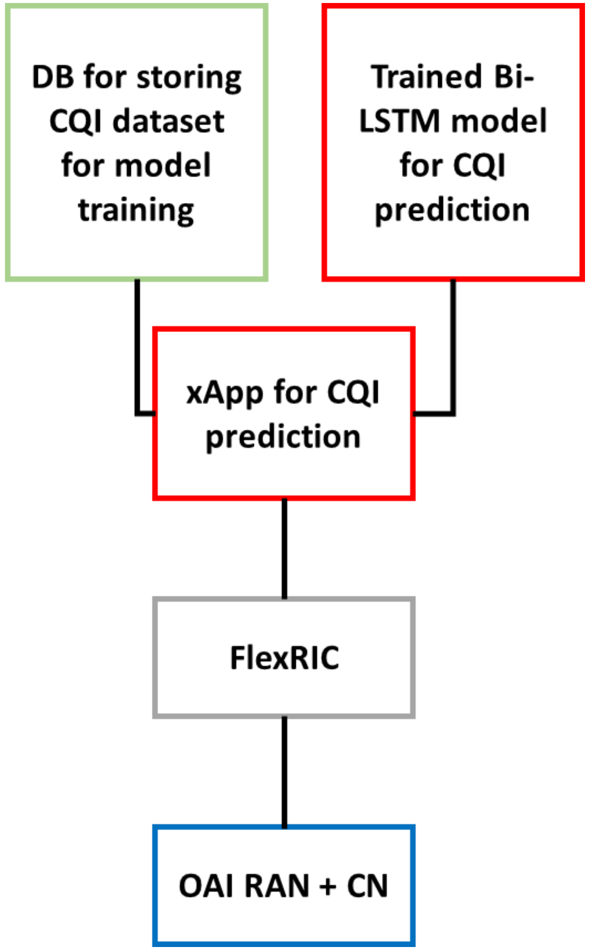


Deploying the xApp for CQI dataset collection

- Step 1: Deploying OAI 5G Core Network
- Step 2: Deploying OAI gNB and UE
  - TDD - Band n78, 30 kHz SCS, 2X2 MIMO
  - FDD - Band n66, 15 kHz SCS, 2X2 MIMO
- Step 3: Deploying FlexRIC (near RT-RIC)
- Step 4: Preparing the Matlab and Expect script for data collection
- Step 5: Deploying the xApp for CQI dataset collection

For detailed deployment guide, please refer to Section 3 in [Input Document or Detailed Report]

PS-2: xApp Design for the Use-case



Overall architecture of the prediction framework

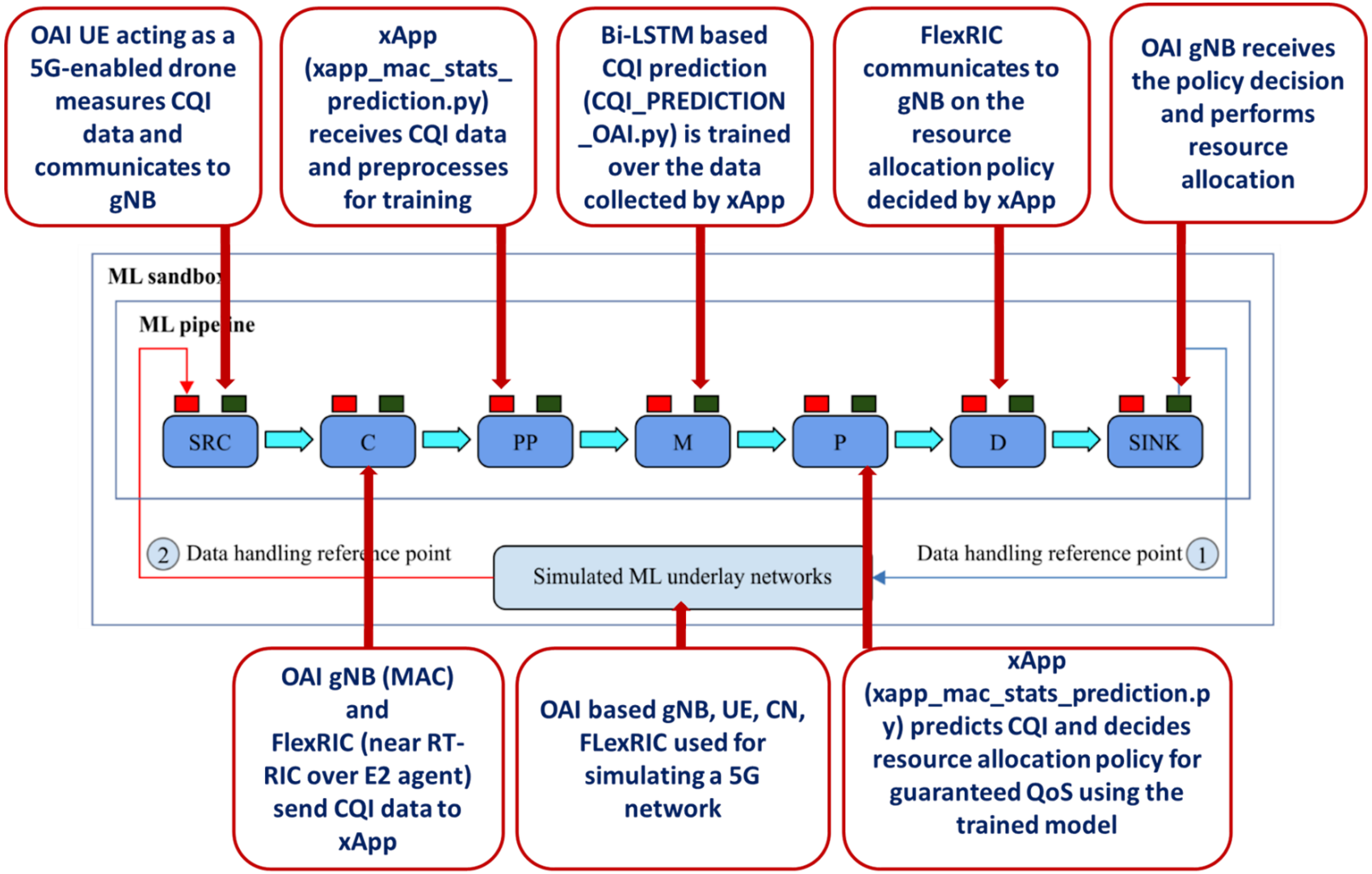
```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 bidirectional (Bidirection  (None, 400, 50)           5400
 al)

 bidirectional_1 (Bidirecti  (None, 50)                15200
 onal)

 dense (Dense)               (None, 1)                 51

=================================================================
Total params: 20651 (80.67 KB)
Trainable params: 20651 (80.67 KB)
Non-trainable params: 0 (0.00 Byte)
```

Proposed Bi-LSTM architecture with SELU activation units

Proposed Bi-LSTM model with SELU activation units has 20,651 parameters making it light-weight and real-time feasible

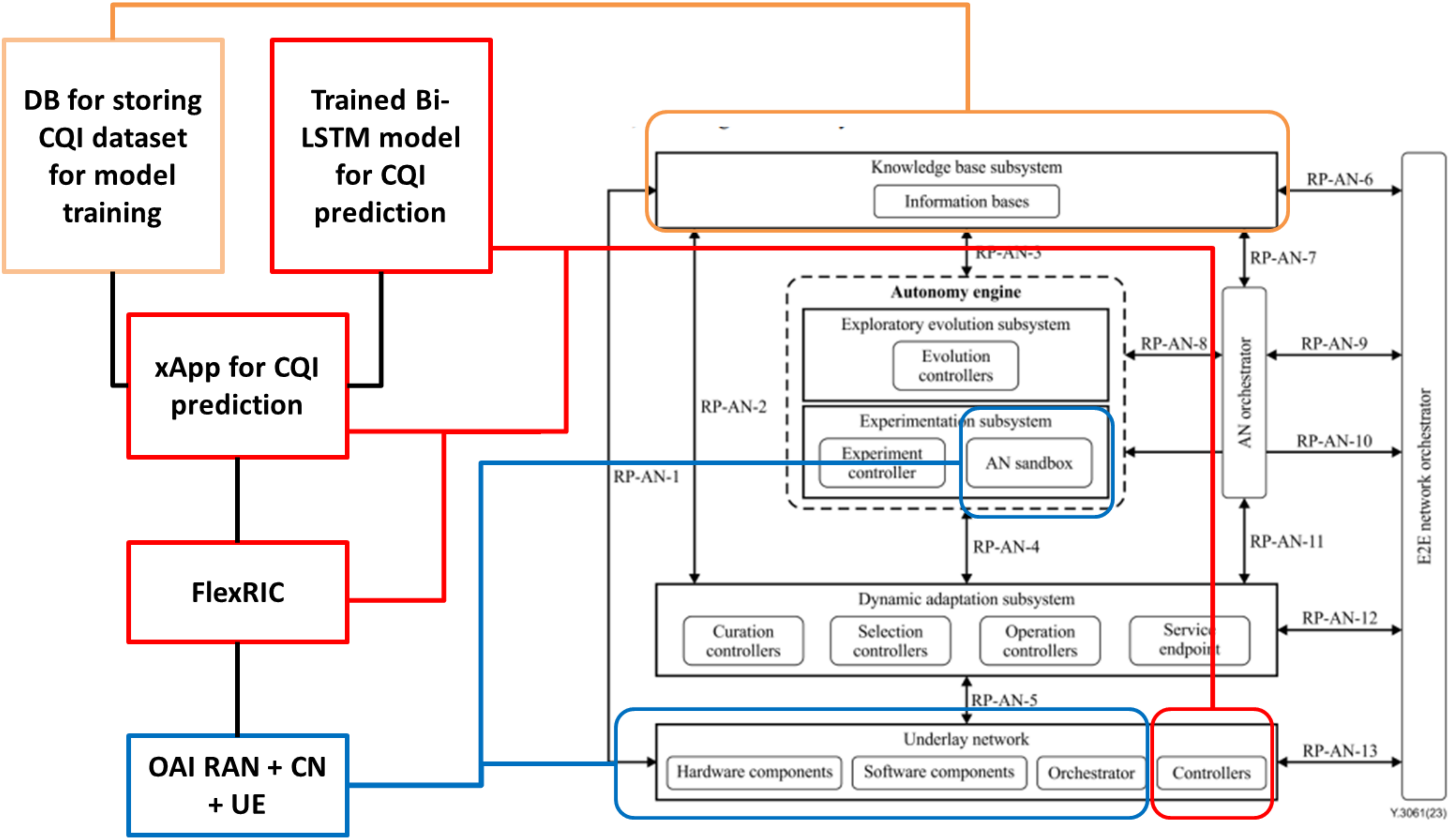
Relevance of the Proposed Use-case with ITU Y.3172 Architecture

ITU Y.3172: Architectural framework for machine learning in future networks including IMT-2020



Relevance of the Proposed Use-case with ITU Y.3061 Architecture

ITU Y.3061: Autonomous networks - Architecture framework

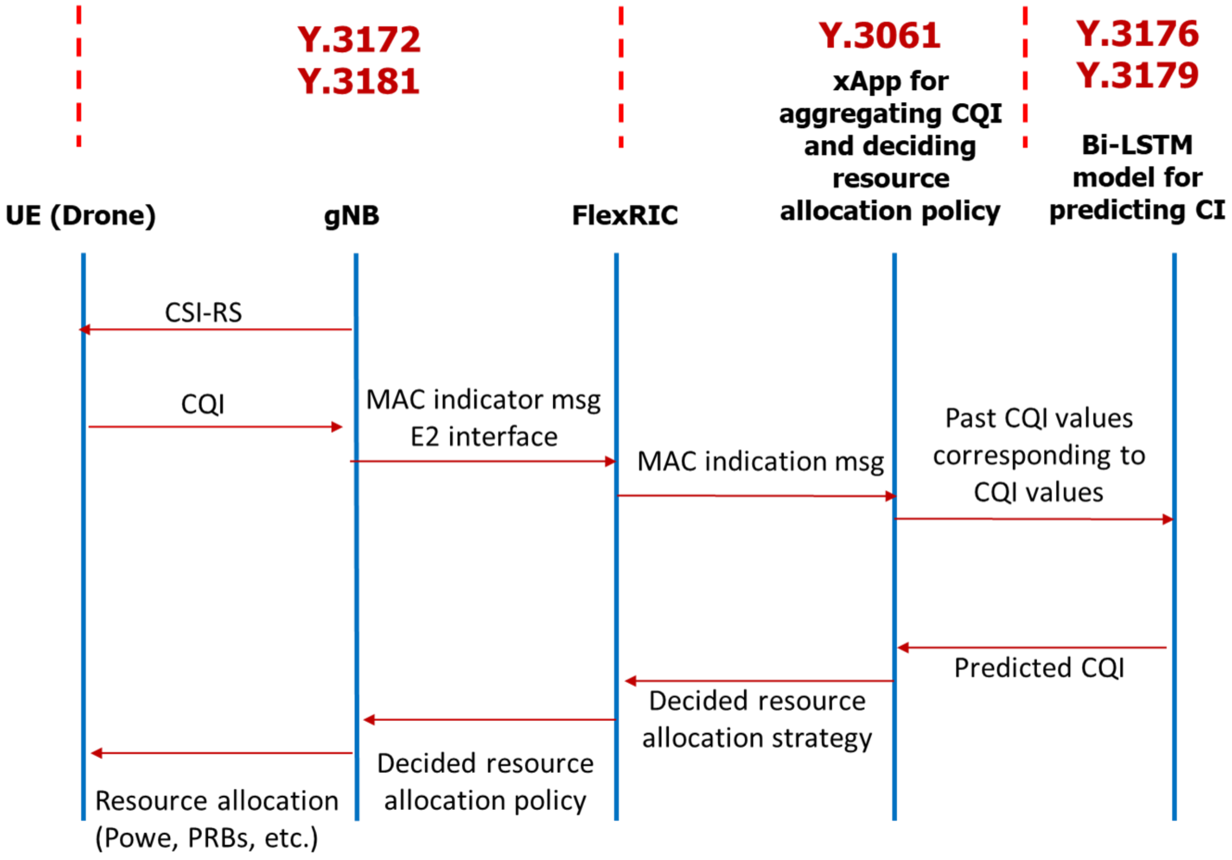


Relation to Standards

The proposed architecture is compatible with the following standards:

- OAI CU & DU are O-RAN compliant disaggregated baseband units. Hence, the proposed use-case can be integrated with any O-RAN compliant 5G telecom network.
- The FlexRIC used in the proposed use-case is compatible with E2 interface and hence, the xApp developed can also be integrated with any O-RAN compliant 5G telecom network.
- OAI is compliant with 3GPP Rel. 15 and 16.
- The proposed xApp architecture is also compatible with the ITU Y.3172 and Y.3061 specifications as discussed earlier.

Relevance to Other ITU Specifications



- ITU Y.3172: Architectural framework for machine learning in future networks including IMT-2020
- ITU Y.3181: Architectural framework for Machine Learning Sandbox in future networks
- ITU Y.3061: Autonomous networks - Architecture framework
- ITU Y.3176: Machine learning marketplace integration in future networks including IMT-2020
- ITU Y.3179: Architectural framework for machine learning model serving in future networks including IMT-2020

Relevance to Other ITU Specifications

Mapping of the proposed Use-case to the ITU-T Use-cases*:

- Use Case – 7: Smart UAV Networks for Efficient Disaster Response
- Use case – 45: Digital twins for AI based xApps in open RAN for smart agriculture in 5G
- Use case – 43: Datasets and AI for 3GPP Mission Critical Services (MCX) in emergency

Secondary Use-cases:

- Providing guaranteed Quality of Experience services to applications such as Netflix, Hotstar, and other streaming platforms.
- Enabling ROVs (remotely operated vehicles) such as cars, robots, aerial vehicles, etc., which are some of the focus areas of the prestigious Technology Innovation Hubs (TIHs) setup by Dept. of Science and Technology, Govt. of India.
- Tele-surgeries as use-cases also require the guaranteed QoS over 5G networks which is the main objective of this work.

****AI for Good-Innovate for Impact, Final Report 2024, ITU Publications***

Code Submission Details

The complete code (with multiple files) along with the necessary documentation is uploaded into the following GitHub repository: CQI-Prediction

CQI-Prediction Public

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main | 1 Branch | 0 Tags | Go to file | t | Add file | Code

mprsk Add files via upload 3caa5de · last week 63 Commits

docs	Add files via upload	last week
CQI_DATASET	Initial commit	2 weeks ago
CQI_PREDICTION_OAI.py	Initial commit	2 weeks ago
DataPreparation.m	Update DataPreparation.m	last week
README.md	Update README.md	last week
channel_parameter_simulator.exp	Initial commit	2 weeks ago
channel_parameter_simulator_validation.exp	Add files via upload	last week
channelmod_rfsimu.conf	Add files via upload	2 weeks ago
gnb.sa.band78.fr1.106PRB.2x2.usrpn300.conf	Add files via upload	2 weeks ago
scaler_training.bin	Initial commit	2 weeks ago
trained_model.keras	Initial commit	2 weeks ago
ue.conf	Add files via upload	2 weeks ago
xapp_mac_stats_prediction.py	Update xapp_mac_stats_prediction.py	last week

Report Submitted

To access the detailed report or input document submitted: Input Document for Hackathon

For accessing the PPT Slides: PPT Submitted for Hackathon

Link to Demonstration: Demo

File Descriptions:

In this project, we use Open Air Interface - OAI 5G CN, RAN, and FlexRIC for deployment of O-RAN compliant 5G network. The below describes the usage of individual files:

1. DataPreparation.m: A MATLAB script written for preparing an expect script that can automate varying channel parameters (noise power in this case) over telnet session in OAI RF Simulator periodically. This will help us in generating a CQI database (CQI_DATASET) that can be used for model training.
2. channel_parameter_simulator.exp: A sample expect script generated using DataPreparation.m where noise power is modified every 100ms in the range of [-15 dB, -5 dB].
3. channel_parameter_simulator_validation.exp: Another expect script generated using DataPreparation.m where noise power is modified every 100ms in the range of [-15 dB, -5 dB] used for validation. This is created for testing the developed AI model performance with unseen data during training.
4. CQI_DATASET: A sample CQI dataset (SQLite3 DB) generated using the channel_parameter_simulator.exp script. The dataset is acquired using the xApp (xapp_mac_stats_prediction.py)
5. xapp_mac_stats_prediction.py: xAPP compatible with FlexRIC and OAI 5G Protocol Stack used for CQI dataset collection and real-time prediction. The ML model is based on Bi-LSTM with SeLu activation units. The xApp simultaneously lodges the CQI data collected into SQLite3 DB and performs prediction. During validation of the

Self Testing Results - AI Model Training

- The Bi-LSTM model training over 15 epochs took approximately 30 minutes on a computing hardware with Intel i9 processor with 16 GB RAM.

- The mean absolute error (MAE, considered as loss function) at the end of the training is well within 0.006 (with MinMaxScaler based scaling of input data with fit range [0,1])

```
-----------------------------------------------------------------
Epoch 1/15
928/928 [==============================] - 119s 127ms/step - loss: 0.0148
Epoch 2/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0095
Epoch 3/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0080
Epoch 4/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0070
Epoch 5/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0063
Epoch 6/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0059
Epoch 7/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0058
Epoch 8/15
928/928 [==============================] - 117s 127ms/step - loss: 0.0059
Epoch 9/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0057
Epoch 10/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0056
Epoch 11/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0056
Epoch 12/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0056
Epoch 13/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0055
Epoch 14/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0055
Epoch 15/15
928/928 [==============================] - 118s 127ms/step - loss: 0.0055
Training Time: 1767.8 seconds.
```

Self Testing Results - Real-time Validation

- The xApp developed is validated in integration with the proposed AI model.
- The validation flow consisted of OAI gNB, CN, UE, and FlexRIC.
- For inducing the channel variations, we have used the Expect script channel_parameter_simulator_validation.exp (different for training) to verify if the model training is generalized and no overfitting happens.
- The MAE and MSE observed are less than 0.5 CQI units and 2 CQI^2 units, respectively.
- Also, the proposed AI model has an inference latency of <5 ms with a total number of 20651 trainable parameters making it light-weight.

```
Frame Level Predictions [Frame Number, Actual CQI, Predicted CQI]

[294,12,12],   [295,12,12],   [296,12,12],   [297,12,12],   [298,12,12],   [299,12,12],   [300,12,12],   [301,12,12],   [302,12,12],   [303,12,12],
[304,08,12],   [305,08,09],   [306,08,09],   [307,08,08],   [308,08,08],   [309,08,08],   [310,08,08],   [311,08,08],   [312,07,08],   [313,07,07],
[314,07,07],   [315,07,07],   [316,07,07],   [317,07,07],   [318,07,07],   [319,07,07],   [320,07,07],   [321,07,07],   [322,07,07],   [323,07,07],
[324,07,07],   [325,07,07],   [326,07,07],   [327,07,07],   [328,12,07],   [329,12,12],   [330,12,12],   [331,12,12],   [332,12,12],   [333,12,12],
[334,12,12],   [335,12,12],   [336,11,12],   [337,11,11],   [338,11,11],   [339,11,11],   [340,11,11],   [341,11,11],   [342,11,11],   [343,11,11],
[344,12,11],   [345,12,12],   [346,12,12],   [347,12,12],   [348,12,12],   [349,12,12],   [350,12,12],   [351,12,12],   [352,06,12],   [353,06,06],
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[364,10,11],   [365,10,10],   [366,10,10],   [367,10,10],   [368,12,11],   [369,12,12],   [370,12,12],   [371,12,12],   [372,12,12],   [373,12,12],
[374,12,12],   [375,12,12],   [376,07,12],   [377,07,07],   [378,07,07],   [379,07,07],   [380,07,07],   [381,07,07],   [382,07,07],   [383,07,07],
[384,13,07],   [385,13,13],   [386,13,13],   [387,13,13],   [388,13,13],   [389,13,13],   [390,13,13],   [391,13,13],   [392,08,13],   [393,08,08],

Stats Summary (100 frames) - Time Elapsed: 24.17 Sec, MAE: 0.48 (CQI), MSE:  1.57 (CQI^2)
------------------------------------------------------------------------------------
```

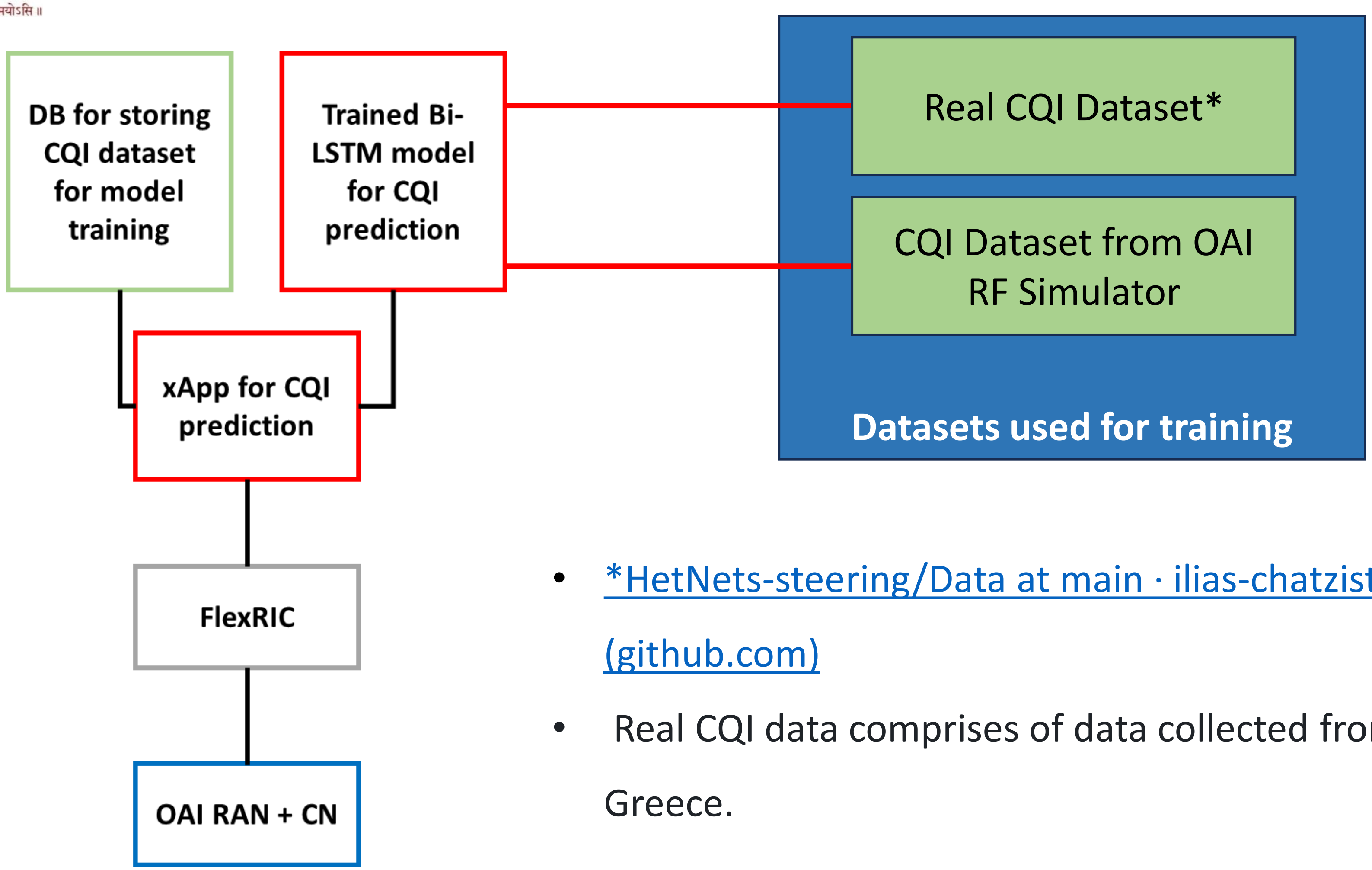
CQI Vs. PRB Mapping

- Guaranteed Rate (R) = 20 Mbps
- Total PRBs (nPRB) = 106
- Sub-carrier Spacing (SCS) = 30 kHz
- Bandwidth = $nPRB \times 12 \times SCS$
- Required Guaranteed PRBs (gPRB) = $\frac{R}{SE \times 12 \times SCS}$
- SE – Spectral Efficiency

CQI mapping table [3GPP 38.214, Release 15]

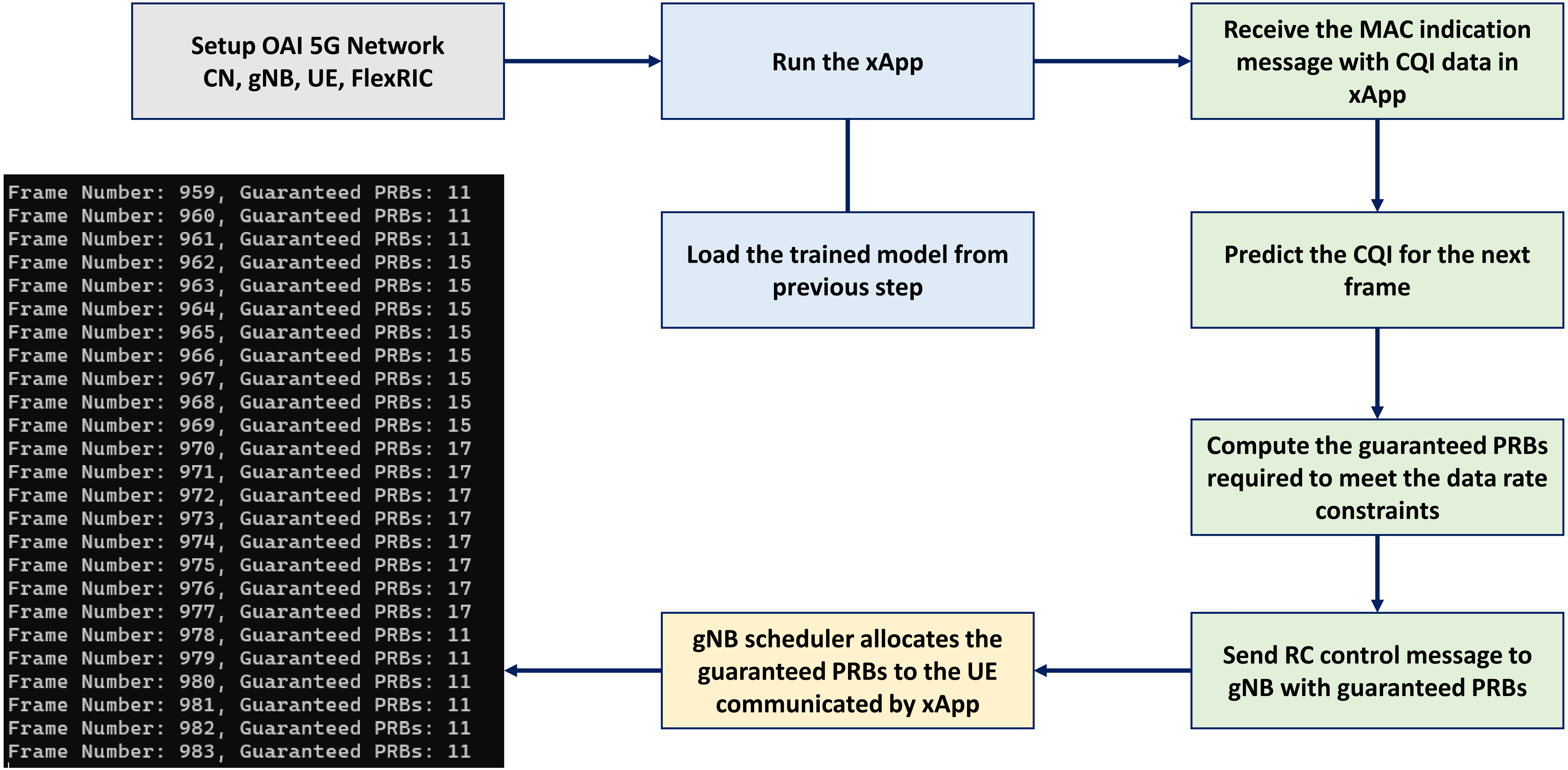
CQI Index	Modulation	Code Rate x 1024	Efficiency	Max. Rate (Mbps)	gPRB	gPRB (Round Off)
1	QPSK	78	0.1523	5.811768	364.78	365
2	QPSK	193	0.377	14.38632	147.36	148
3	QPSK	449	0.877	33.46632	63.35	64
4	16 QAM	378	1.4766	56.347056	37.62	38
5	16 QAM	490	1.9141	73.042056	29.02	30
6	16 QAM	616	2.4063	91.824408	23.09	24
7	64 QAM	466	2.7305	104.19588	20.35	21
8	64 QAM	567	3.3223	126.778968	16.72	17
9	64 QAM	666	3.9023	148.911768	14.24	15
10	64 QAM	772	4.5234	172.612944	12.28	13
11	64 QAM	873	5.1152	195.196032	10.86	11
12	256 QAM	711	5.5547	211.967352	10.00	11
13	256 QAM	797	6.2266	237.607056	8.92	9
14	256 QAM	885	6.9141	263.842056	8.04	9
15	256 QAM	948	7.4063	282.624408	7.50	8

Model Training



- *HetNets-steering/Data at main · ilias-chatzistefanidis/HetNets-steering (github.com)
- Real CQI data comprises of data collected from 73 real cars in a route in city Volos, Greece.

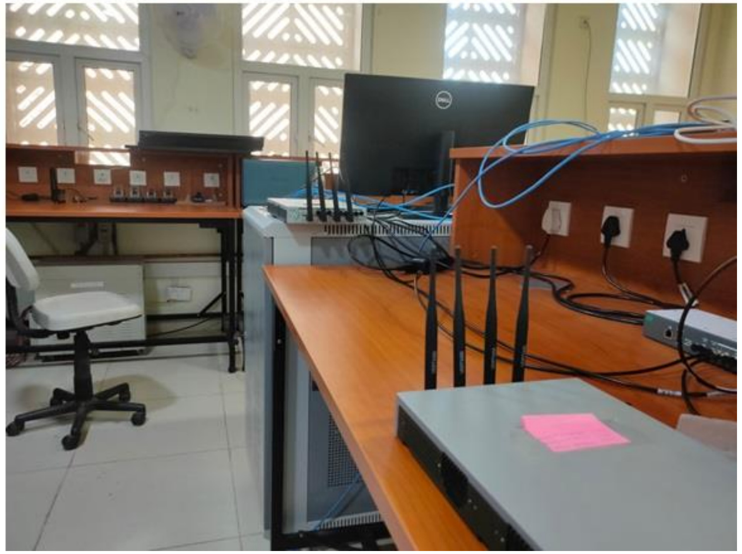
Model Training

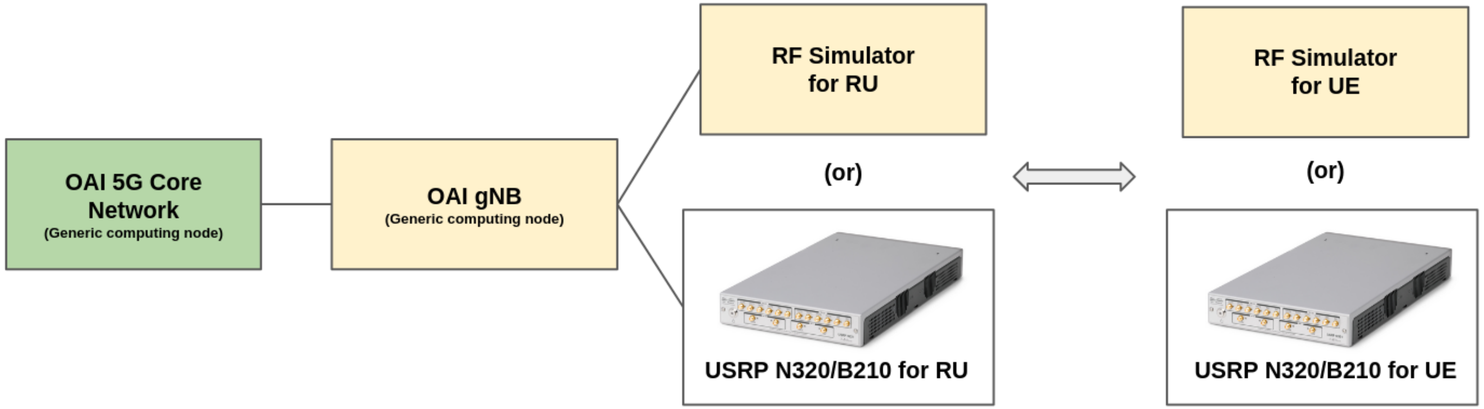


OAI gNB logs

Thank You!!!

Wireless *Communications and Navigation Lab, Dept. of EE, IIT Jodhpur*





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