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

Submitted by:

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भारतीय प्रौद्योगिकी संस्थान जोधपुर

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॥ त्वं ज्ञानमयो विज्ञानमयोऽसि ॥

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

Proposed Objectives

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

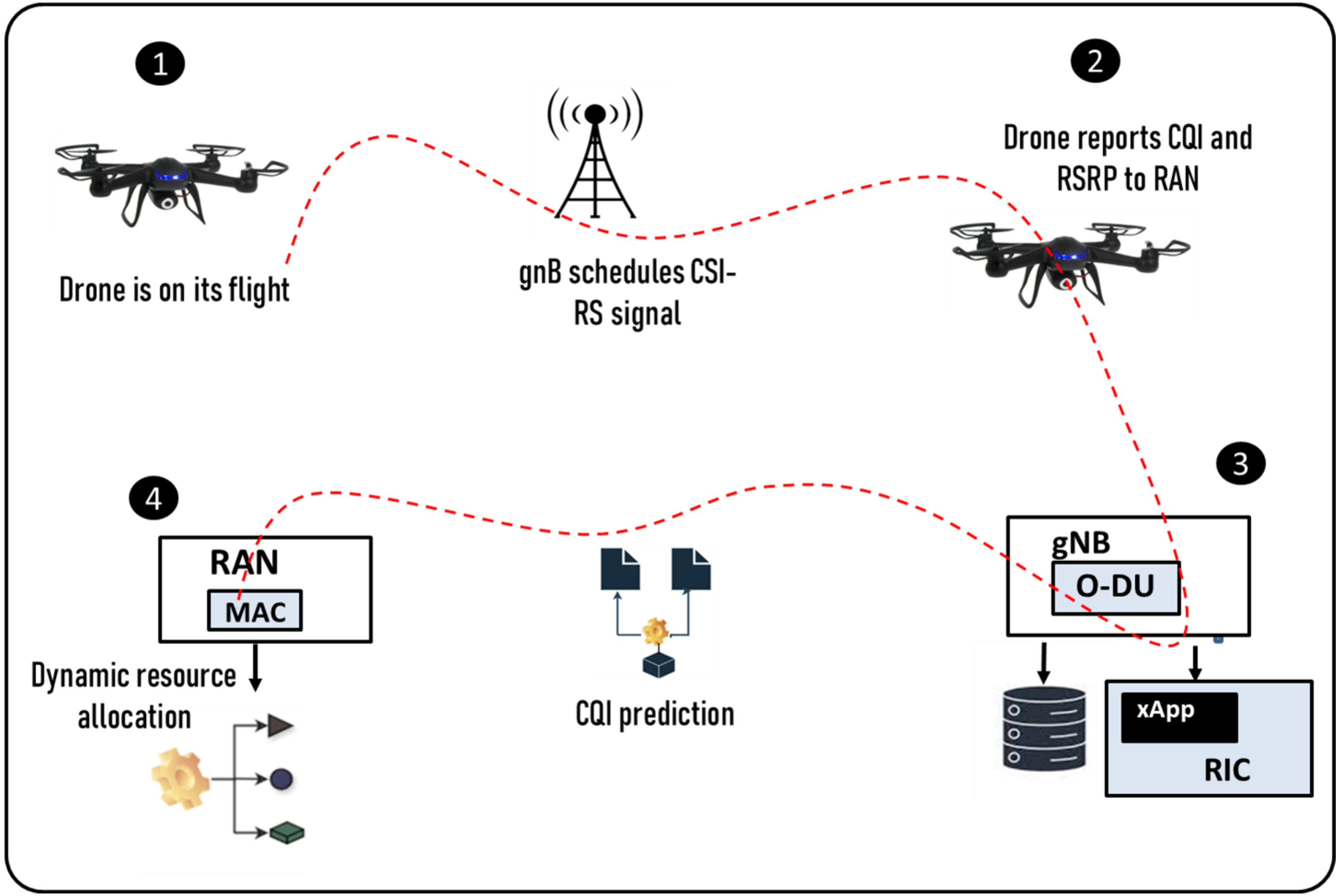
↓

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

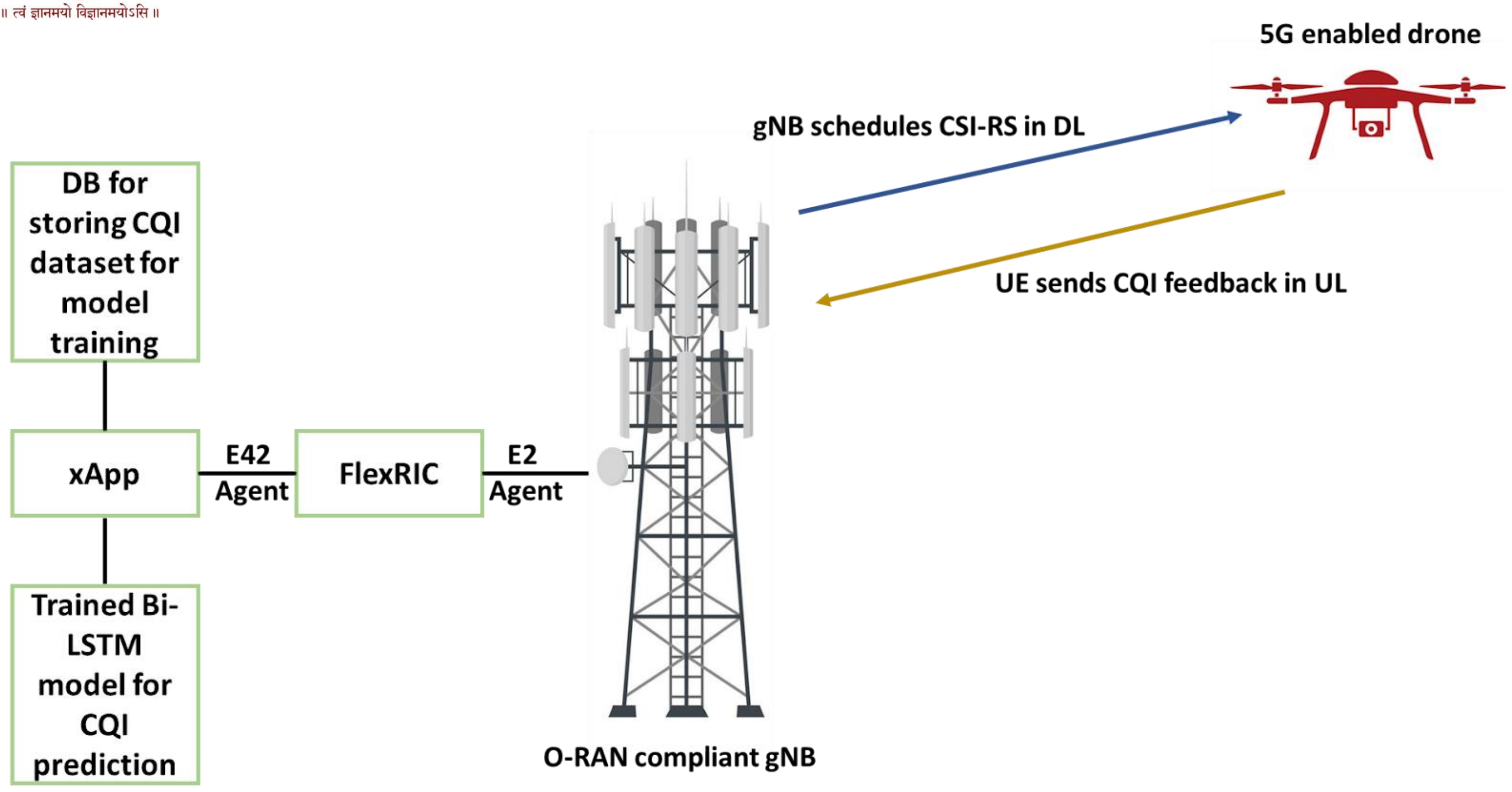
↓

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

Use-case Flow Diagram



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	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

CQI mapping table [3GPP 38.214, Release 18]

- 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.

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.

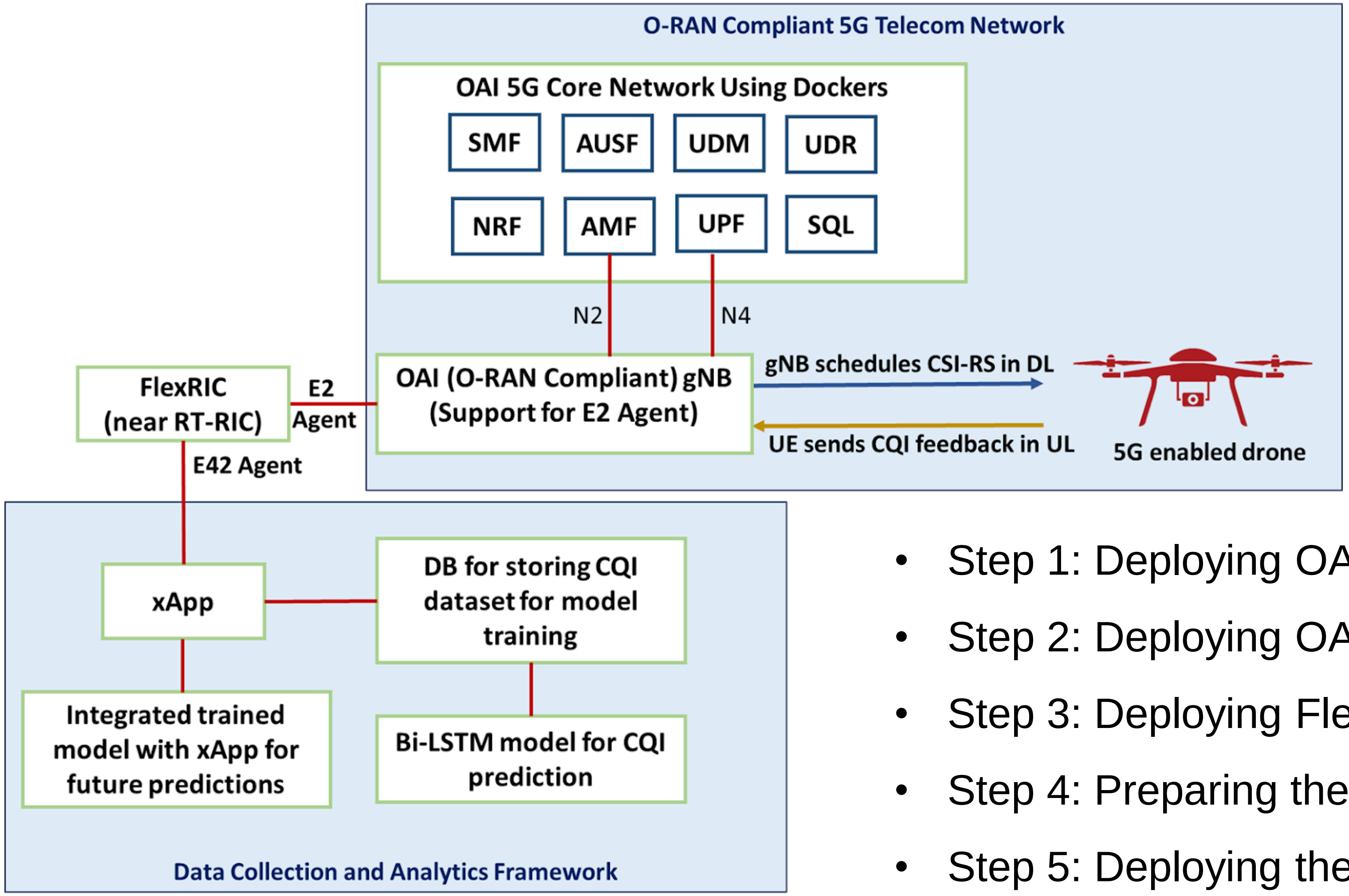
Requirement 2 (Critical)

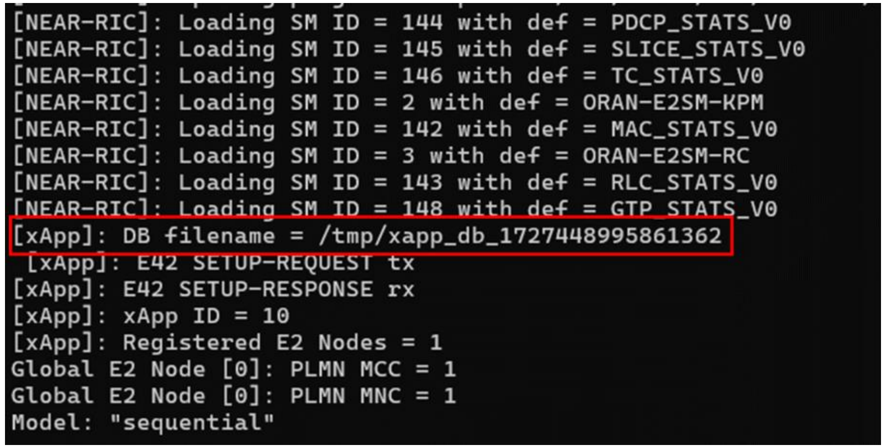
- Accurately predicting the CQI values considering the past CQI instances.

Requirement 3 (Added value with good commercialization potential)

- xApp will intimate RAN to allocate resources based on the proposed scheduling strategy using the predicted CQI value.

PS-1: Pipeline Design for the Use-case



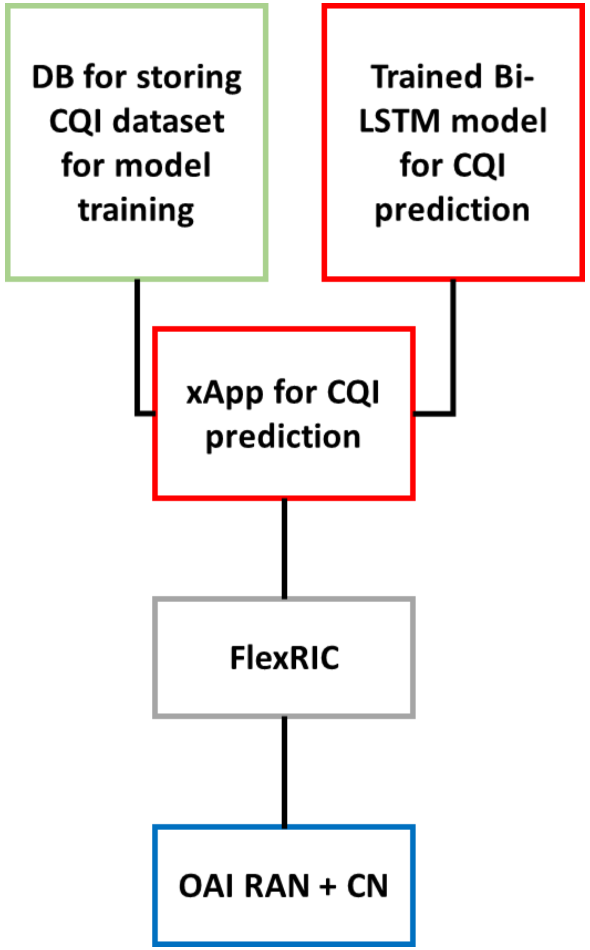


Deploying the xApp for CQI dataset collection

- Step 1: Deploying OAI 5G Core Network
- Step 2: Deploying OAI gNB and UE
- 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

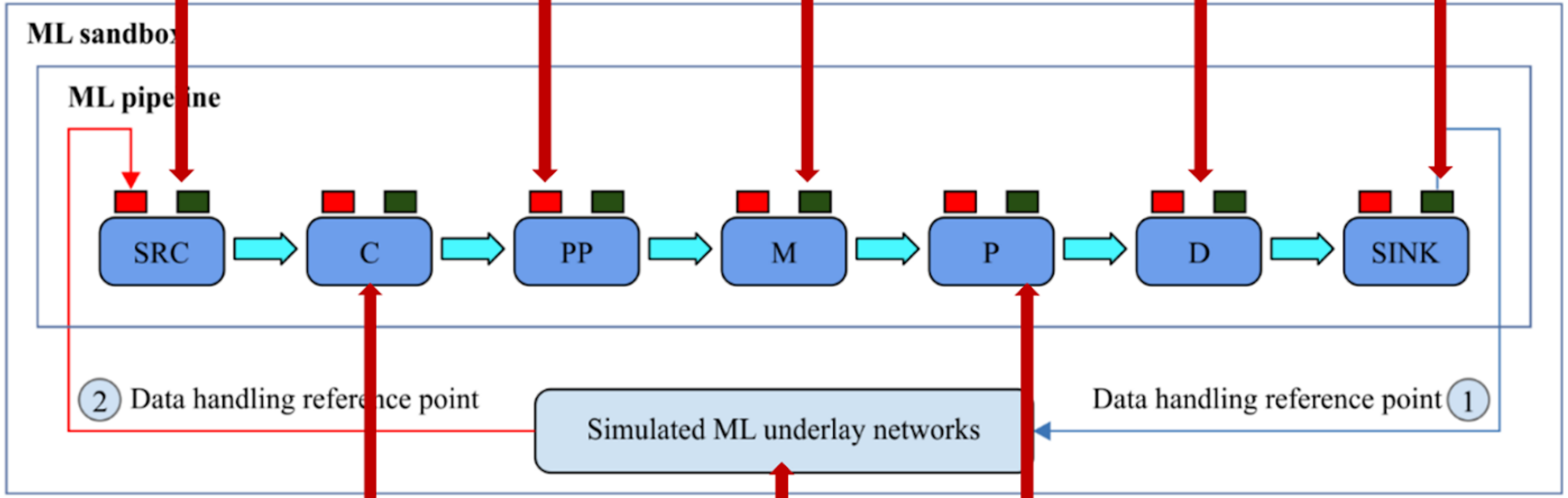
OAI UE acting as a 5G-enabled drone measures CQI data and communicates to gNB

xApp (xapp_mac_stats_prediction.py) receives CQI data and preprocesses for training

Bi-LSTM based CQI prediction (CQI_PREDICTION_OAI.py) is trained over the data collected by xApp

FlexRIC communicates to gNB on the resource allocation policy decided by xApp

OAI gNB receives the policy decision and performs resource allocation

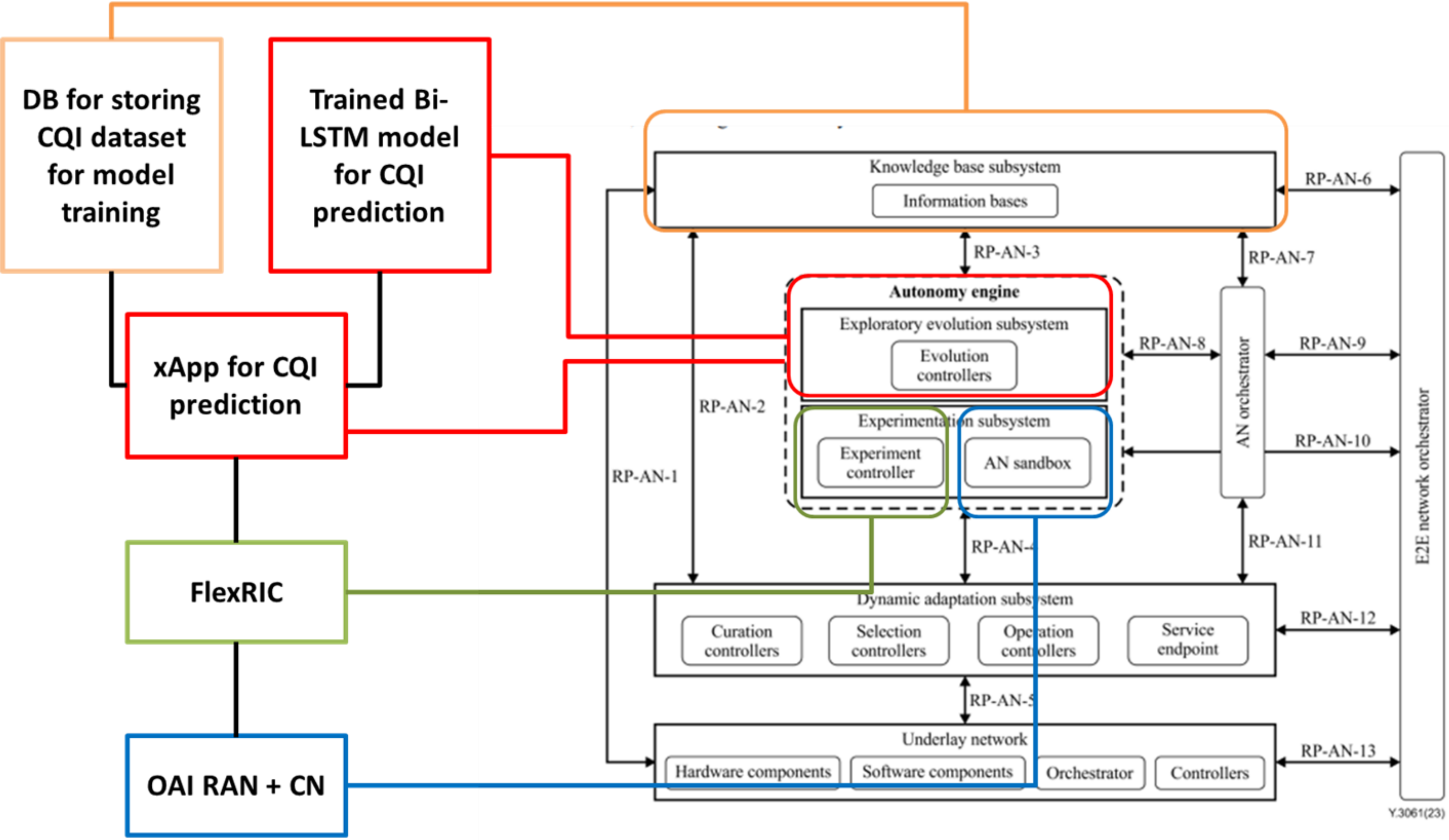


OAI gNB (MAC) and FlexRIC (near RT-RIC over E2 agent) send CQI data to xApp

OAI based gNB, UE, CN, FLexRIC used for simulating a 5G network

xApp (xapp_mac_stats_prediction.py) predicts CQI and decides resource allocation policy for guaranteed QoS using the trained model

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

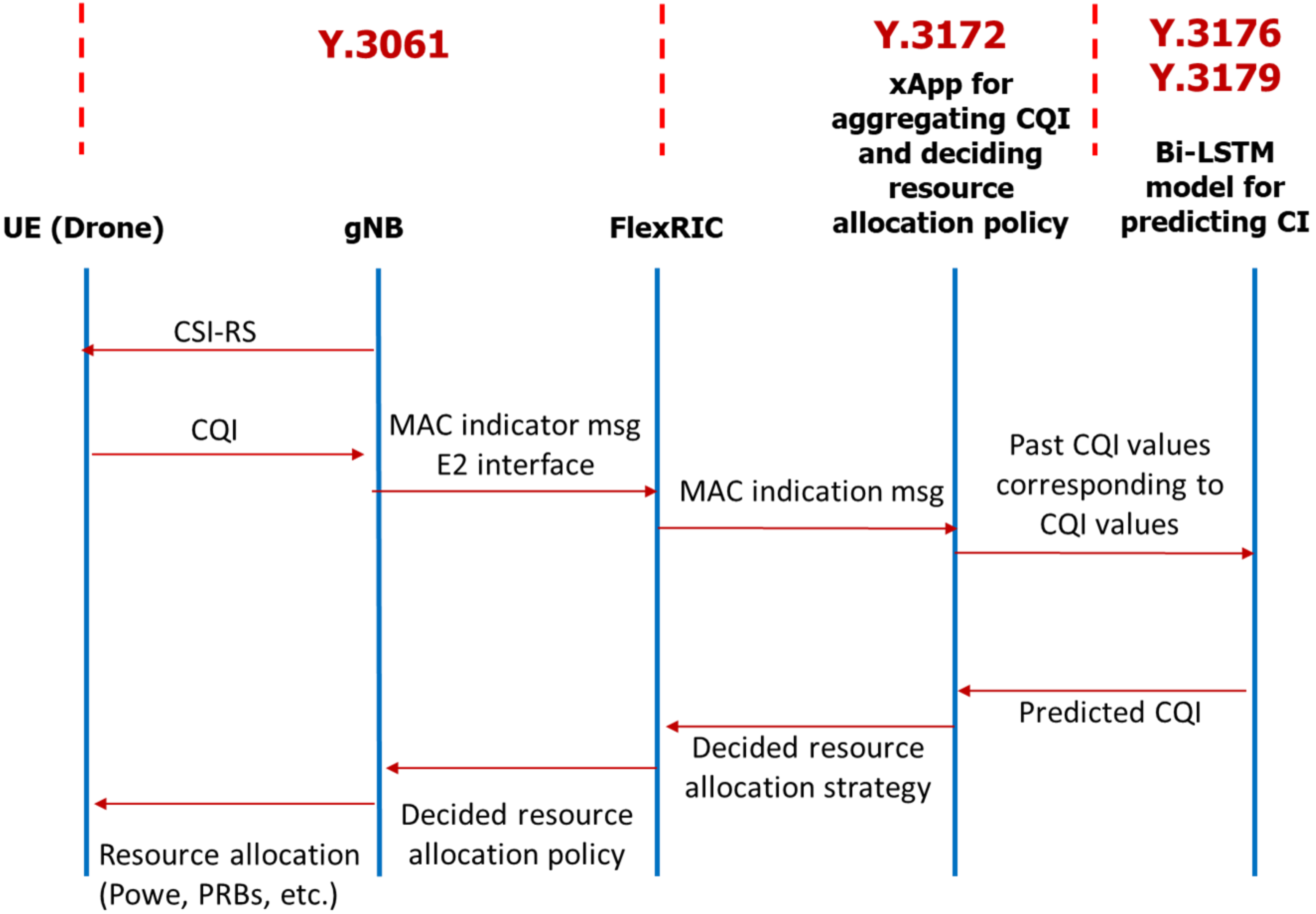


Relation to Standards

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



Relevance to Other ITU Specifications

Mapping of the proposed Use-case to the SDGs:

- SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable

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.

Code Submission Details

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

Self Testing Results

- 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

- 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],
[354,06,06],  [355,06,06],  [356,06,06],  [357,06,06],  [358,06,06],  [359,06,06],  [360,10,06],  [361,10,11],  [362,10,11],  [363,10,11],
[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)
-----------------------------------------------------------------------------------
```

Thank You!!!

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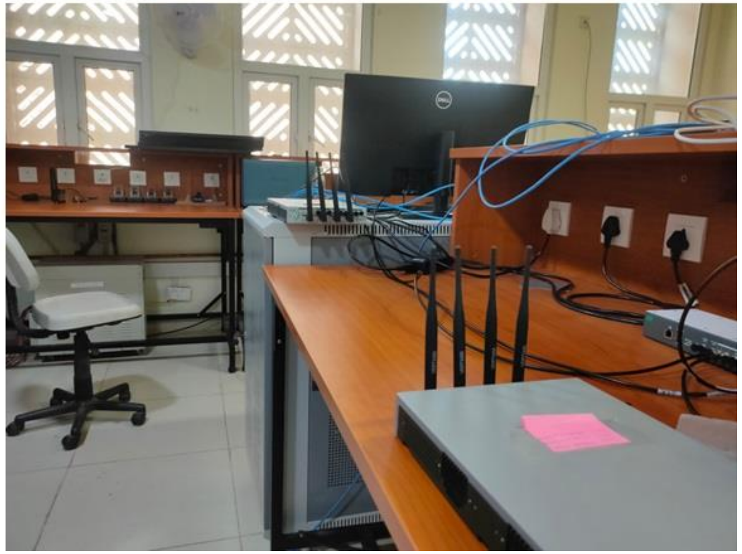

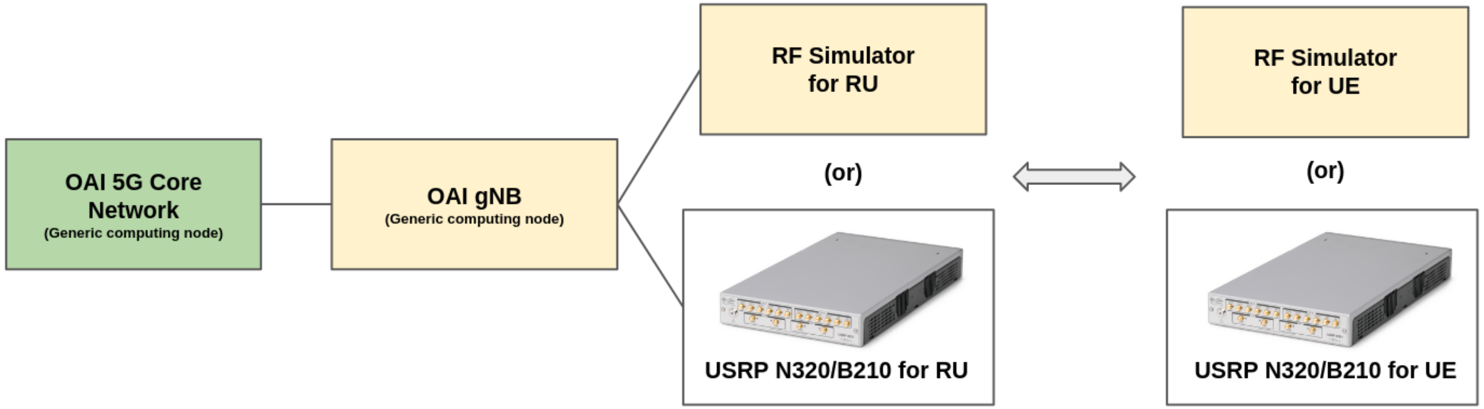

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