5G RAN Optimization with AI-RAN (Draft)

Use Case Reference Blueprint

For Power and QoE Optimization

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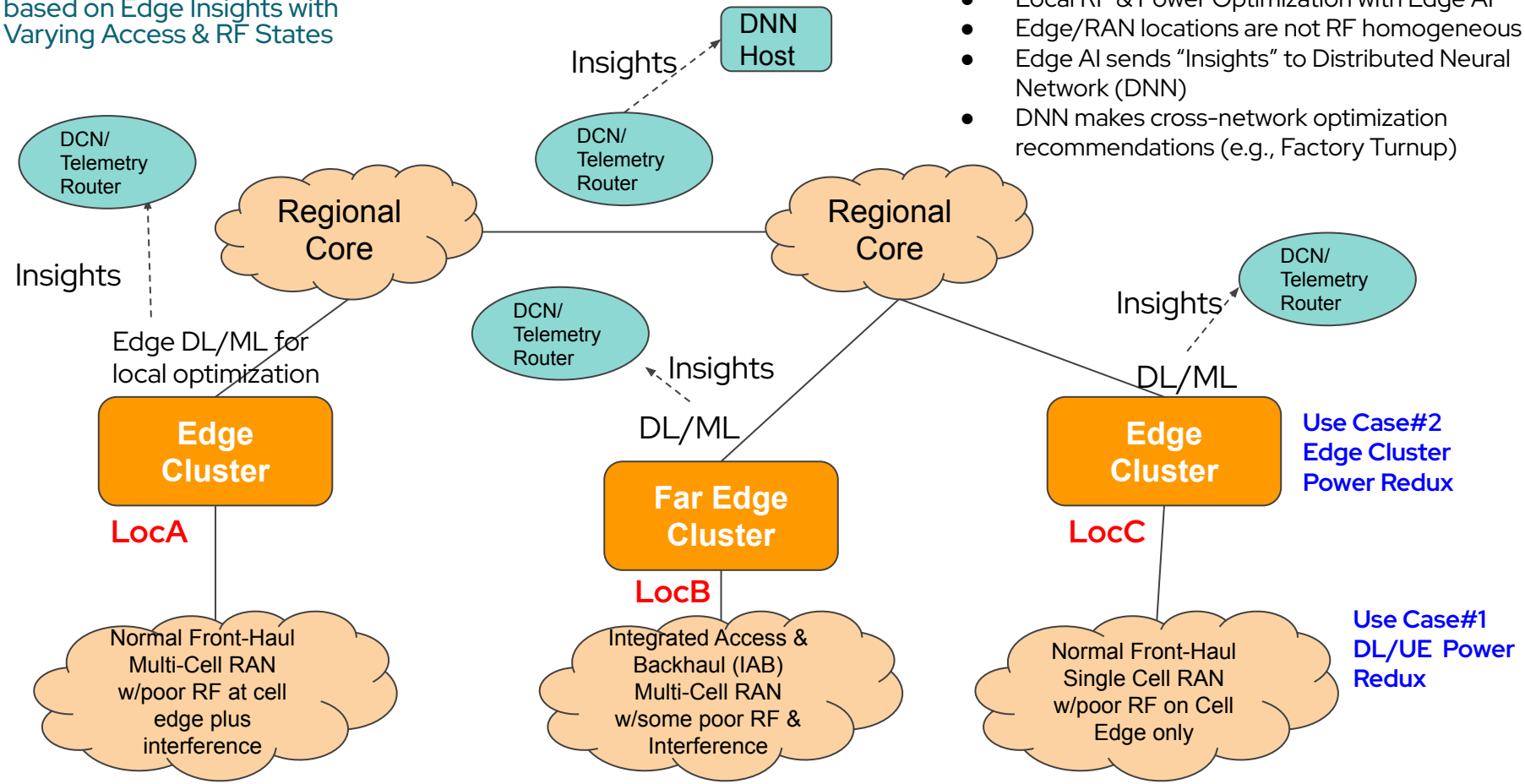
1 November 2024

Use Cases & Partners

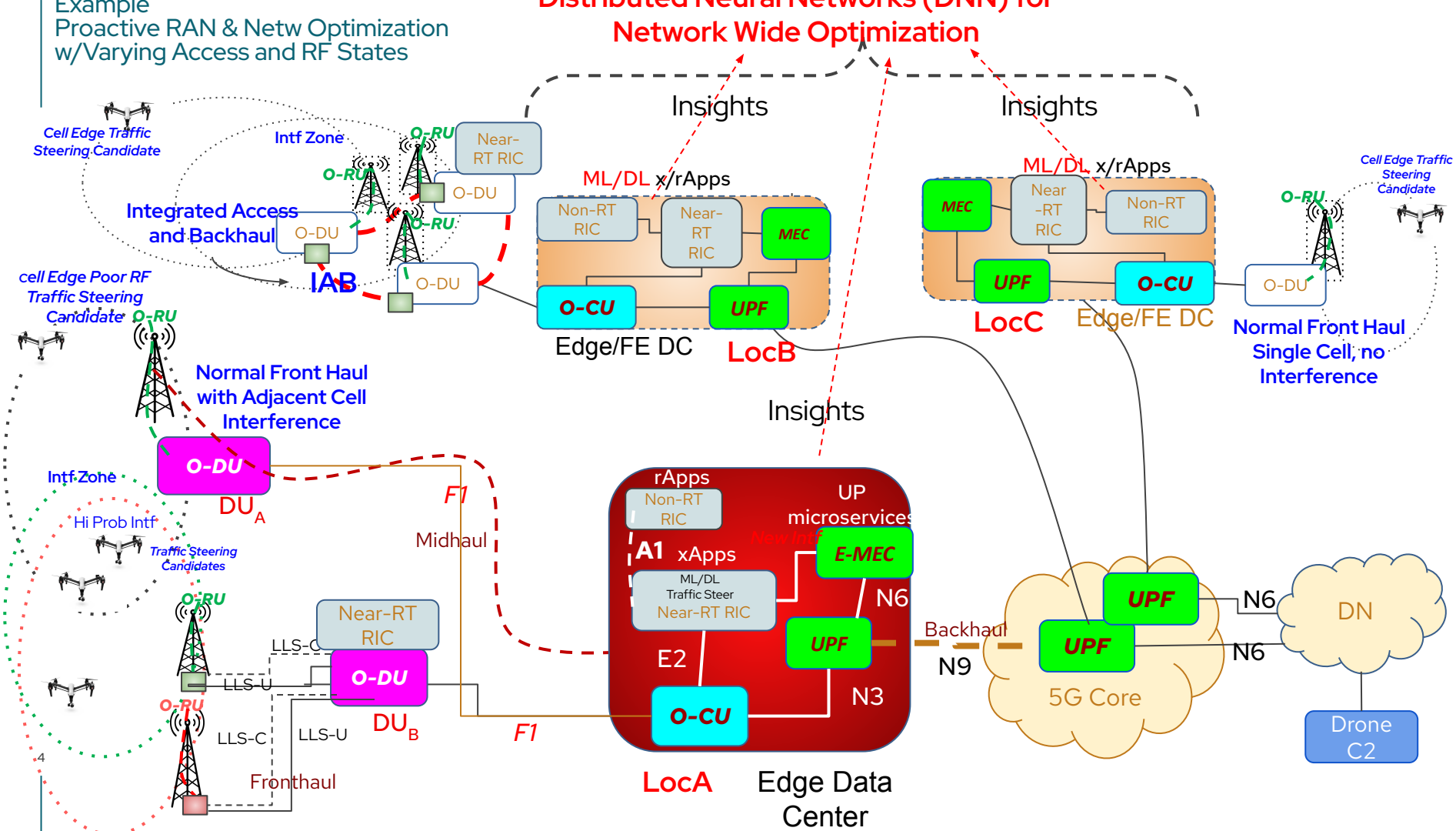
- Use Case #0: RAN Slicing with SLA guarantees
  - Optionally includes SLA security checking and alarming
  - **Tech Partners:** Red Hat OCP, Juniper RICs, Rebaca E2SIM, Intel xApps, AccuKnox Security Software
- Use Case #1: Link (and UE) Power Optimization at Cell Edge
  - Perform link (and UE) power optimization & maintain or improve QoE
  - Use of O-RAN RICs and x/rApps with SMO for continuous optimization over time
  - **Tech Partners:** Red Hat OCP, Juniper RICs, Rebaca or Viavi E2SIM, Intel xApps, Future Connections
- Use Case #2: Optimize Processes within Edge K-Clusters
  - Create disjoint sets of processes to minimize resource contention hence lower power consumption
    - Each process within a set has no inter-process resource contentions
  - **Tech Partners:** Red Hat OCP, Juniper RICs,Rebaca or Viavi, Intel xApps

Network Wide RAN Optimization based on Edge Insights with Varying Access & RF States

- Local RF & Power Optimization with Edge AI
- Edge/RAN locations are not RF homogeneous
- Edge AI sends "Insights" to Distributed Neural Network (DNN)
- DNN makes cross-network optimization recommendations (e.g., Factory Turnup)

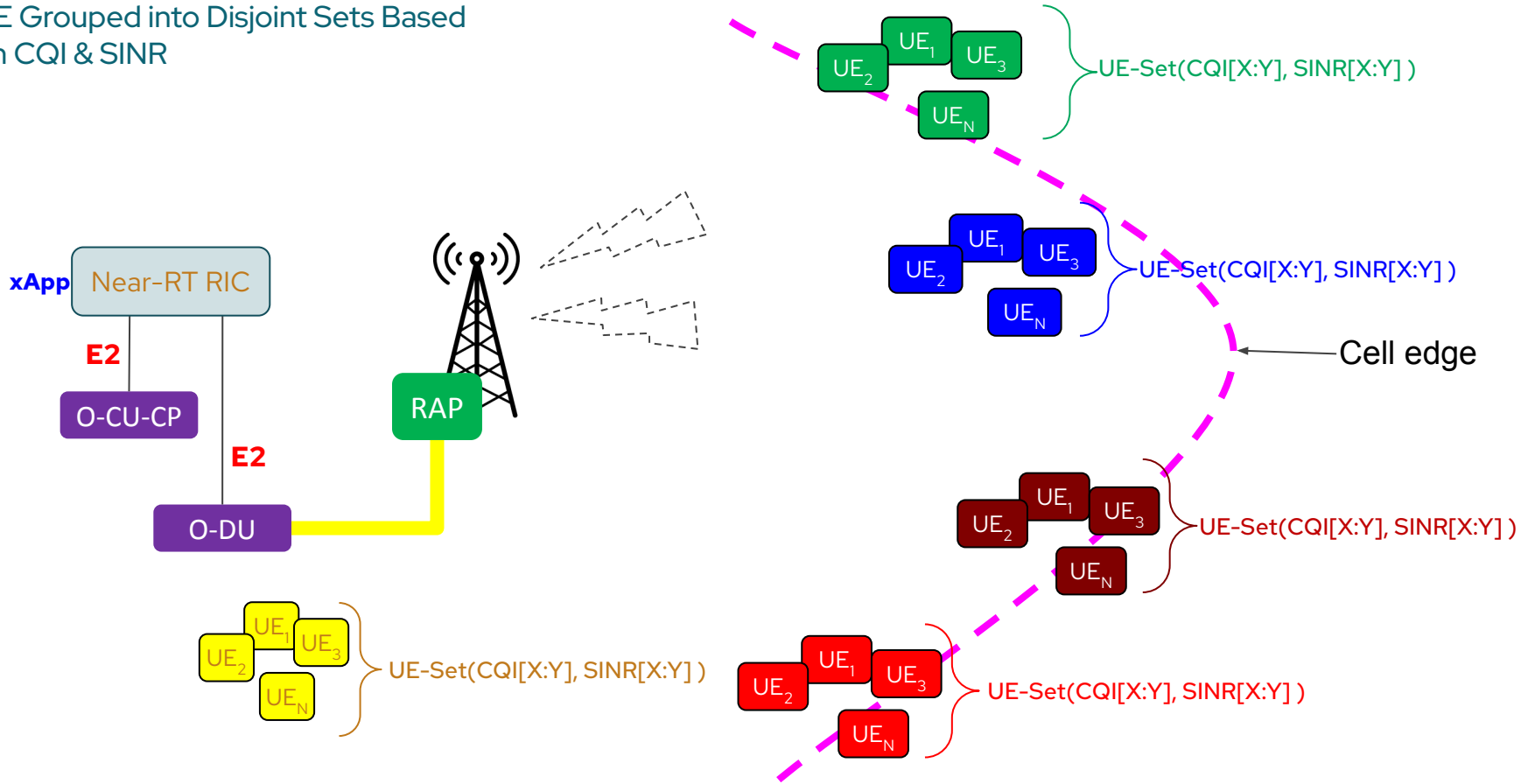


Example
Proactive RAN & Netw Optimization
w/Varying Access and RF States



UseCase#1 DL Power & Modulation

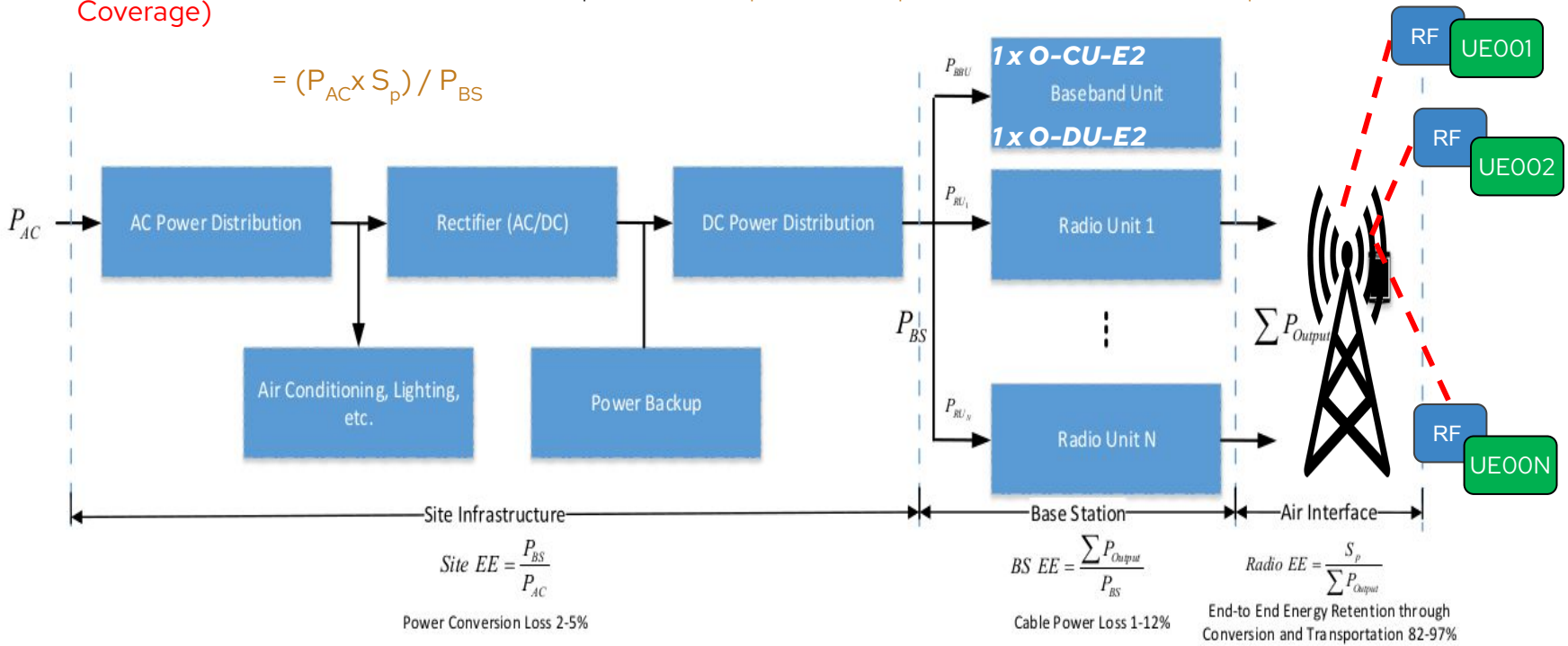
UE Grouped into Disjoint Sets Based on CQI & SINR



E2E Efficiency = SiteEE x BaseStationEE x AirInterfaceEE

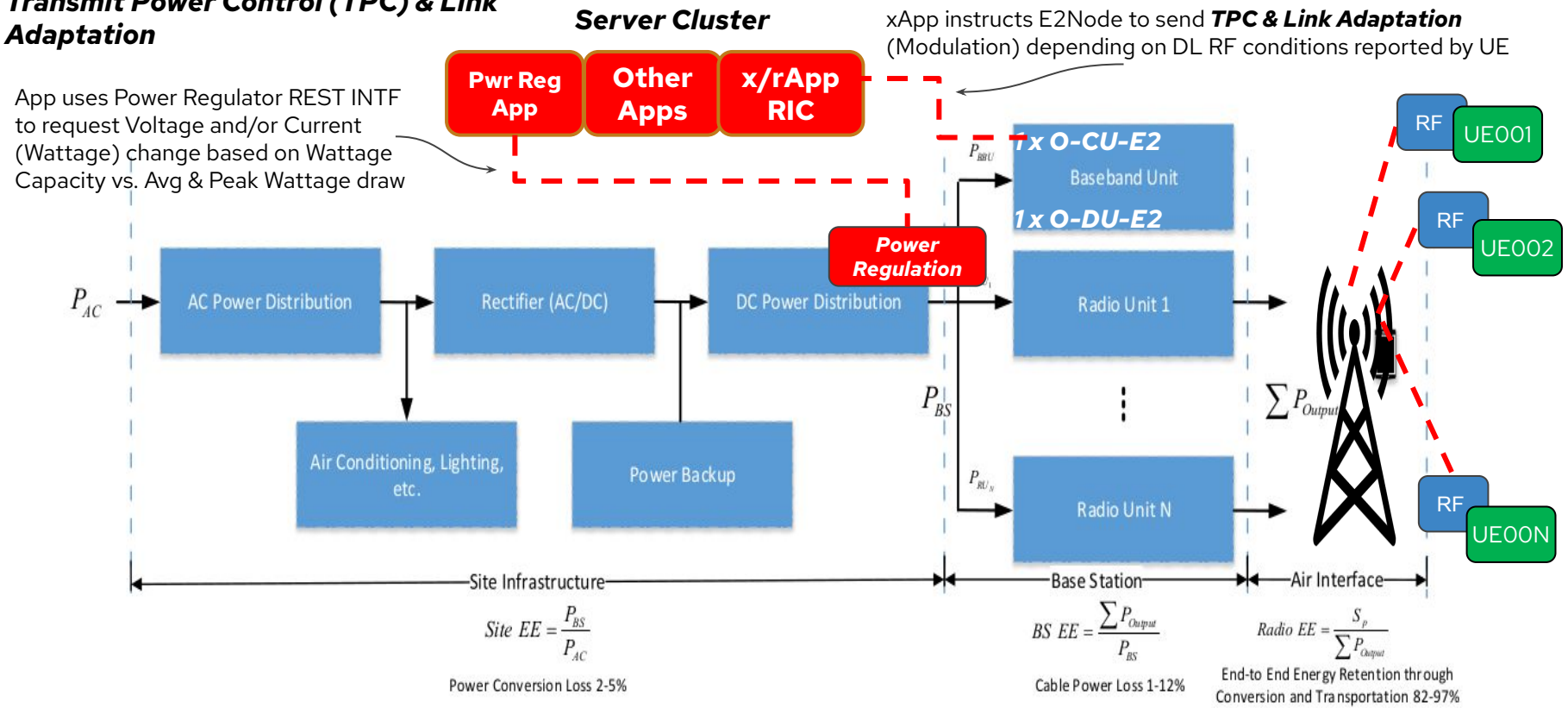
= (P_{BS} / P_{AC}) x $(SumP_{Output} / P_{BS})$ x $(S_p / SumP_{Output})$ = $(1 / P_{AC})$ x $(1 / P_{BS})$ x S_p(#Bits/UE, #UE, Coverage)

= $(P_{AC} x S_p) / P_{BS}$



- The power consumption in the base station is measured from the DC power input to the cabinet-top power output of the base station antenna.
- The power efficiency of a base station can be measured by dividing the cabinet-top power by the DC input power of the base station.

Example Power Efficiency Using DL/UL Transmit Power Control (TPC) & Link Adaptation

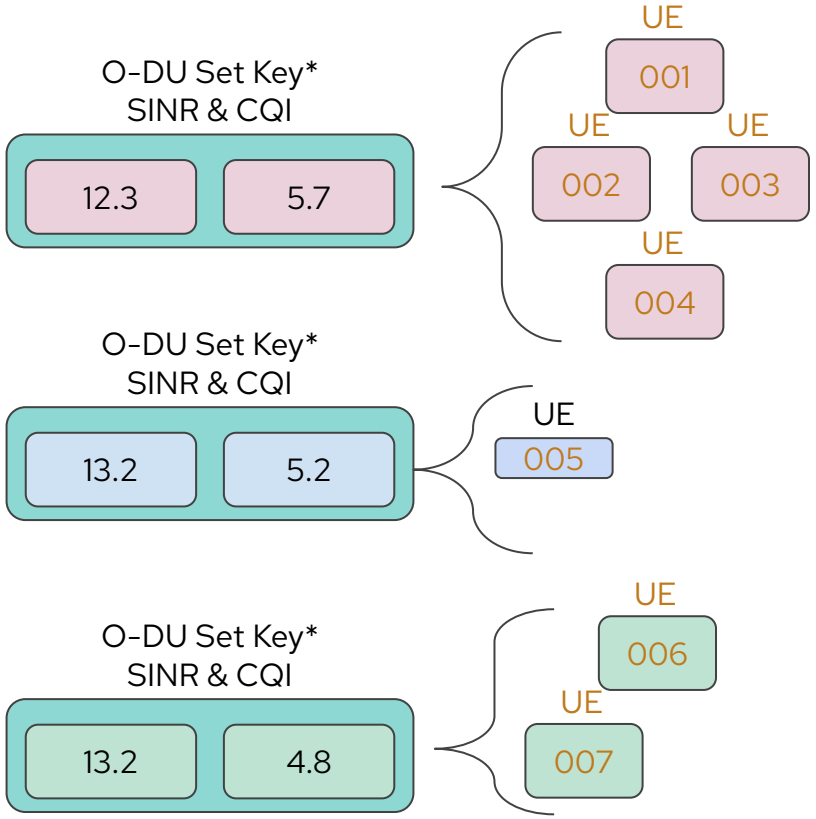


- Link Adaptation (change modulation) for each UE based on calculated CQI
- TPC estimation based on each UE's estimated SINR
- Group UE into sets based on need for power change
- TPC command to reduce power to each UE where SINR > SINR threshold

Example Disjoint Sets of UE/DL Based on DL Signal Quality (UE-SET Table)

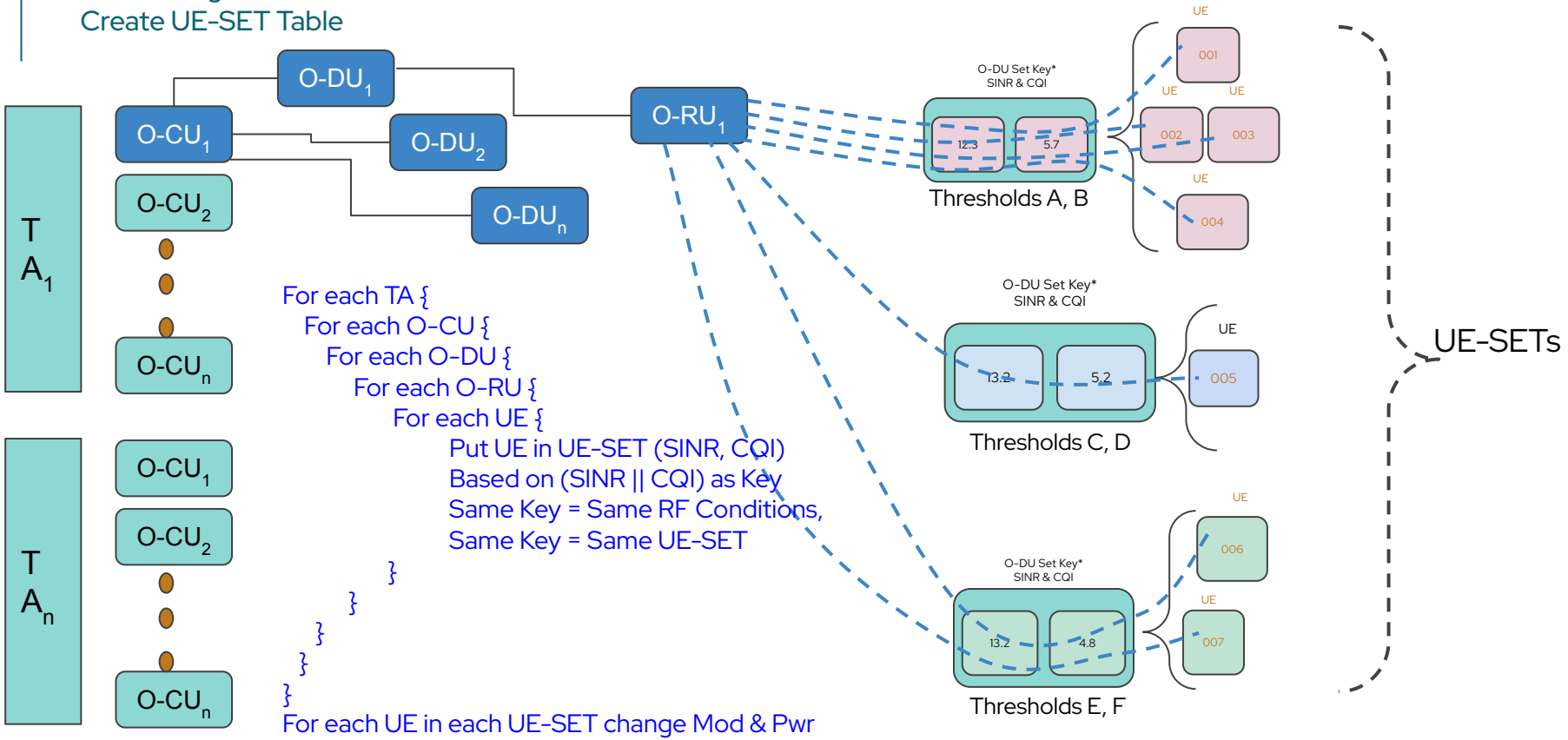
Cell-ID	Key (SINR & CQI)*		Set Index	UIDs within Set Key
O-DU	SINR	CQI	Index	UID
1	12.3	5.7	1	001
2	12.3	5.7	2	002
3	12.3	5.7	3	003
4	12.3	5.7	4	004
5	13.2	5.2	5	005
6	13.2	4.8	6	006
7	13.2	4.8	7	007

UE-SET Table



*Numbers provided are fictitious & do not reflect realistic RF conditions; data is shown to highlight the grouping of UE based on SINR & CQI as a combined Key.

Hi-level Algorithm Flow to Create UE-SET Table

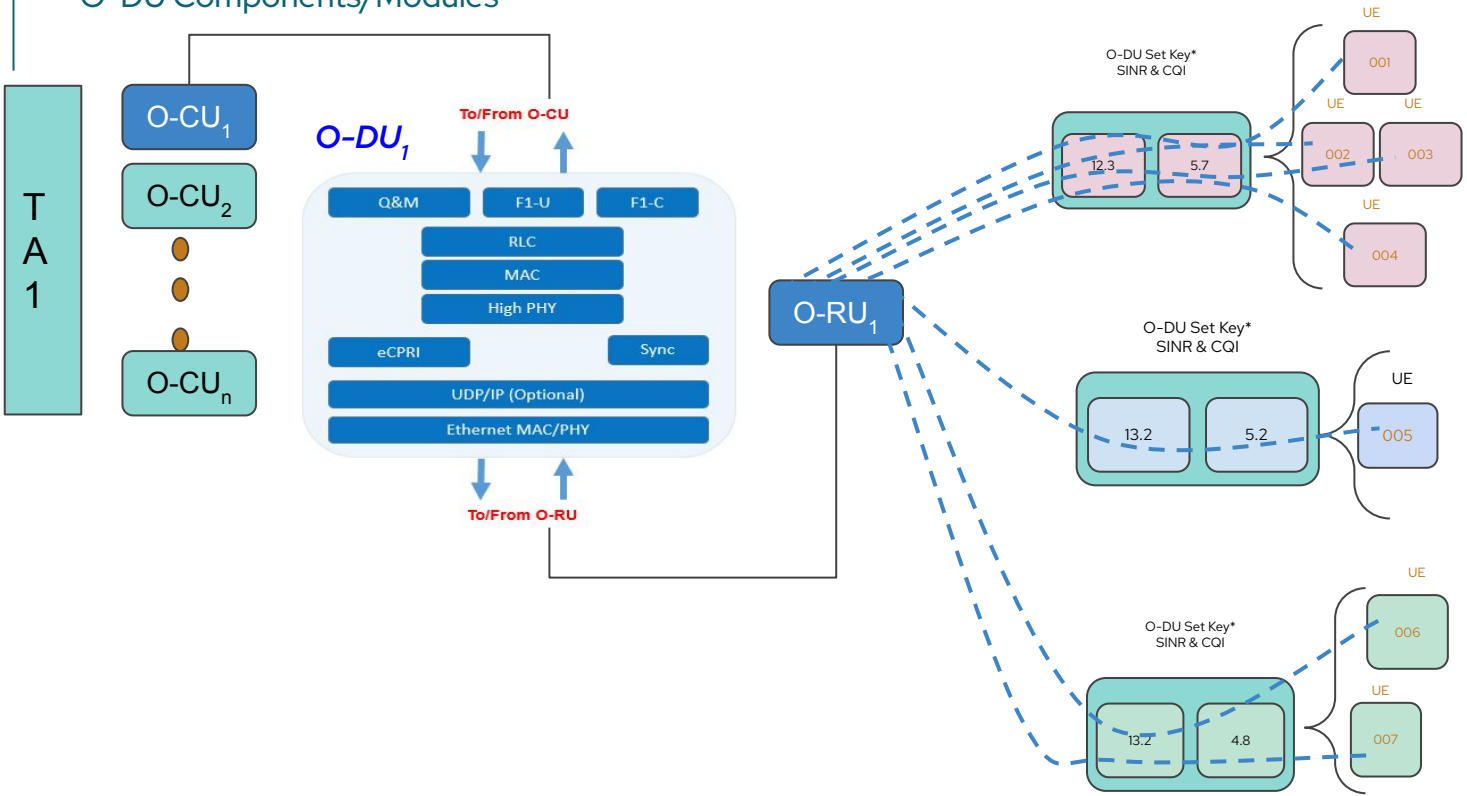



```
For each TA {
  For each O-CU {
    For each O-DU {
      For each O-RU {
        For each UE {
          Put UE in UE-SET (SINR, CQI)
          Based on (SINR || CQI) as Key
          Same Key = Same RF Conditions,
          Same Key = Same UE-SET
        }
      }
    }
  }
}
```

For each UE in each UE-SET change Mod & Pwr based on thresholds for that UE-SET.

*Numbers provided are fictitious & do not reflect realistic RF conditions; data is shown to highlight the grouping of UE based on SINR & CQI as a combined Key

O-DU Components/Modules



*Numbers provided are fictitious & do not reflect realistic RF conditions; data is shown to highlight the grouping of UE based on SINR & CQI as a combined Key.

UE-SET Table

Down Link Signal Quality Estimation

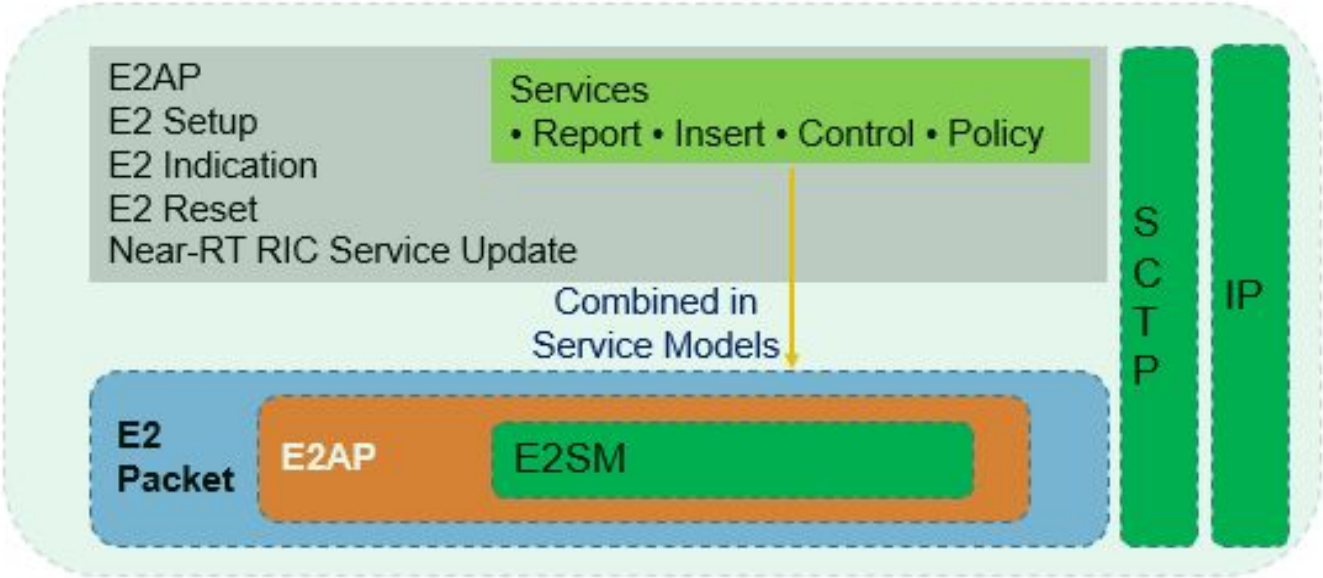
```
/* xApp Algorithm for Downlink (DL) Signal Quality Estimation */
For TA_ID = 1 to #TrackingAreas {
      For O-CU = Next-CU (TA_ID)                          /* Obtain the E2Node (O-CU) ID(s) */
          Index = 0
          For O-DU = 1 to #Cells (O-CU) {                 /* For each cell (O-DU) within an O-CU */
               OldKey = Null; NewKey = OldKey
               For UID = 001 to #UE (O-DU) {              /* For each UE within a given cell */
                     Index++                              /* Set "Index" for Key */
                     X = PSD (RS (UID))                   /* (DownLink (DL), Power Spectral Density (PSD),
                                                                 Reference Signal (RS) */
                     Y = PSD-Offset (PDSCH (UID), RS (UID))   /* Physical Downlink Shared Channel (PDSCH) */
                     SINR = SINR-Estimate (X, Y)          /* Estimate SINR of DL */
                     CQI = CQI-Conversion (SINR)          /* Convert DL SINR to CQI */
                     CFR2 (UID, CQI, Rank_Indicator)      /* Update the Channel Feedback Report with
                                                                 CQI and Rank_Indicator for this UE */
                     NewKey = SINR || CQI                 /* Create Key by concatenating SINR & CQI */
                     If NewKey != OldKey { OldKey = NewKey }
                     UE-SET [ O-DU, NewKey, Index ] = UID /* Create & update disjoint sets of UE indexed
                                                                 by 2-Tuple [CQI, SINR] */
               }
          }
     }
}
```

Down Link & UE Power Control based on DL Signal Quality

```
/* xApp Algorithm for Downlink (DL) and UE Power Control (PC) based on DL Signal Quality */
For TA_ID = 1 to #TrackingAreas {
        O-CU = Next-CU (TA_ID)
        For O-DU = 1 to #Cells (O-CU) {                          /* Obtain the next E2Node (O-CU, O-DU) ID(s) */
            Index = 1                                            /* Start in KeyTable Row 1, Column 1, Index 1 */
            Key = GetNextKey (UE-SET, O-DU, * , NextRow, Index)  /* Get first "Key" by traversing DB rows  */
            Where UE-SET (O-DU, SINR, CQI, Index) = Key {        /* Process equal SINR || CQI keys */
                UID = GetNextUE (UE-SET, O-DU, Index)            /* For each UE equal keys (same RF conditions) */
                Mod = StaySame; Pwr = StaySame
                If CQI (Key) > CQI_Threshold {Mod = HiOrder)     /* If good RF conditions, use higher order modulation */
                  Else If CQI (Key) < CQI_Threshold {Mod = LowOrder} /* If poor RF conditions, use lower order modulation */
                If SINR (Key) > SINR_Threshold {Pwr = Reduce}     /* Reduce link/UE power for good signal conditions */
                  Else If SINR (Key) < SINR_Threshold {Pwr = Increase} /* May increase slightly link/UE power for poor signal
                                                                         conditions */
                IssueMod (O-DU, UID, Mod, Index)                 /* Issue Modulation and TPC changes, if any */
                IssueTPC (O-DU, UID, Pwr, Index)
                RMR (A1, rApp, O-DU, UID, Mod, Pwr}              /* Tell rApp about Mdulation and Power changes */
                Key = GetNextKey (UE-SET, O-DU, NextRow, NextIndex) /* Get next "Key" by traversing DB rows  */
                Index++
                }
            }
        }
}
```

- xApps receive the following E2 Metrics (E2KPM) and issue the following RAN Control (E2RC) commands:
  - ***Receive Metrics (KPM)***
    - Channel feedback report, CQI, Rank indicator from each UE
  - ***Issue Controls (RC)***
    - Link Adaptation (change modulation) for each UE based on CQI
    - TPC estimation based on each UE's SINR
    - Group UE into sets based on need for power change
    - TPC command to reduce power to each UE where SINR > SINR threshold

E2 Services Initiated after E2AP Setup Procedure then Combined in E2 Service Models



- E2 AP Setup Procedure
- E2 Services Definitions (Report, Insert Control, Policy)
- E2 SM (Service Model) Information Elements (KPM, Control, NI, Custom)

E2 Dependencies: Services

- The following E2 Services must be satisfied to enable the use case
  - E2AP Services (Report, Insert, Control, Policy)

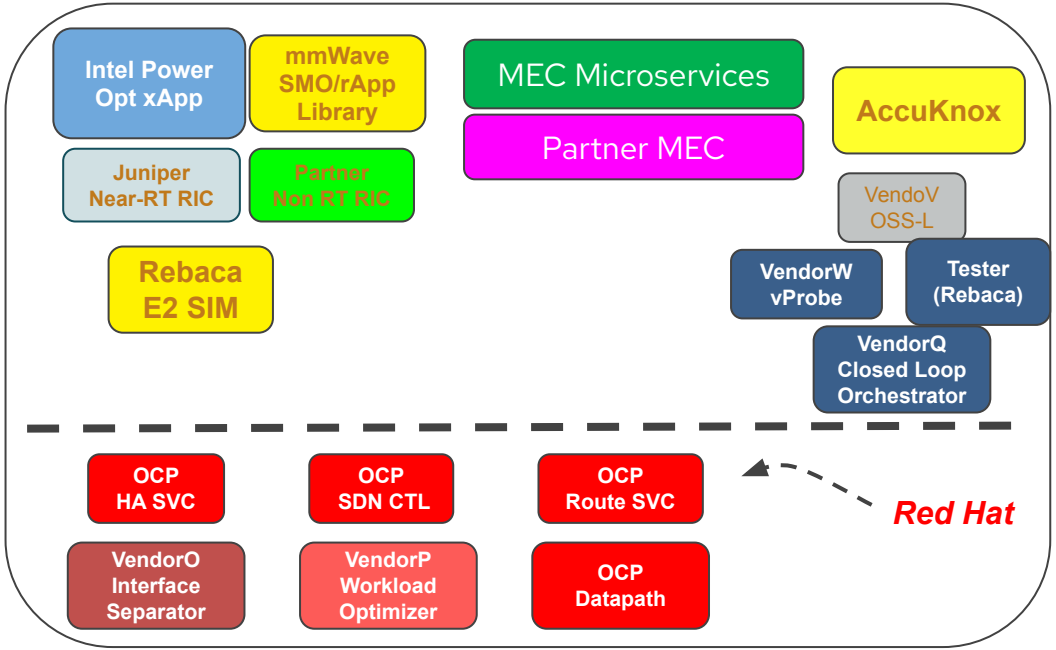
E2 Dependencies: Service Models

- E2 Service Models needed for use case
  - E2 Nodes and/or E2SIM must support current KPM and RC (RAN Control) Service Models plus some additional RC commands (Power change Controls, TPC)
  - KPM data must contain
    - 3GPP UE & Cell metrics: TS 28.552 and TS 32.425
      - UE Channel Feedback Report 2, with CQI and Rank Indicator
      - UE SINR Estimate with CQI Conversion
        - UEs estimate SINR based on the Power Spectral Density (PSD) of the DL Reference Signals (RSs) and PSD offset between PDSCH and RSs.
        - The SINR is converted to Channel Quality Indicator (CQI) and reported to the node in the Channel Feedback Report (CFR) having CQI and rank indicator.
  - RC must support UE and O-CU-CP and O-CU-UP power change controls

Power Optimization High Level Blueprint

$Value: Increased volume, decreased churn based on reliability

Tech Partners: x/rApp Dev (Intel), RICs (Juniper), Cloud (Red Hat), Test Sets (Rebaca)



- Co-develop & test Multi-partner Reference Telco Edge Blueprints to enable new Enterprise Revenues, reduce churn, & lower costs
- Optimize Blueprints with a well-engineered partner mix to deliver Max Revenue Potential and/or Max OpEx/CapEx reduction

Use Case #2: *Minimization of Resource Contention*

- Objective: Lower Power Consumption by minimizing resource contention
  - Multiple processes on edge nodes create resource contention, which results in higher power consumption
    - E.g., SWAP space contention results in SWAP-thrashing, which significantly increases CPU consumption and thus power consumption
  - We create a solution, which intelligently organizes processes across edge nodes in such a way as to minimize contention, hence lower power consumption

Use Case#2: *Minimization of Resource Contention*, K-Cluster Optimization

- Solution description
  - Create disjoint sets of processes
    - Each process within a set has no or minimal inter-process resource contentions
    - That is, we organize processes across worker nodes in such a way that CPU, Network, Memory, Cache, and other resources are minimally or not contended within a worker

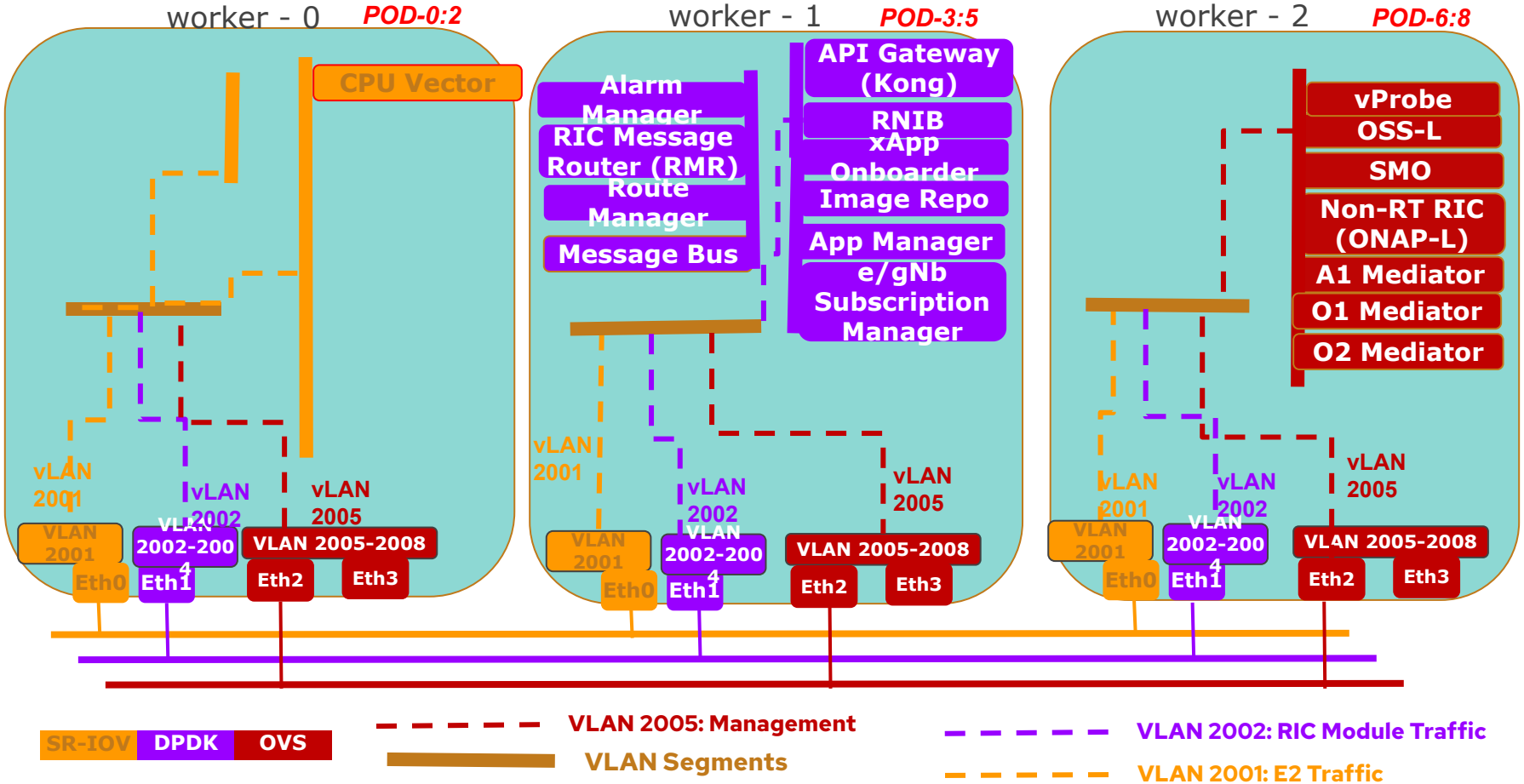
*Example: https://networkbuilders.intel.com/university/webcasts/ran-intelligence-enabling

Use Case#2: *Minimization of Resource Contention*, K-Cluster Optimization

- Methodology: How to isolate processes that compete for resources
  - Create disjoint “Sets” where processes within a set have minimal Cross Process resource contentions
  - Isolate Container with competing process to its own Worker node
  - Use O2 Interface to communicate to the cluster scheduler to dispatch processes to calculated nodes

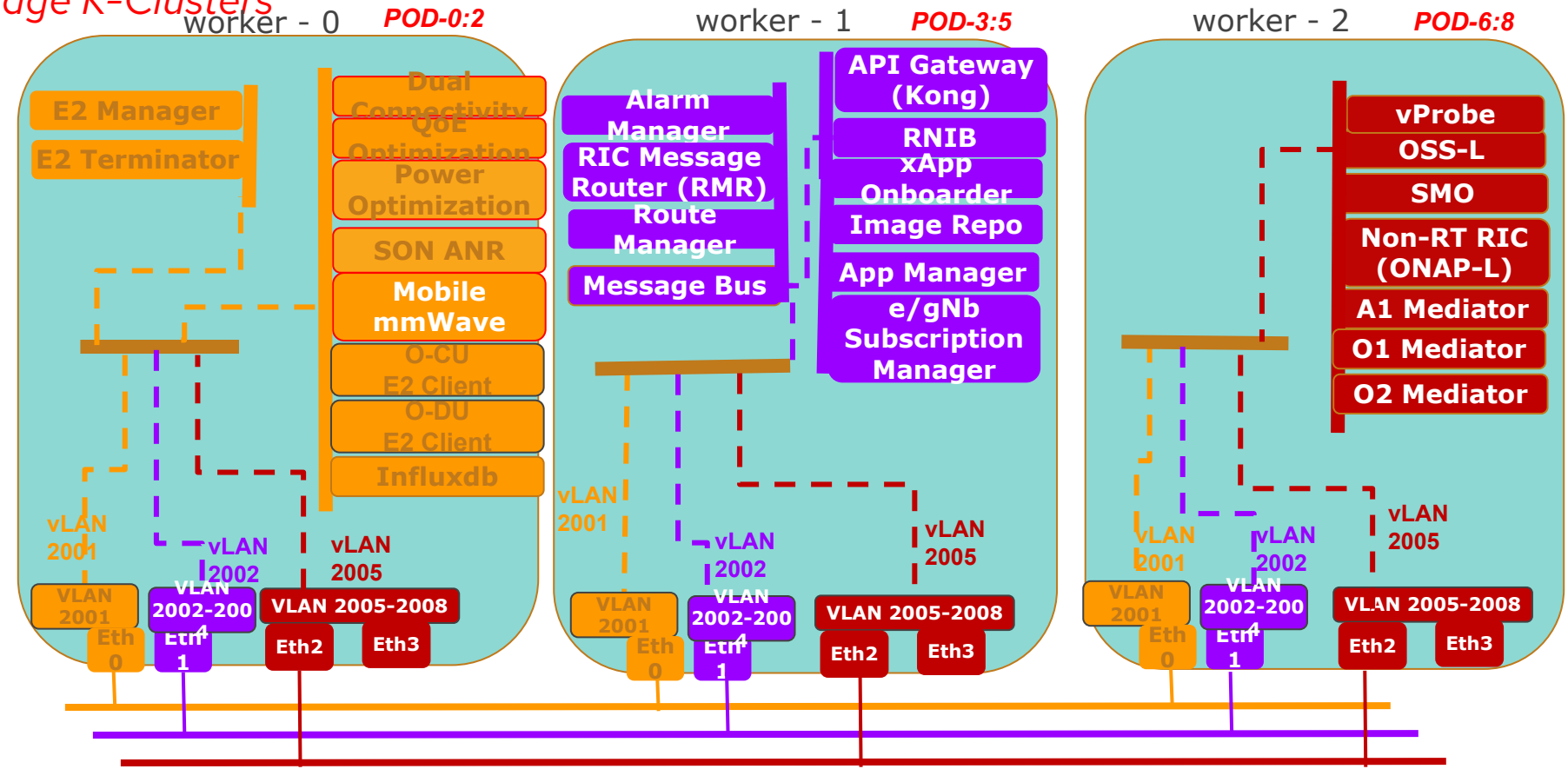
UNDER CONSTRUCTION

Conceptual Power Redux Blueprint
K-Cluster Container and Process Distribution



Use Case #2: *Optimize Processes within Edge K-Clusters*

UNDER CONSTRUCTION



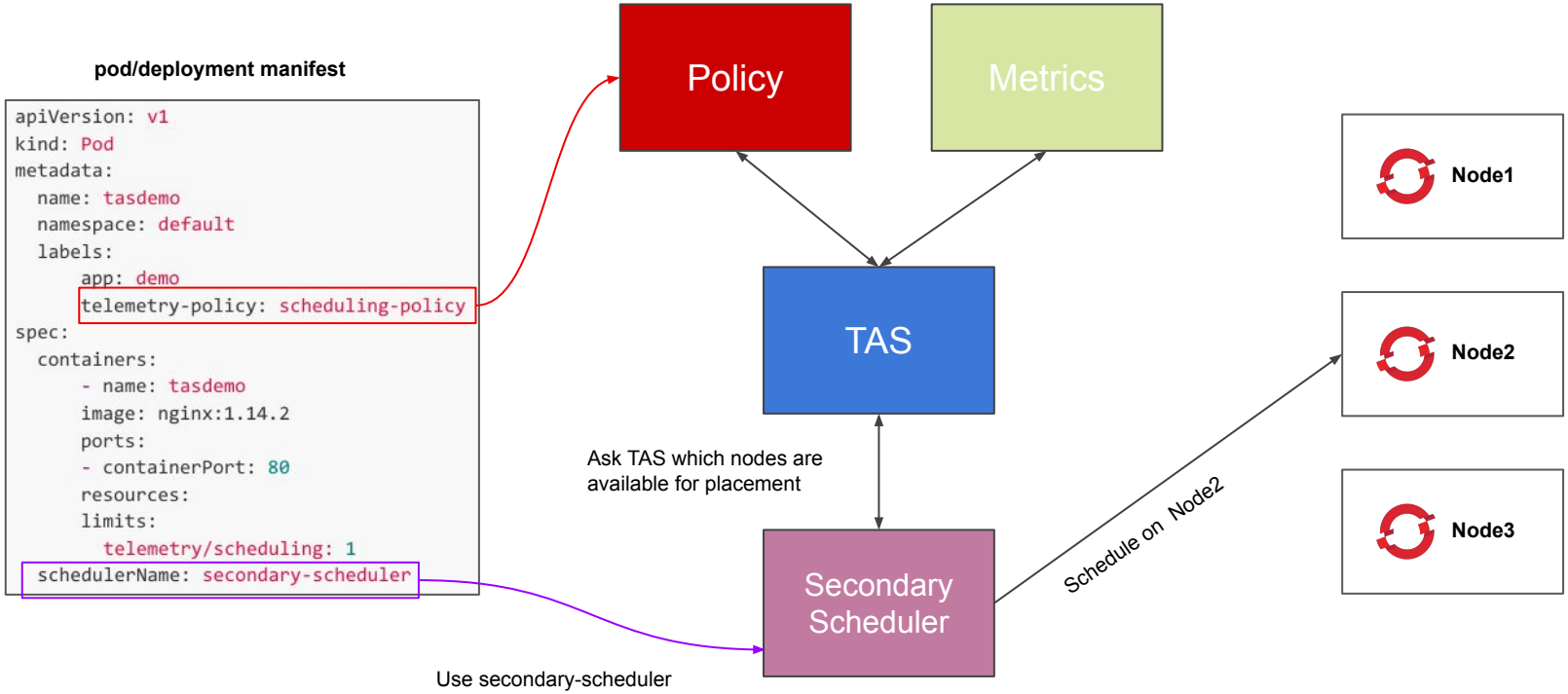
Backup

Use Case Details with xApp & RIC Message Flows

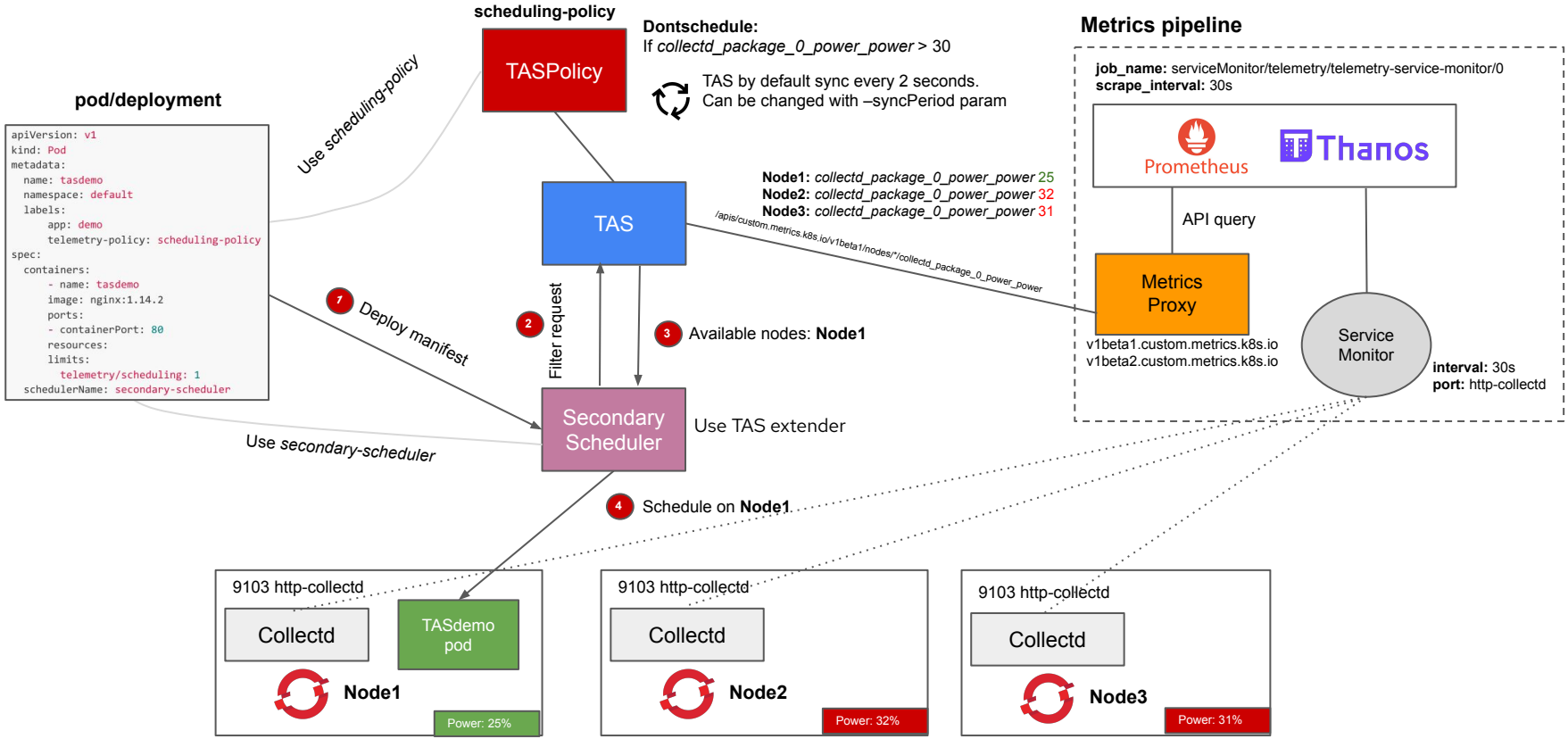
High-level architecture

pod/deployment manifest

```
apiVersion: v1
kind: Pod
metadata:
  name: tasdemo
  namespace: default
  labels:
      app: demo
      telemetry-policy: scheduling-policy
spec:
  containers:
      - name: tasdemo
      image: nginx:1.14.2
      ports:
      - containerPort: 80
      resources:
      limits:
        telemetry/scheduling: 1
  schedulerName: secondary-scheduler
```



OCP Telemetry Aware Scheduler (TAS) Architecture



Down Link/UE Power Adjustment

- For each UE within the Cell estimate SINR based on the Power Spectral Density (PSD) of the DL Reference Signals (RSs) and PSD offset between PDSCH and RSs.
- Each UE's SINR is converted to Channel Quality Indicator (CQI) and reported to the node in the Channel Feedback Report (CFR) having CQI and rank indicator.
- Put each UE into a set, UE-Set (CQI[X:Y], SINR[X:Y]), where each set reflects particular CQI & SINR values or range of values.
- In Near-Real Time, continuously examine the CQI & reported SINR for each UE-Set$_X$ and UE-Set$_{[A:B]}$ and change the modulation scheme and other parameters to influence link and UE power consumption.
    - The CQI indicates the radio quality and is used by the link adaptation function.
    - Based on CQI, the modulation scheme is determined which helps to select the suitable transport block size.
    - Good radio conditions dictate that a higher order modulation scheme, such as 64QAM, can be selected. Poor radio conditions dictate that a lower modulation, such as QPSK, can be selected.
    - Reported SINR is considered to determine the PC action. In Figure 1, UE1 reported SINR is higher than the threshold, while UE2 reported SINR is lower than the threshold.
    - The base station will send the Transmit Power Control (TPC) command to UEs as per the output of step 3B. E.g., UE1 is directed to reduce the power while UE2 is asked to increase the power.

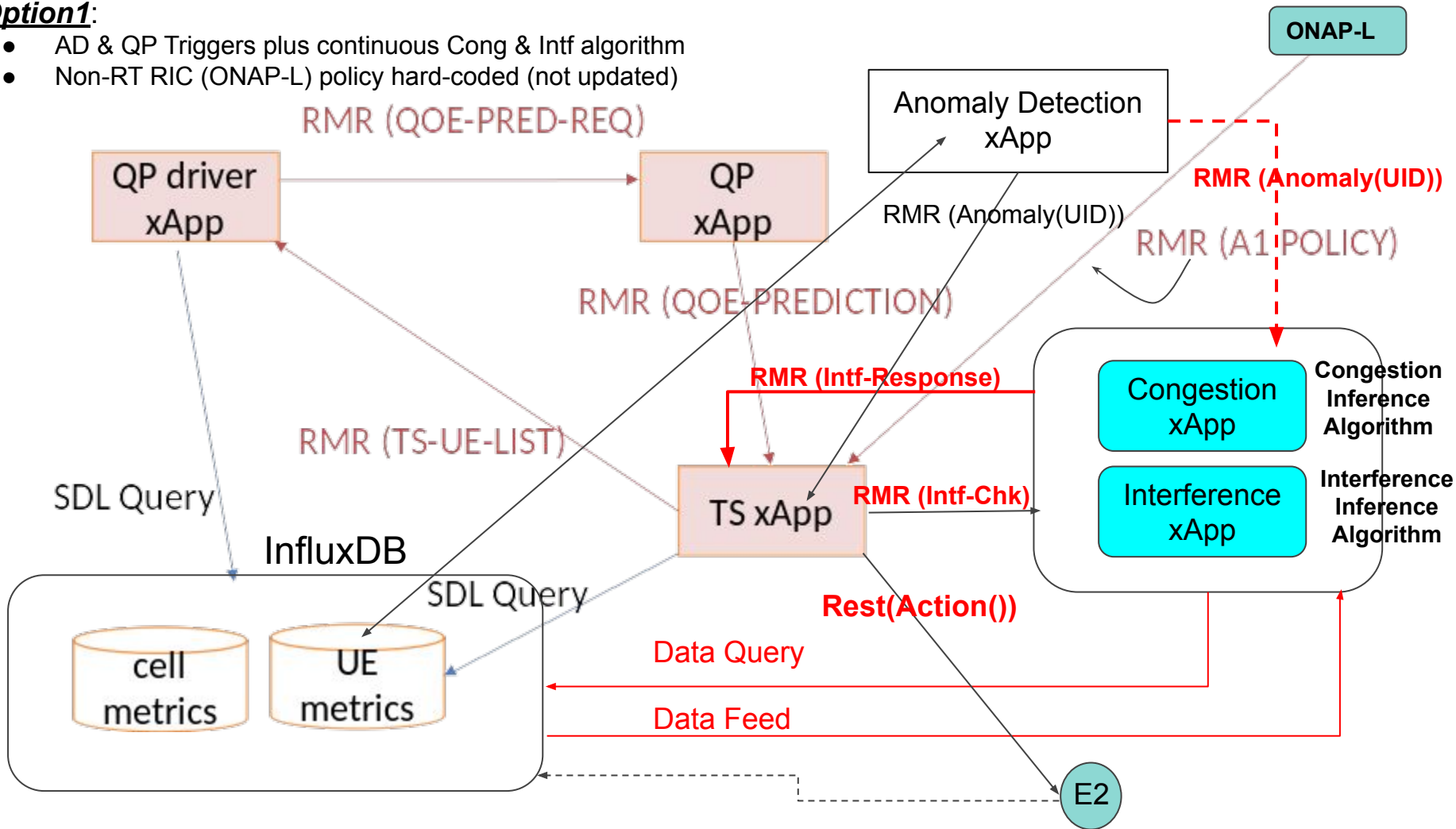
Down Link/UE Power Adjustment*

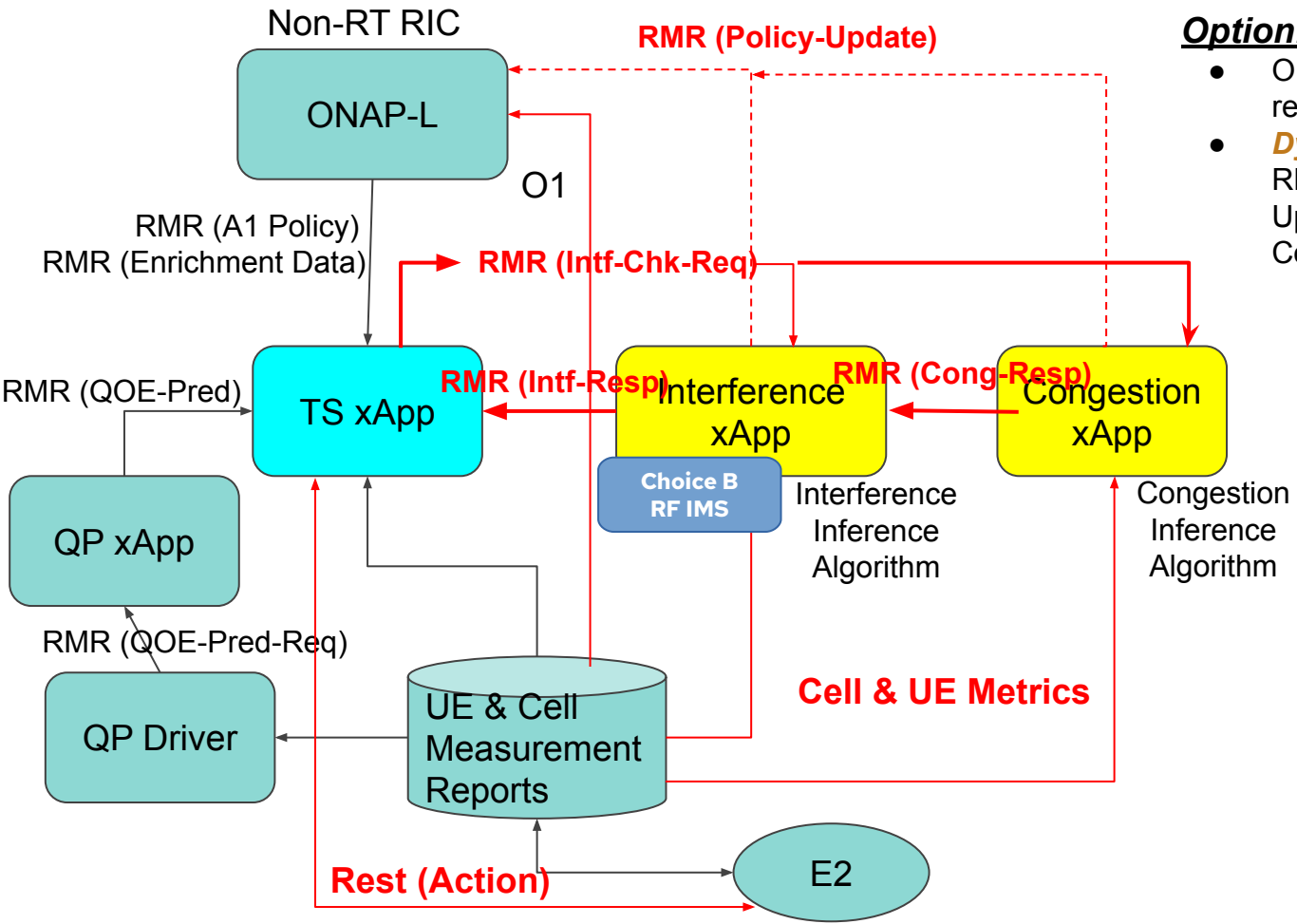
- UEs (e.g., UE1, UE2) estimate SINR based on the Power Spectral Density (PSD) of the DL Reference Signals (RSs) and PSD offset between PDSCH and RSs.
- The SINR is converted to Channel Quality Indicator (CQI) and reported to the node in the Channel Feedback Report (CFR) having CQI and rank indicator. In Figure 1, two-channel feedback reports corresponding to UE1 and UE2 are shown.
- The CQI indicates the radio quality and is used by the link adaptation function.
    - Based on CQI, the modulation scheme is determined which helps to select the suitable transport block size. For example, UE1 reported CQI is >9, which indicates good radio conditions, hence a higher order modulation scheme e.g., 64QAM can be selected. Similarly, UE2 reported CQI is <5 (indicating poor radio conditions), hence lower modulation such as QPSK can be selected.
    - Reported SINR is considered to determine the PC action. In Figure 1, UE1 reported SINR is higher than the threshold, while UE2 reported SINR is lower than the threshold.
    - The base station will send the Transmit Power Control (TPC) command to UEs as per the output of step 3B. E.g., UE1 is directed to reduce the power while UE2 is asked to increase the power.
- Group UE into sets based on CQI, SINR, other factors, such that >=1 set can reduce li

*https://www.ericsson.com/en/blog/2022/11/uplink-power-control-reinforcement-learning

Option1:

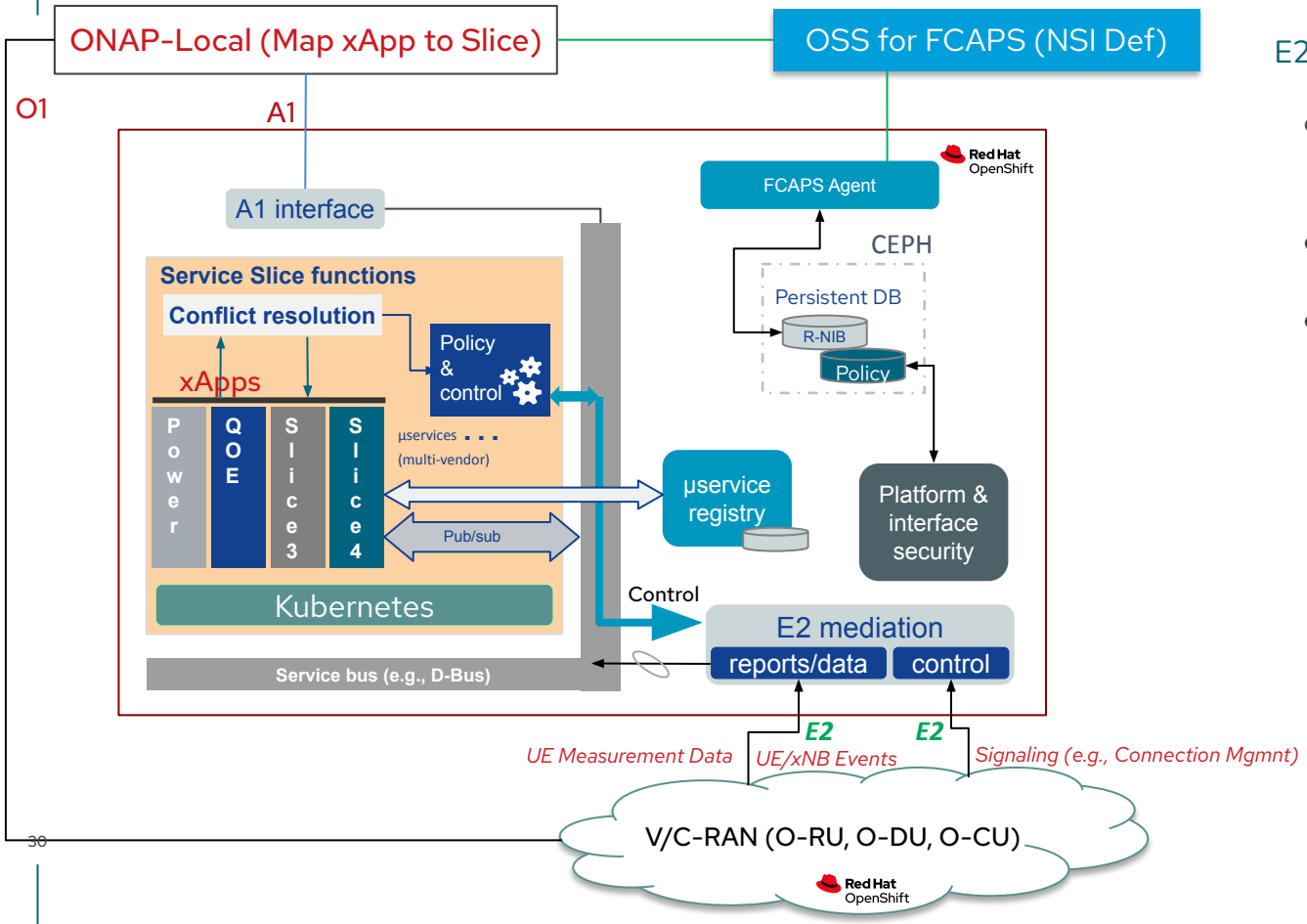
- AD & QP Triggers plus continuous Cong & Intf algorithm
- Non-RT RIC (ONAP-L) policy hard-coded (not updated)





Option2:

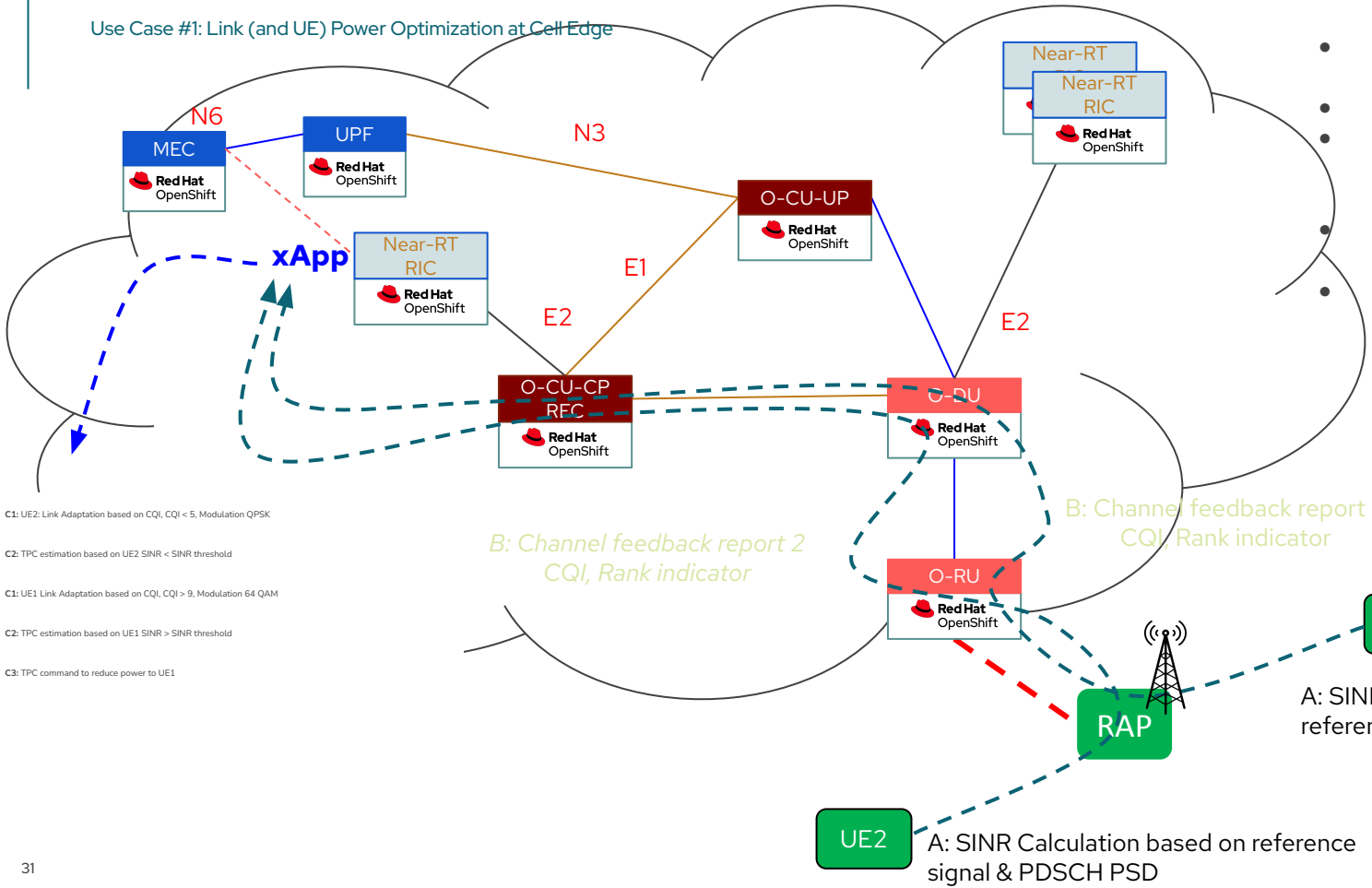
- ONAP-L (Non-RT RIC) receives Cell metrics.
- ***Dynamic update of Policy***: RMR used to send Policy Update Request from Intf & Cong xApps decisions



E2AP Node Subscription

- Subscribe to E2 Nodes (O-CU, O-DU) with Reports (Data) and Control
- E2 Service Models must include KPM and RC
- xApps will provide power and QoE optimization activities

Use Case #1: Link (and UE) Power Optimization at Cell Edge



- xApp E2 subscription services (Reports, Control)
- E2SM = KPM
- Metrics include standard 3GPP UE & Cell metrics: TS 28.552 and TS 32.425
- Control needed: Link Adaptation, TPC
- O-DU, O-CU, xApps, rApps, RIC modules, etc., run as CNFs on OCP Clusters

C1: UE2: Link Adaptation based on CQI, CQI < 5, Modulation QPSK

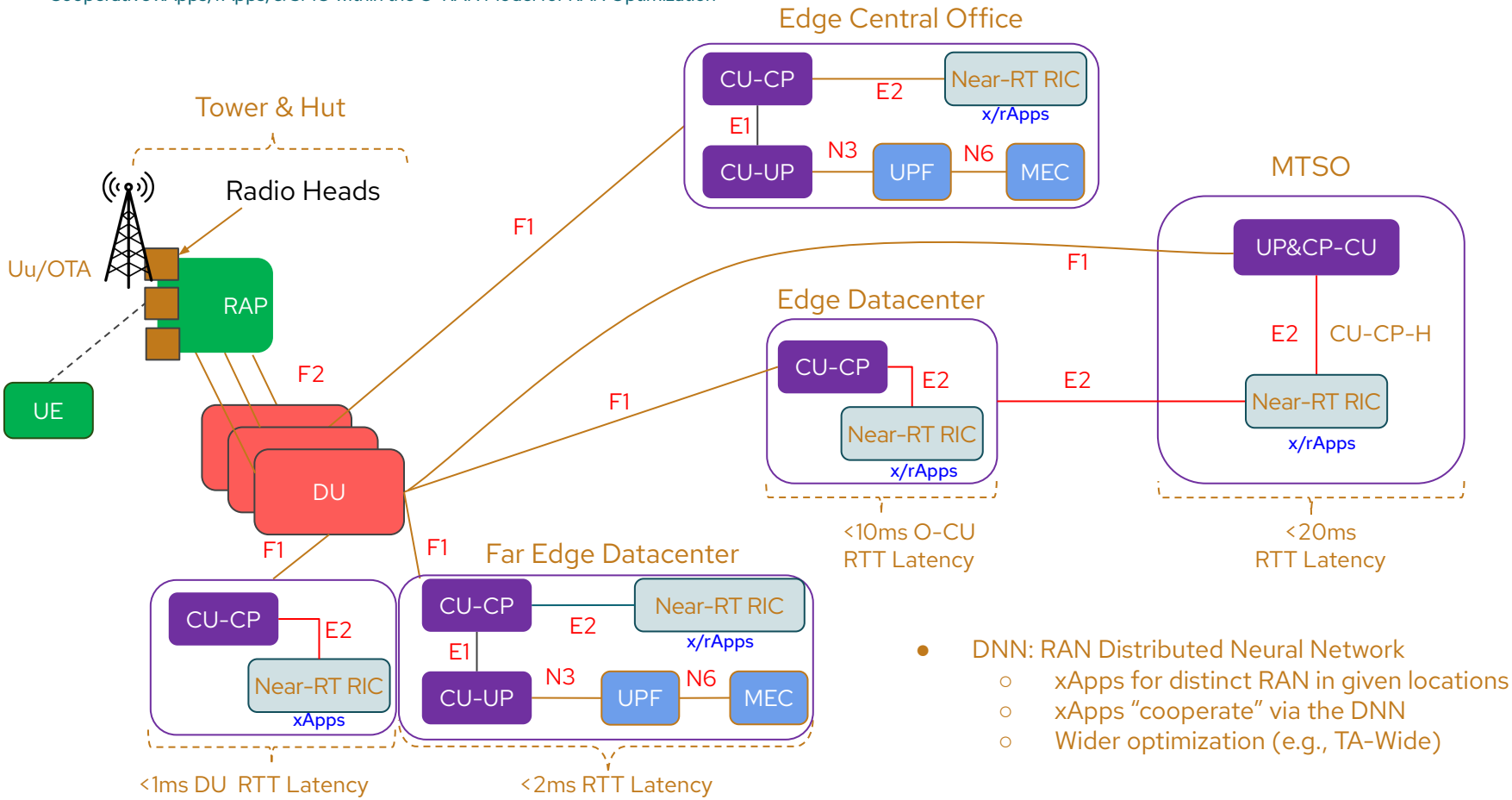
C2: TPC estimation based on UE2 SINR < SINR threshold

C1: UE1 Link Adaptation based on CQI, CQI > 9, Modulation 64 QAM

C2: TPC estimation based on UE1 SINR > SINR threshold

C3: TPC command to reduce power to UE1

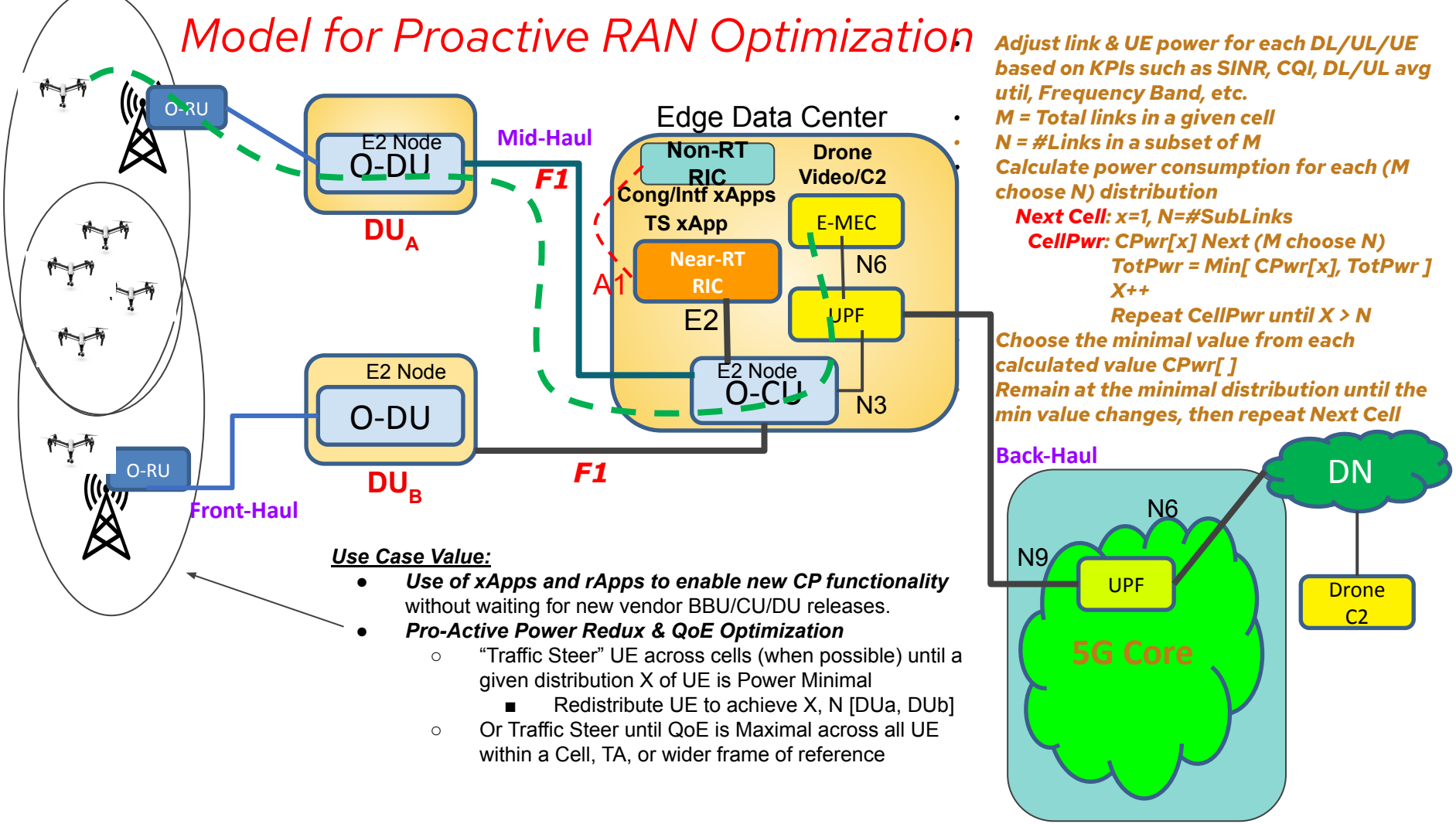
*https://www.ericsson.com/en/blog/2022/11/uplink-power-control-reinforcement-learning



- DNN: RAN Distributed Neural Network
  - xApps for distinct RAN in given locations
  - xApps "cooperate" via the DNN
  - Wider optimization (e.g., TA-Wide)

1ms – 20ms RTT Latency

Model for Proactive RAN Optimization

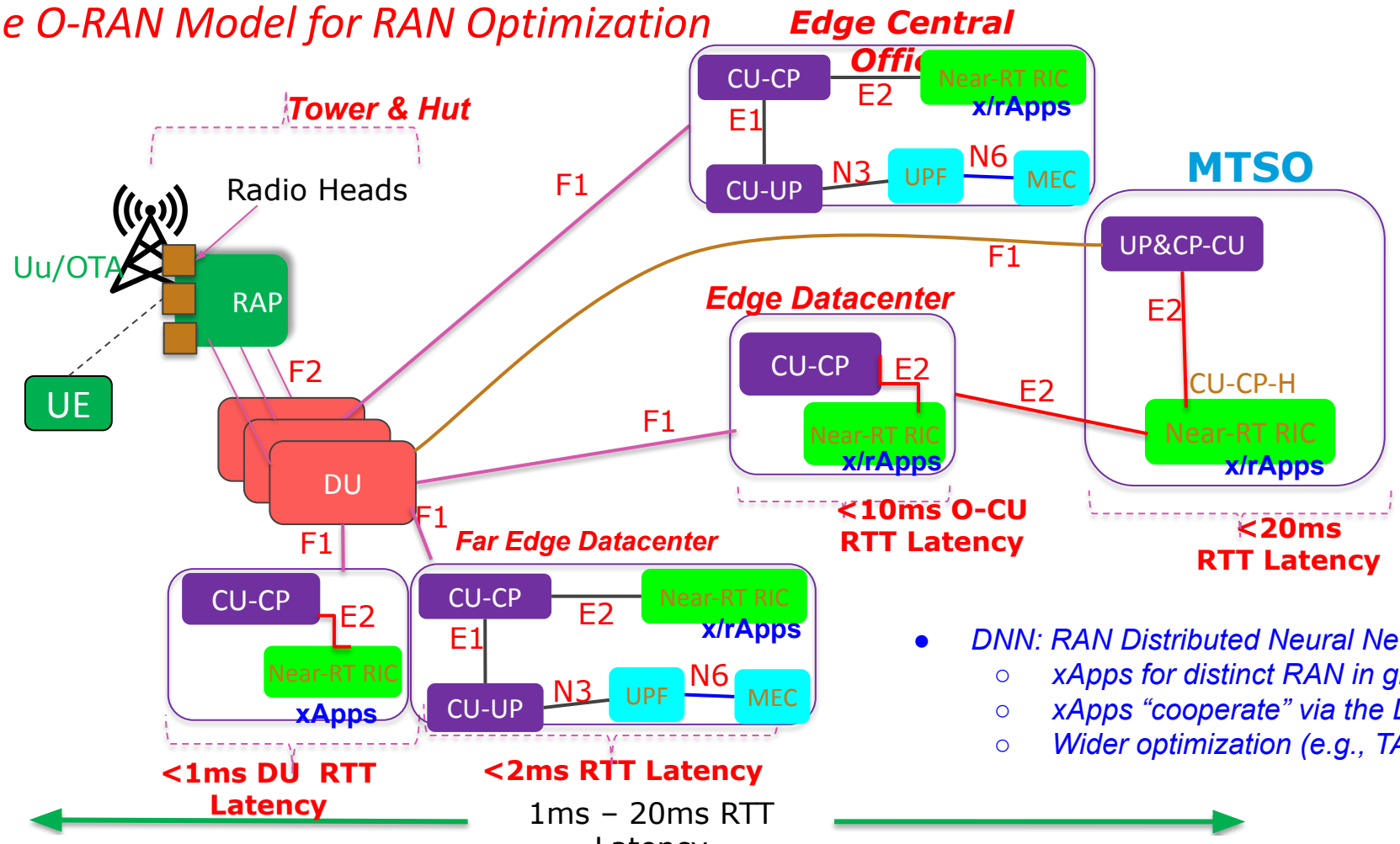


Adjust link & UE power for each DL/UL/UE based on KPIs such as SINR, CQI, DL/UL avg util, Frequency Band, etc.
M = Total links in a given cell
N = #Links in a subset of M
Calculate power consumption for each (M choose N) distribution
Next Cell: x=1, N=#SubLinks
CellPwr: CPwr[x] Next (M choose N)
TotPwr = Min[CPwr[x], TotPwr]
X++
Repeat CellPwr until X > N
Choose the minimal value from each calculated value CPwr[ ]
Remain at the minimal distribution until the min value changes, then repeat Next Cell

Use Case Value:

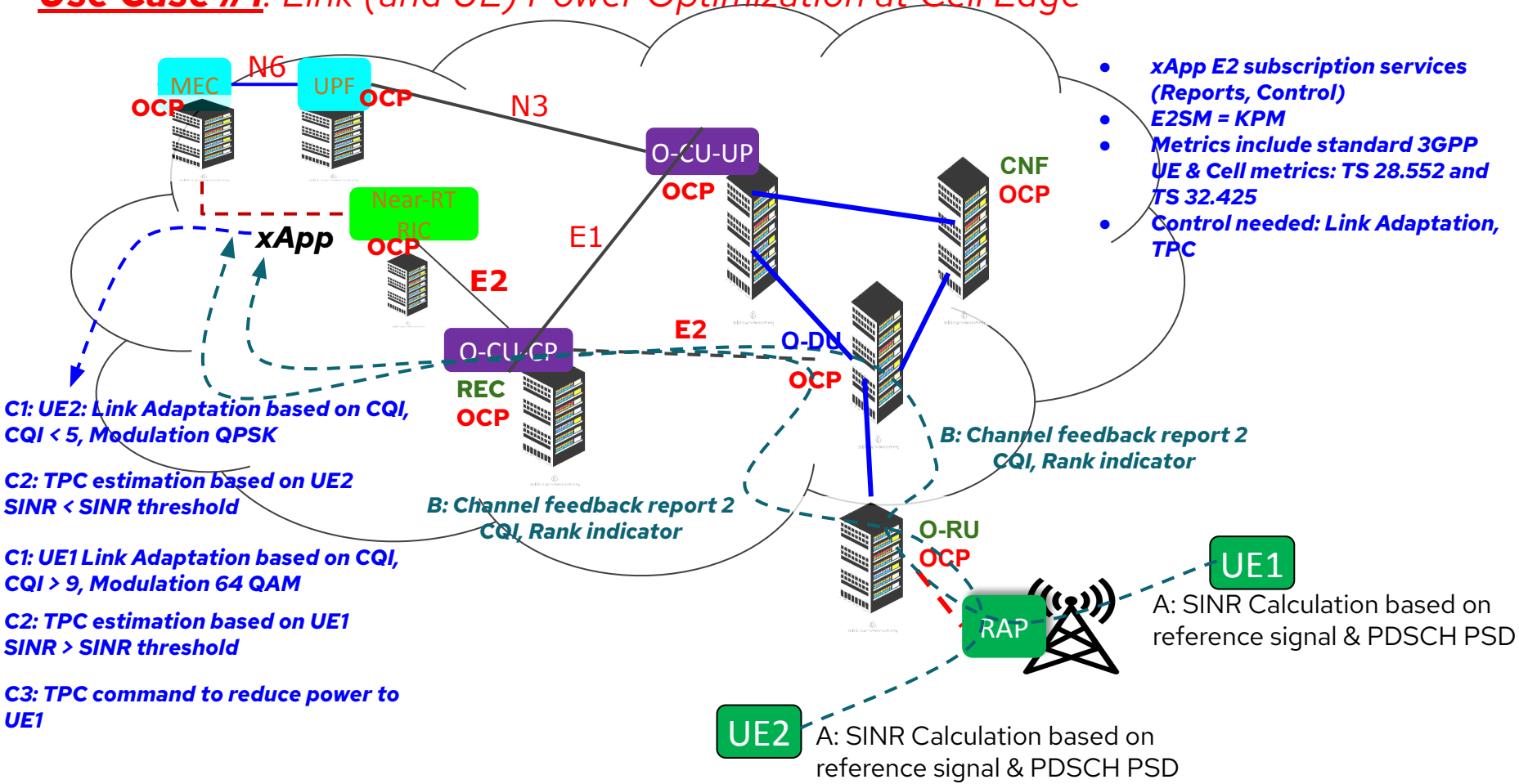
- ***Use of xApps and rApps to enable new CP functionality*** without waiting for new vendor BBU/CU/DU releases.
- ***Pro-Active Power Redux & QoE Optimization***
  - "Traffic Steer" UE across cells (when possible) until a given distribution X of UE is Power Minimal
    - Redistribute UE to achieve X, N [DUa, DUb]
  - Or Traffic Steer until QoE is Maximal across all UE within a Cell, TA, or wider frame of reference

Cooperative xApps, rApps, & SMO within the O-RAN Model for RAN Optimization



- *DNN: RAN Distributed Neural Network*
  - *xApps for distinct RAN in given locations*
  - *xApps "cooperate" via the DNN*
  - *Wider optimization (e.g., TA-Wide)*

Use Case #1: *Link (and UE) Power Optimization at Cell Edge*



*https://www.ericsson.com/en/blog/2022/11/uplink-power-control-reinforcement-learning

Thank you

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