Critical C-RAN Technologies

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Three key technologies to realize C-RAN

- **Function split solutions for fronthaul design**

Goal: reduce the fronthaul bandwidth while keeping C-RAN's advanced features such as the support of CoMP.

- **Efficient DU pool design**

Goal: flexibly share computation and bandwidth resource to save overall resource consumption.

- **IT virtualization**

Goal: meet real-time constraint for radio signmal processing.

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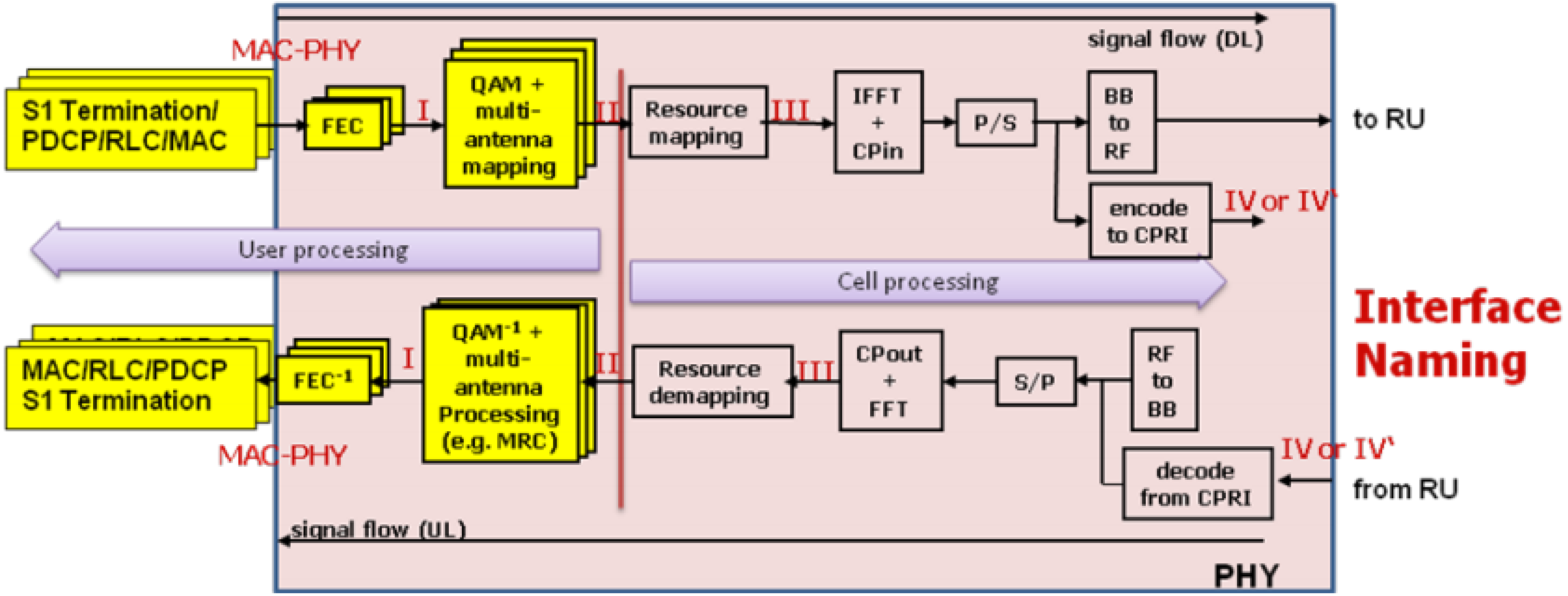
Function split solutions for fronthaul design



Functional block diagram of LTE baseband processing for DL and UL

Function split solutions for fronthaul design

User processing part

contains following bi-directional entities

- S1 Termination
- PDCP
- RLC
- MAC
- PHYuser with FEC and QAM + multi-antenna mapping for DL
- PHYuser with FEC-1 and QAM-1 + multi-antenna Processing for UL

Cell processing part

contains following bi-directional entities

- Resource mapping (framer)/ Resource Demapping (Deframer)
- FFT+CPin (Cyclic Prefix insertion) for DL
- CPout + FFT for UL
- P/S + CPRI encoding (with or without Compression) for DL

Function split solutions for fronthaul design

Potential fronthaul interfaces

- **MAC-PHY** as the interface between the MAC part and the FEC/ FEC-1 (MAC-PDUs)
- **Interface I** as Hard/Soft-bit fronthauling (Hard/Softbits + control info) between FEC and QAM+Multi-antenna mapping in DL and QAM-1 + multi-antenna Processing and FEC-1 in UL
- **Interface II** as Subframe data fronthauling (frequency domain I/Q + control info) between QAM+Multi-antenna mapping and Resource mapping (Framer) in DL and Resource Demapping (Deframer) and QAM-1 + multi-antenna Processing in UL
- **Interface III** as Subframe symbol fronthauling (frequency domain I/Q) between Resource Mapping (Framer) and IFFT/CPin in DL and CPout/FFT in UL.
- **Interface IV'** as Compressed CPRI fronthauling (time domain I/Q) between IFFT/CPin and P/S + CPRI Encoding with compression in DL and CPRI Decoding with Decompression + S/P and CPout/FFT in UL
- **Interface IV** as CPRI fronthauling (time domain I/Q) between IFFT/CPin and P/S + CPRI Encoding without compression in DL and CPRI Decoding without decrompression + S/P and CPout/FFT in UL

Function split solutions for fronthaul design

Low latency fronthaul

LTE timing (HARQ) requires a round trip time of 8ms

transport latency = 8ms – UE processing time (DL,UL) – eNodeB processing time (DL-UL) – Propagation time AirIF

All interface rates including overheads are summarized (20MHz, 3 sectors and 4 antennas)

- **MAC-PHY** DL with overhead: 136.9Mb/s UL with Overhead: 123.2Mb/s
- **Interface I** DL with overhead 298.9 Mb/s UL with Overhead 1.944 Gb/s
- **Interface II** DL with overhead 2.9Gb/s UL with Overhead 4.17 Gb/s
- **Interface III** DL with overhead 3.02 Gb/s UL with Overhead 4.78 Gb/s
- **Interface IV'** DL with overhead 4.9 Gb/s UL with Overhead 4.9 Gb/s
- **Interface IV** DL with overhead 14.7 Gb/s UL with Overhead 14.7 Gb/s

Function split solutions for fronthaul design

Low latency fronthaul

Analysis

1. A split according the interfaces MAC-PHY and I is not interesting, due to limited CRAN feature and CoMP support and the drawbacks putting major baseband functions to the RU.

2. Interface II due to its potential support of packetization. It opens the possibility toward packet-based fronthaul networks and may need further future study.

3. UL data rates of the interfaces II and III are similar to that of IV', the CRAN features are the same considering optical transport systems are deployed with symmetrical bandwidth for DL and UL, the interface IV' is the best choice as processing split interface from fronthaul data rate perspective.

4. The interface IV' can be preferred against the interface IV.

Function split solutions for fronthaul design

High latency fronthaul

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- **Interface III** DL with overhead 3.02 Gb/s UL with Overhead 4.3 Gb/s

Function split solutions for fronthaul design

High latency fronthaul

Analysis

1. Interface I and the split between PHY and MAC are also not recommended due to limited C-RAN feature support and inconvenient future upgrade.

2. Interface II and III, although they can support major C-RAN feature, the data rate is still high and future system update would be difficult since some major function blocks including FFT and resource mapping are deployed on the RU site.

3. Interface IV' and IV would be difficult to be implemented for high latency case due to critical CPRI timing requirement.

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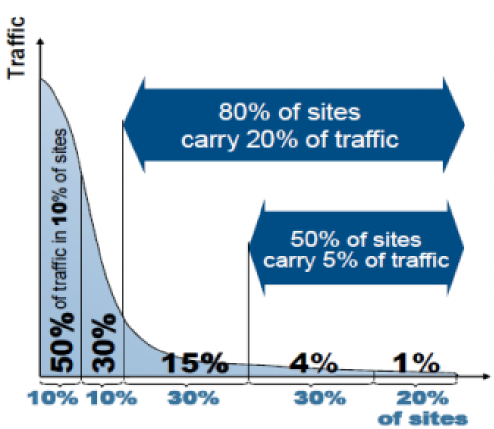
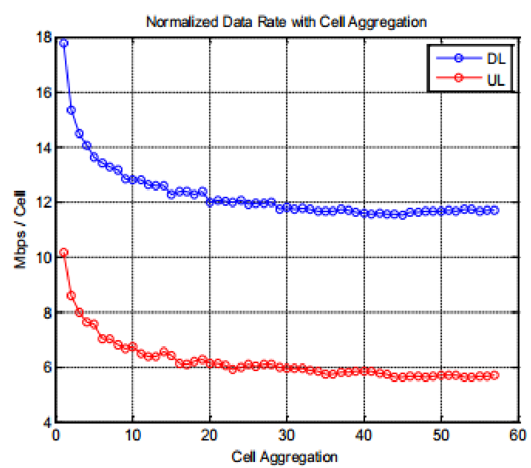
Design of DU Pool

Analysis of traffic characteristics

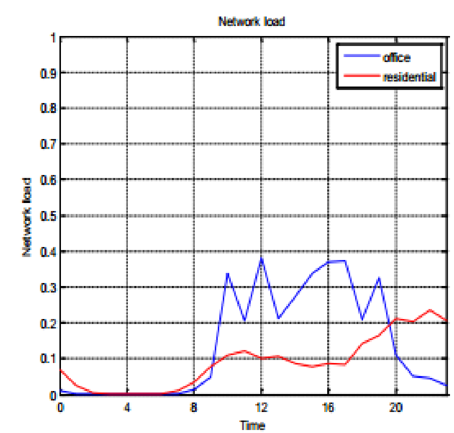
- **The aggregation effect:** the reduction of the traffic load aggregated over several cells with respect to the peak rate of each individual cells.
  1. Traffic imbalance among BaseStations
  2. Traffic average effect in DU pool
  3. Traffic imbalance from Day-night effect
  4. DL/UL sharing for TDD system
- **The pooling gain:** the reduction of the amount of processing resource which is possible in a C-RAN with respect to a conventional distributed RAN.



Europe aggregated network traffic profile



Normalized throughput vs. number of aggregated sectors



day night traffic profile for office and residential area

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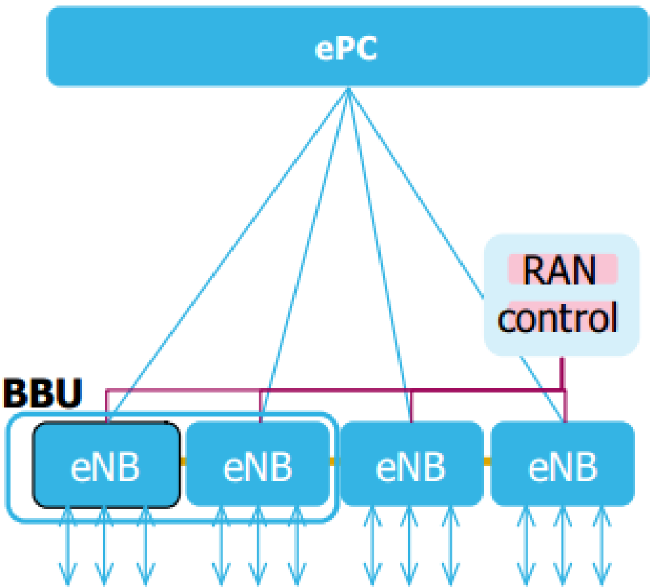
Reference C-RAN Architectures



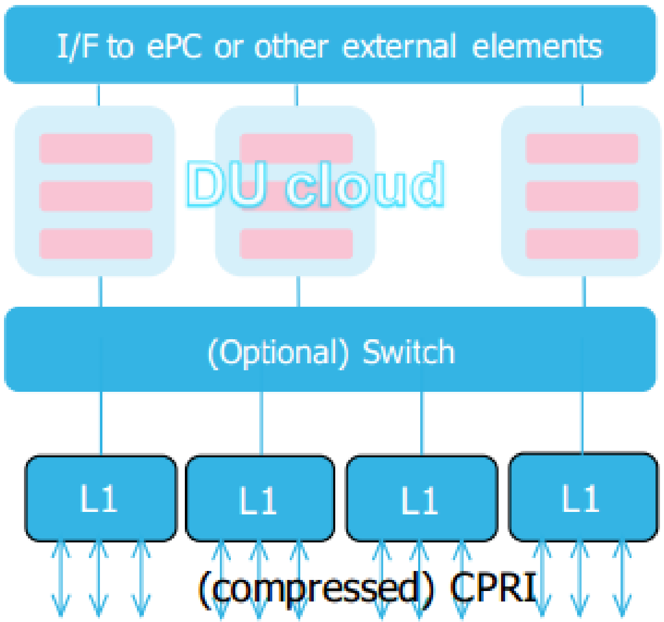
Stacked BBU

- **Baseband units**
  - Include all usual eNB functions
  - High speed data exchanges between BB units
  - Local X2 exchanges
- **RAN controller**
  - Includes multi cell coordination functions (Schedulers coordinator, MRC), and possibly Local applications (e.g. CDN)

Stacked BBU architecture

- CPRI are directly connected to the BBU units.
- CoMP can be limited to intra-BBU processing

Reference C-RAN Architectures



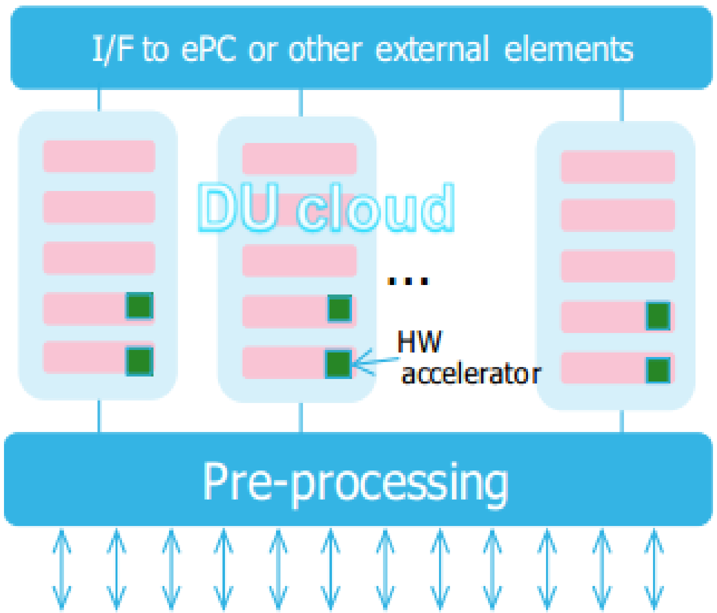
L1 is out of the DU cloud

- **L1 processing**
  - 'Standalone' external module
  - Proprietary vendor HW and SW
  - The Switch distributes load to servers and exchanges data between L1 (for CoMP). Can also be a high speed bus
- **DU cloud**
  - L2, L3 and RAN control functions
  - Optionally: ePC and local applications

Standalone L1 architecture

- L1 processing is done in externally to the DU cloud, in specialized HW.
- The DU pool is in charge of L2 and L3 functions, as well as of other eNB functions.
- A switch is used to provide connectivity between the L1 units and the DU pool.

Reference C-RAN Architectures



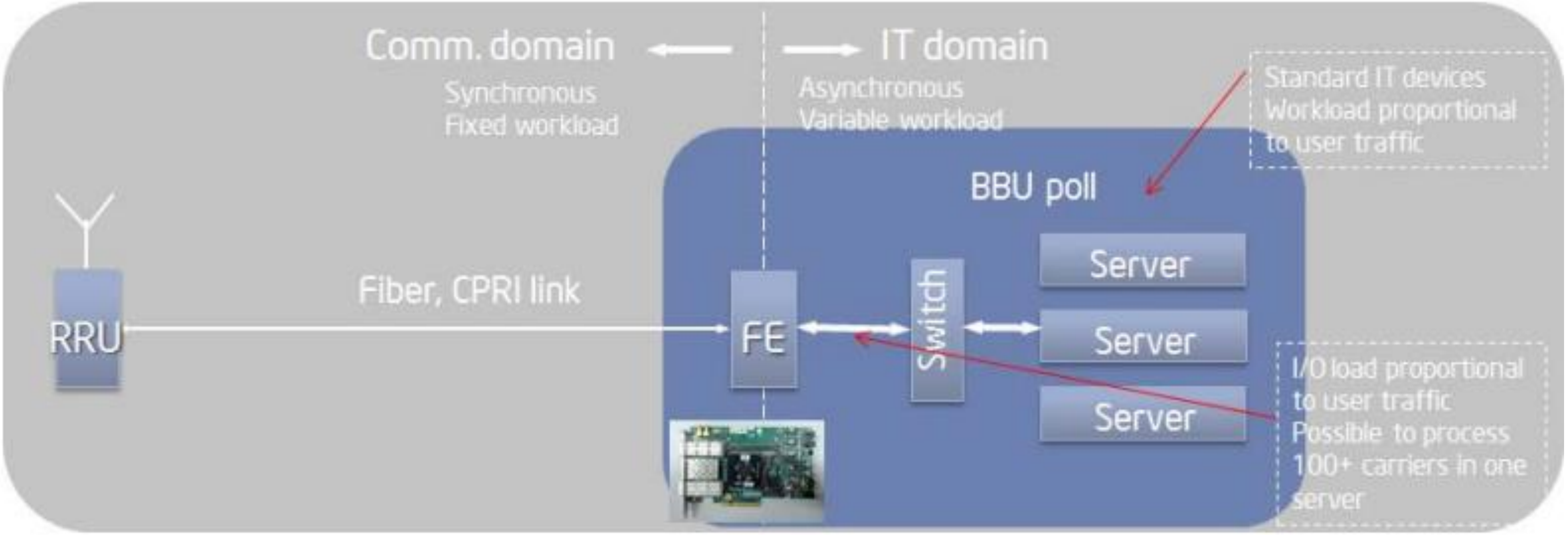
L1 is in the DU cloud

- **Pre-processing**
  - Cell specific L1 functions
  - Distribution to DU cloud
- **DU cloud**
  - User specific L1 functions
  - Optional HW co-processors boards
  - L2 and L3 and RAN control functions
  - Optionally: ePC and local applications

L1 in the pool architecture

- L1 processing is implemented in the DU cloud
- Some (or all) processing elements may include HW accelerators for L1.

GPP-based DU pool design



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- Some (or all) processing elements may include HW accelerators for L1.

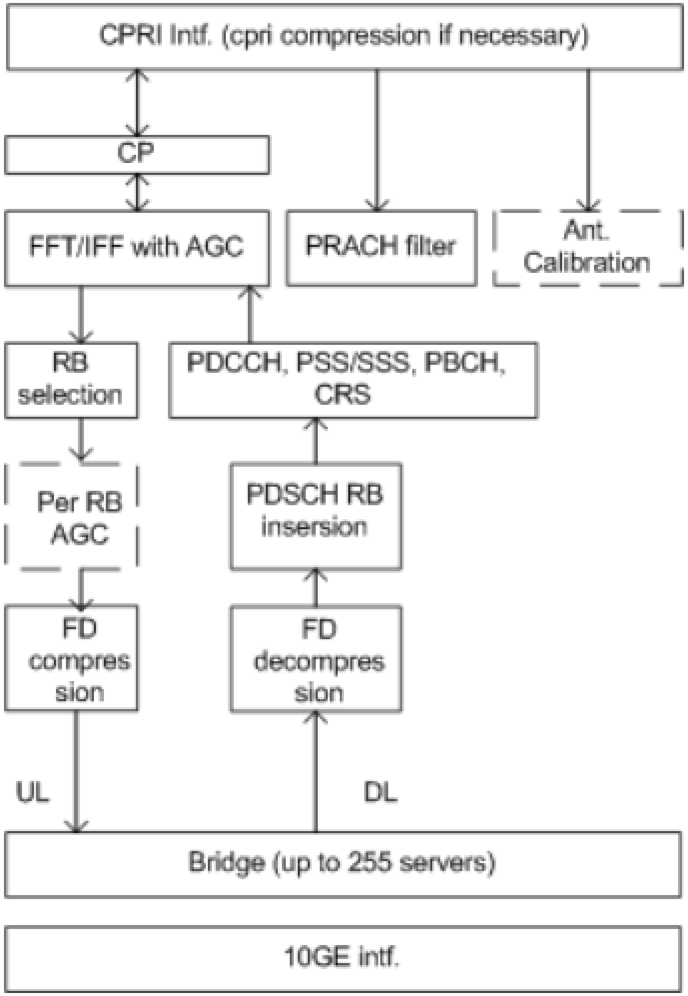
GPP-based DU pool design

Front-End processing

Antenna I/Q data from RRU is directly fed into front-end processing board throughput CPRI interface.

Benefits

- Reduced bandwidth
- Reduce processing burden for DU
- Flexible support joint processing
- Simplify live migration



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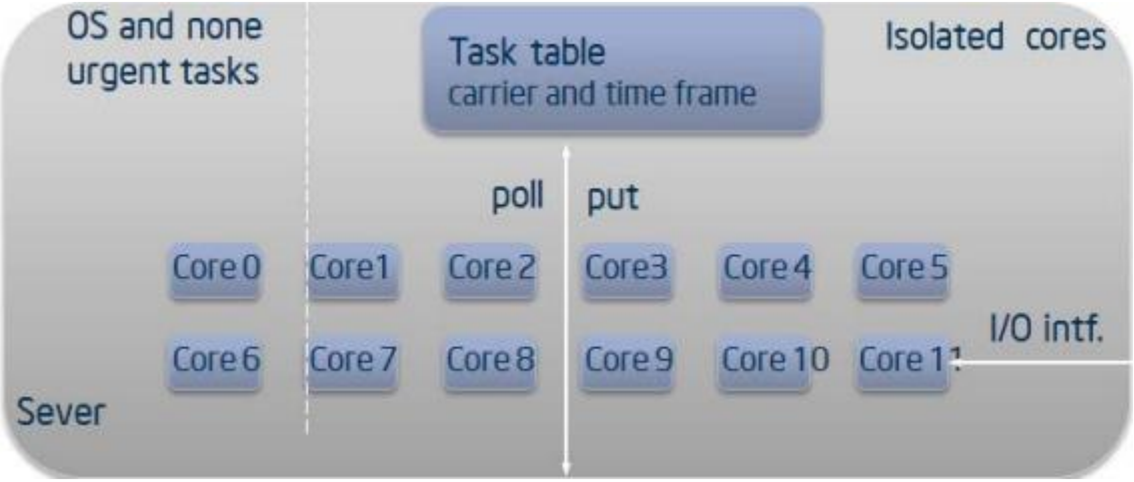
GPP-based DU pool design

Intra-DU task scheduler

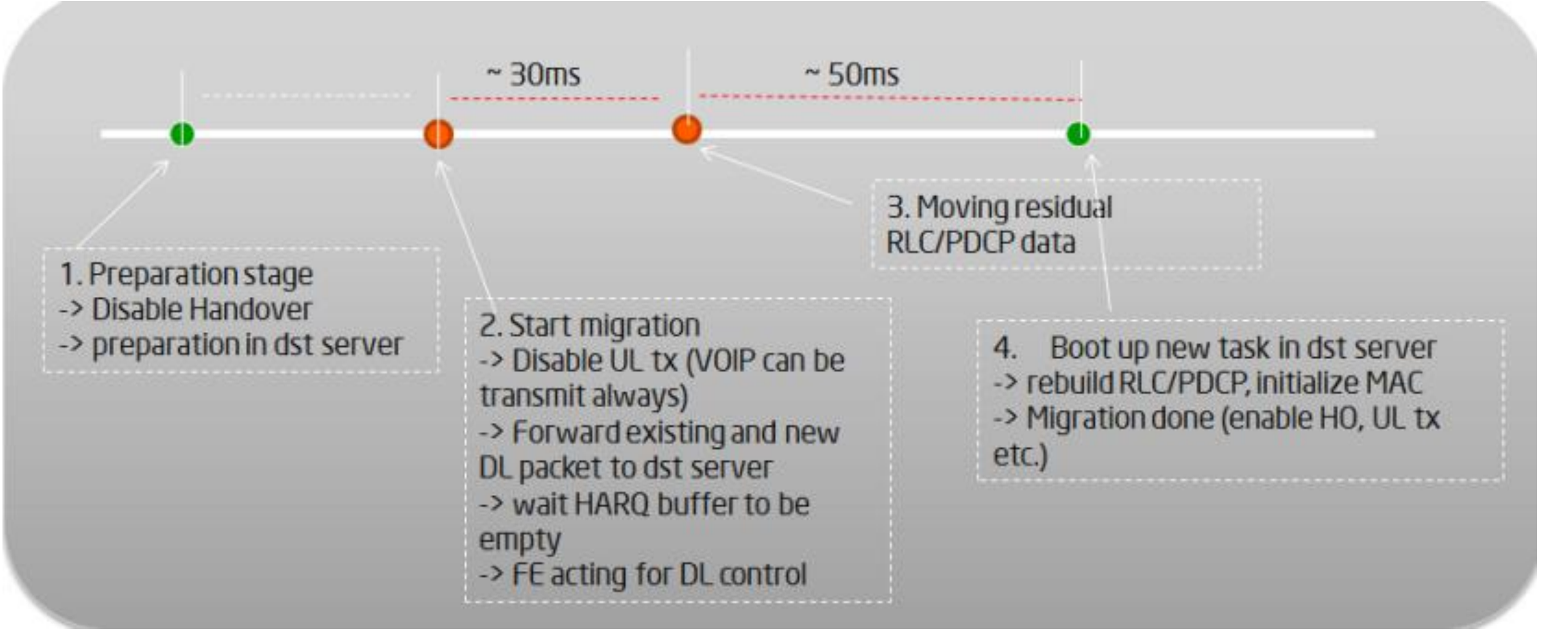
- Each processing core runs a full function thread, and is always trying to fetch task from the central task table when it's idle. When new task is done, processing core may put new tasks in the table according to the task.
- The priority indicator in the task table guarantee the real time process for urgent tasks, and poll-put mechanism make the processing pipeline correctly.



GPP-based DU pool design

Inter-DU live migration

- Step 1: Preparation
- Step 2: Migration
- Step 3: Restart



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- **C-RAN virtualization**

Goal: meet real-time constraint for radio signal processing.

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C-RAN Virtualization

Motivation for virtualization

- Resource optimization to balance the load and allocate the necessary resources based on the user/application and context requirements.
- Substantial efficiency gains.
  Network / resource, energy, and mobility on demand.
  Sharing, and "soft" (logical) isolation of simultaneous but different use of resources.
- Ubiquity across environments & dynamic network, technology, spectrum band, or cloud selection.
- Flexibility, scalability, and resilience.
  Dynamically adapt to needs, variety and variability.
- High speed of change (innovation).
- Dynamic service orchestration and granular control and management.

C-RAN Virtualization

Major challenges

- Meeting the real-time constraint for system performance.
- Virtualization granularity.
- Meeting the RT requirement for VM management, especially for live migration.
- I/O virtualization.
- Evaluation of different hypervisor alternatives.

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