Virtualization in Mobile Networks

Speaker: Xinbo Wang

UCDAVIS

Outline

- **LTE Architecture and Protocol Stack**
- **Virtualizing Individual Layers and Functions**
- **Backhaul and Fronthaul Alternatives**
- **Research Ideas**

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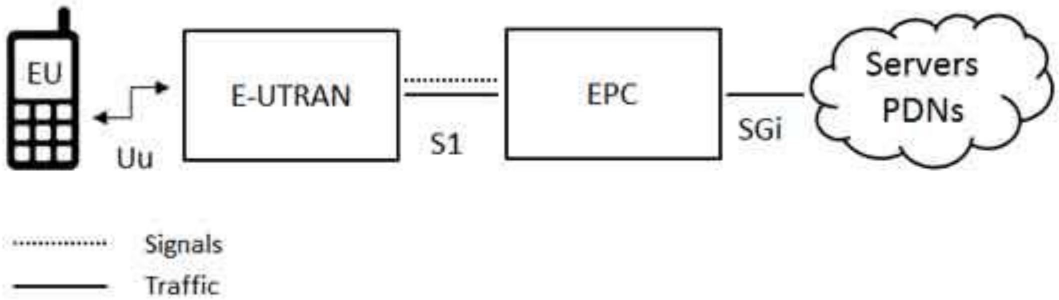
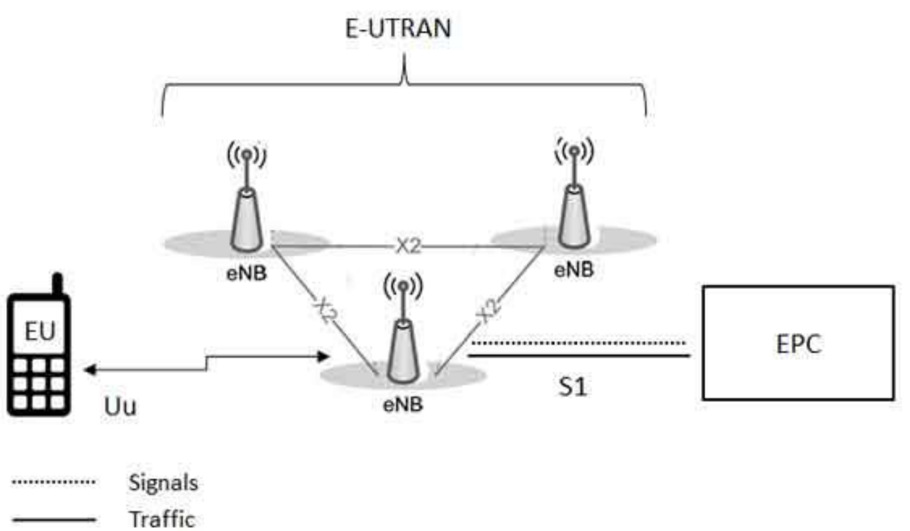
LTE Architecture





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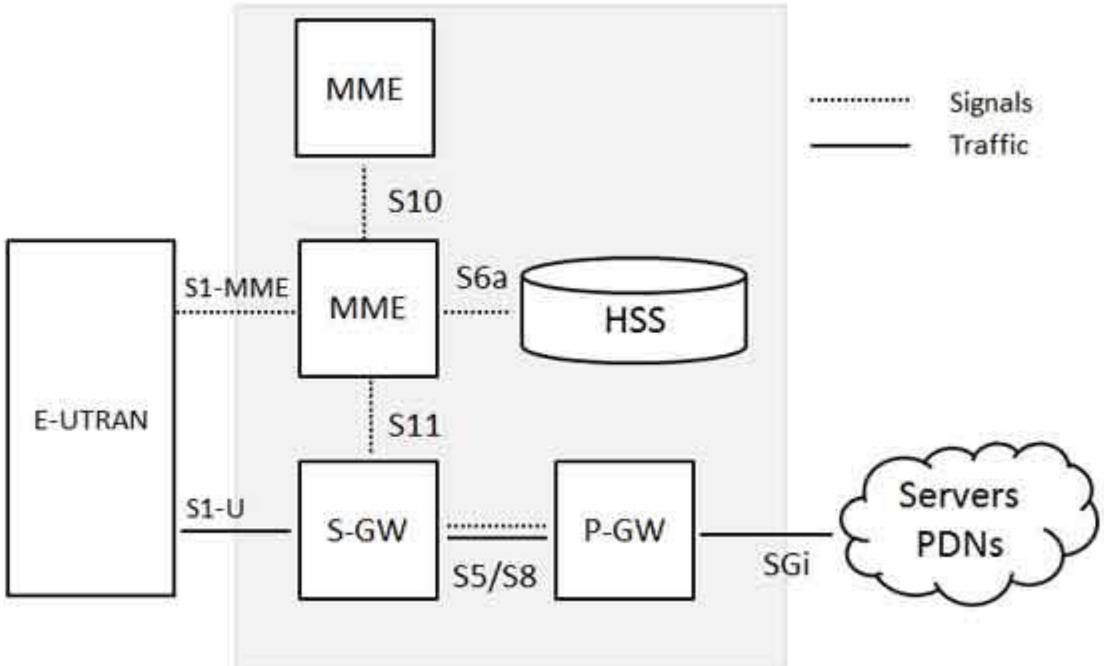
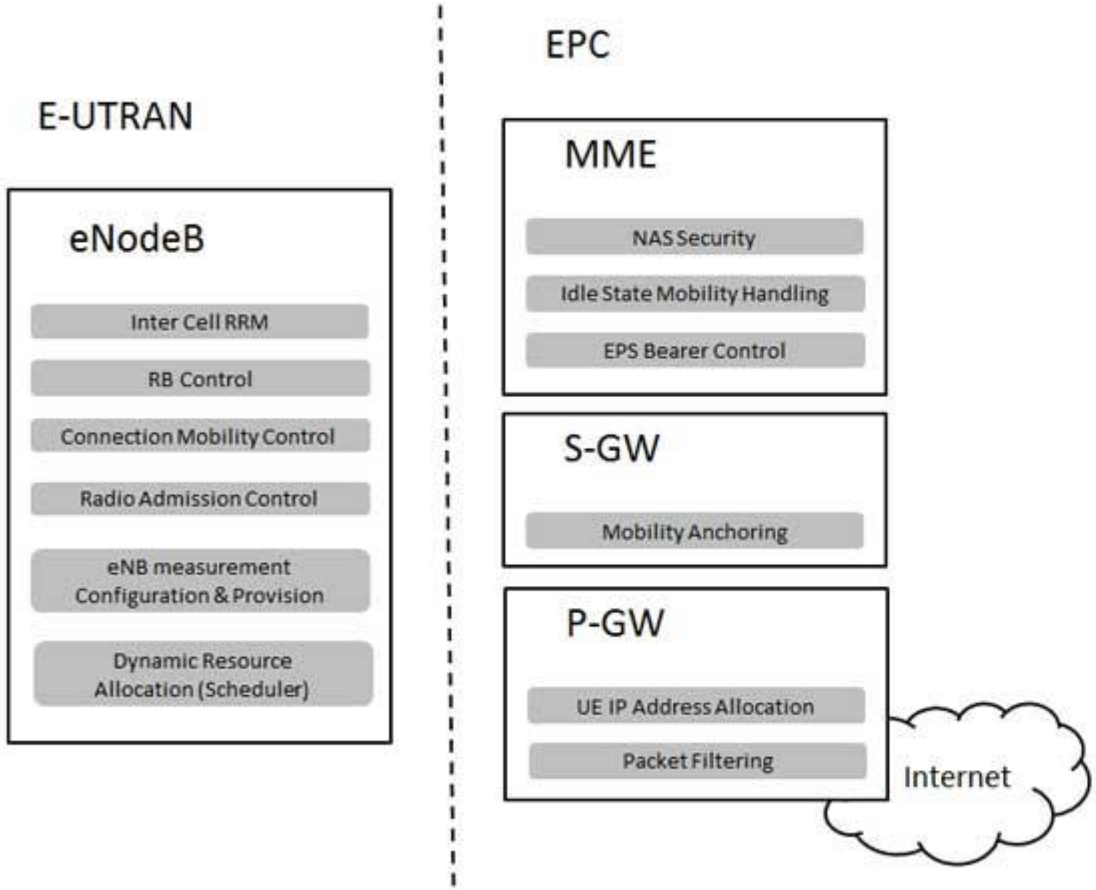
[1] LTE Tutorials, http://www.tutorialspoint.com/lte/index.htm

LTE Architecture



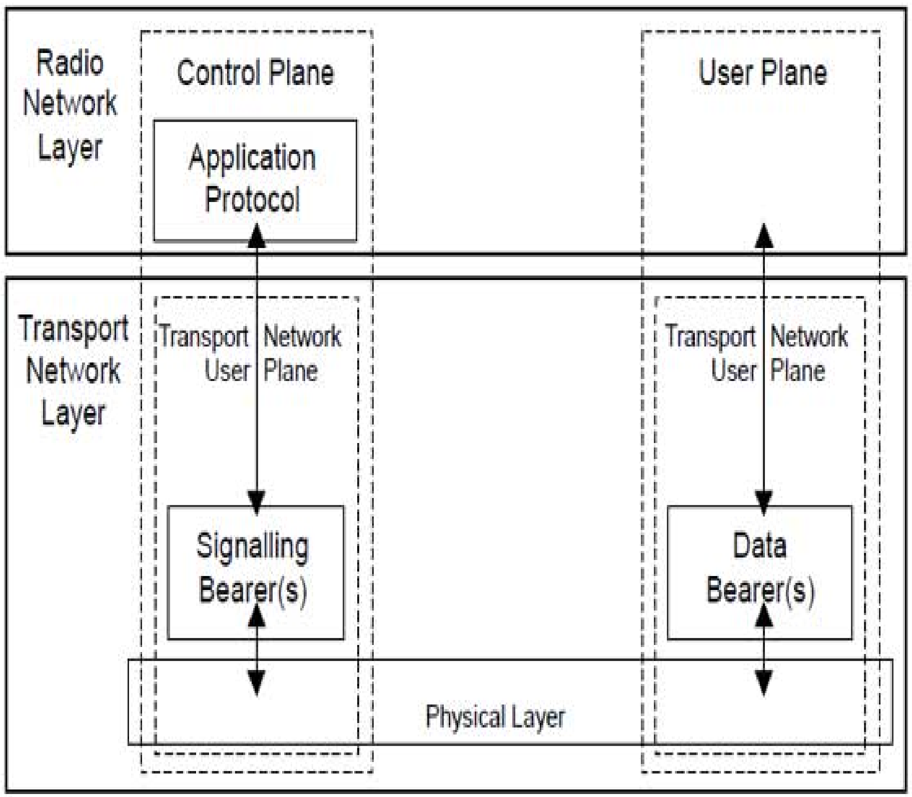
[1] LTE Tutorials, http://www.tutorialspoint.com/lte/index.htm

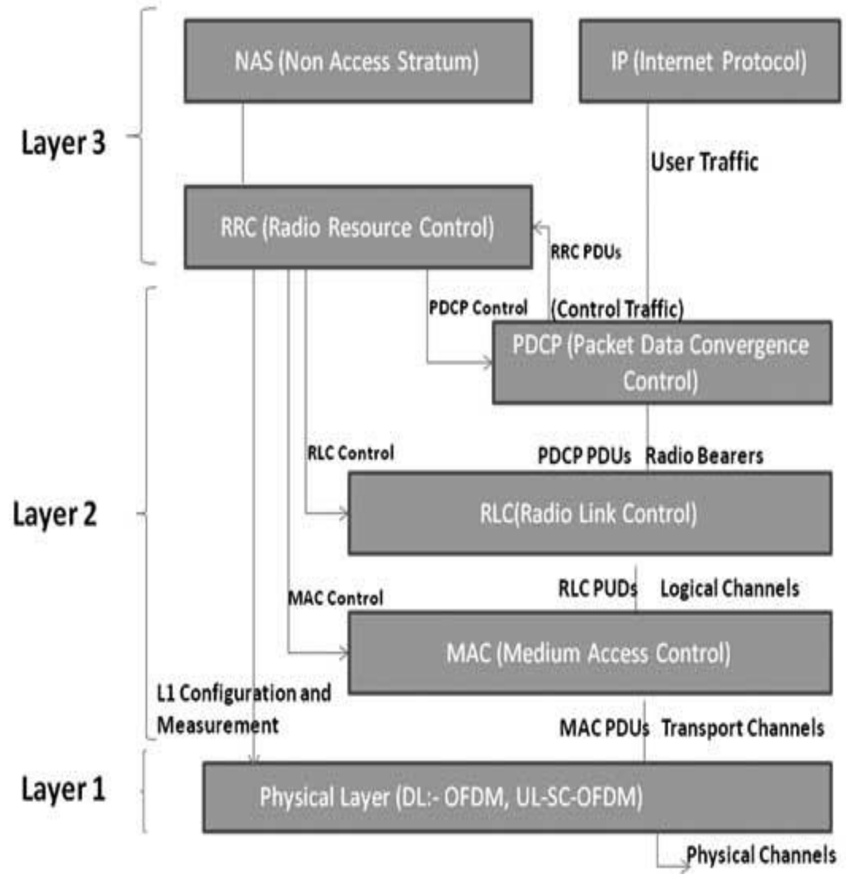
Functional split between the E-UTRAN and the EPC



[1] LTE Tutorials, http://www.tutorialspoint.com/lte/index.htm

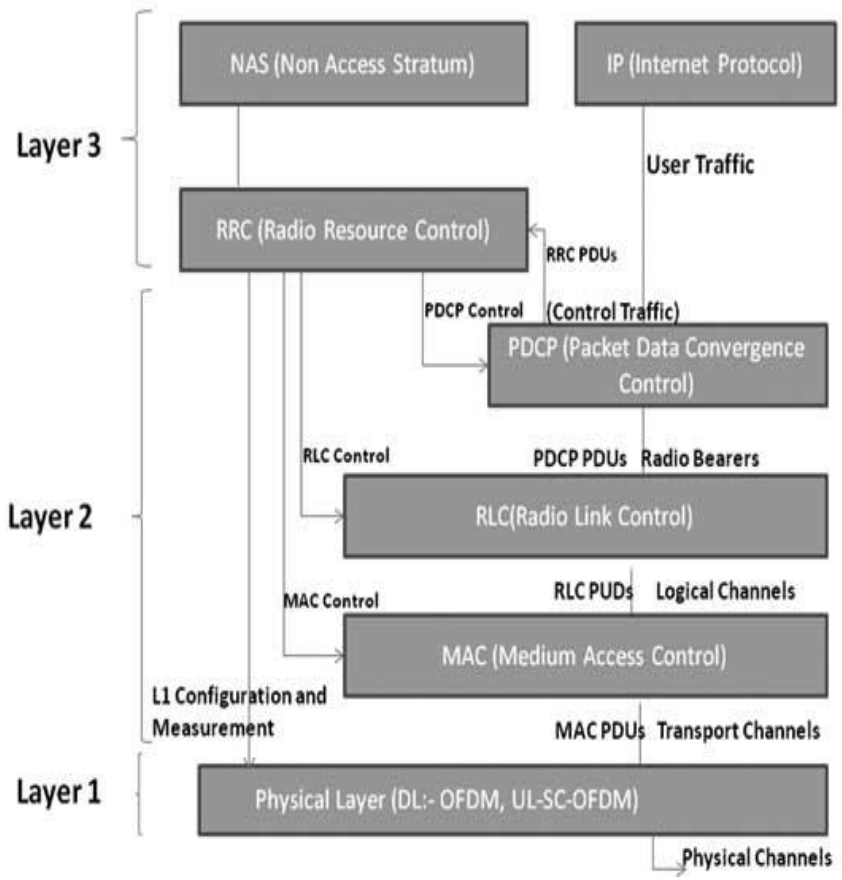
LTE Radio Protocol Stack





[1] LTE Tutorials, http://www.tutorialspoint.com/lte/index.htm

- Physical Layer
  - ✓ information from the MAC transport channels and the air interface.
  - ✓ link adaptation (AMC), power control, cell search
  - ✓ other measurements
- Medium Access Layer (MAC)
  - ✓ Mapping between logical channels and transport channels
  - ✓ Multiplexing of MAC SDUs from different logical channels onto transport blocks (TB) to be delivered to the physical layer on transport channels



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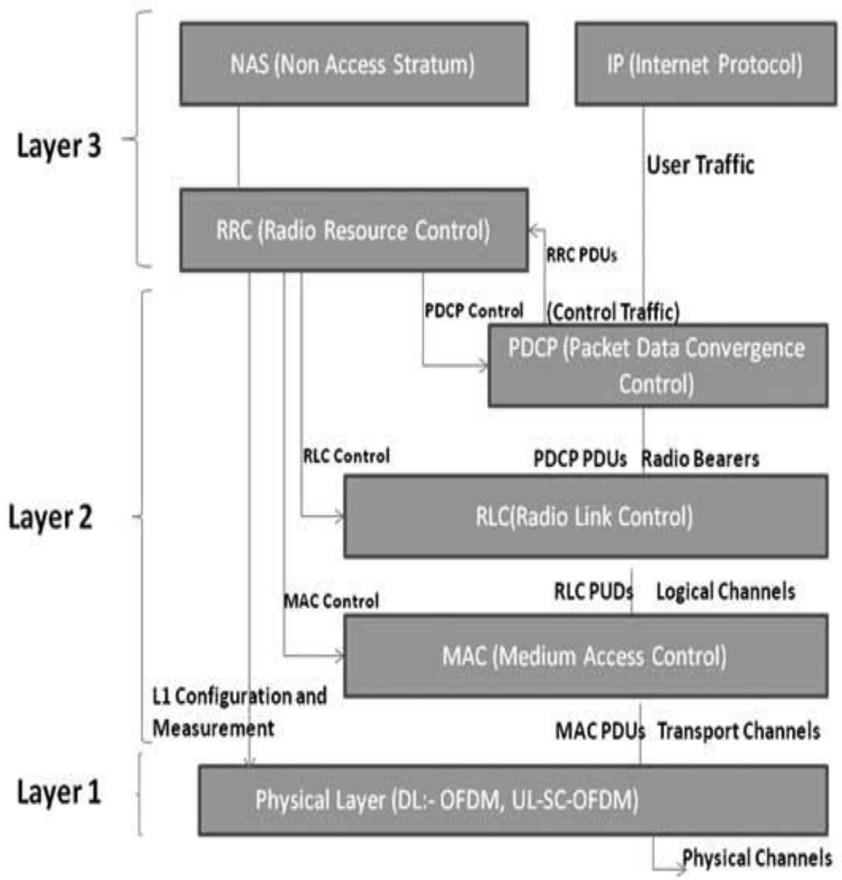
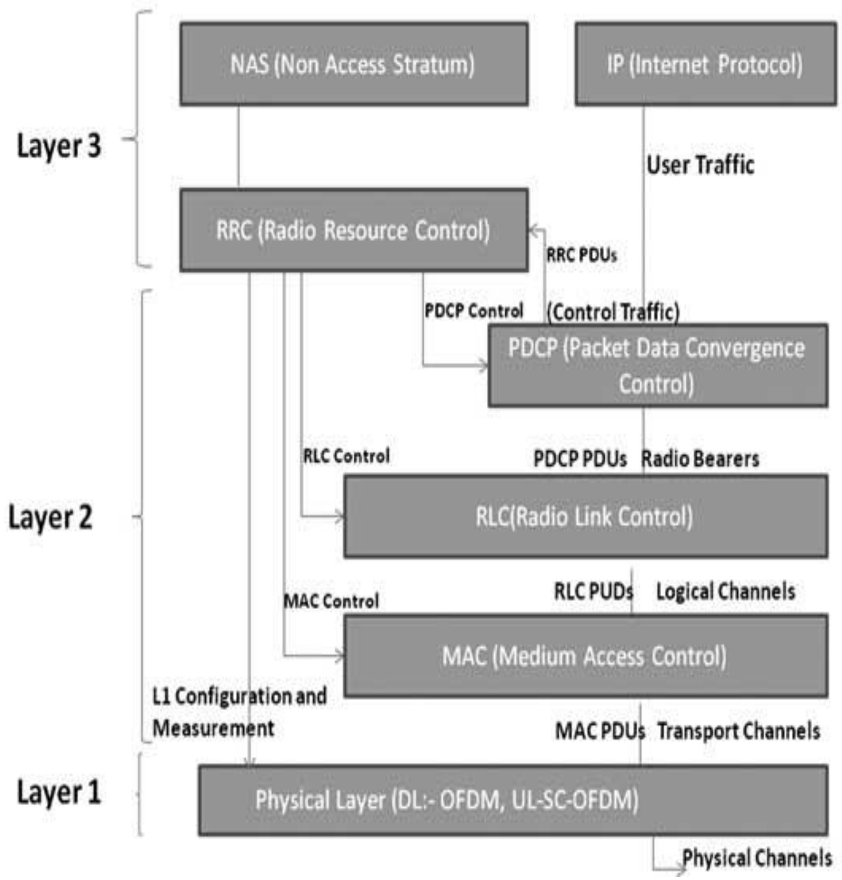
[1] LTE Tutorials, http://www.tutorialspoint.com/lte/index.htm

- Medium Access Layer (MAC)
  - ✓ De multiplexing of MAC SDUs from one or different logical channels from transport blocks (TB) delivered from the physical layer on transport channels
  - ✓ Scheduling information reporting
  - ✓ **Error correction through HARQ**
  - ✓ *Priority handling* between UEs by means of dynamic scheduling.
  - ✓ *Priority handling* between logical channels of one UE, Logical Channel prioritization.
- Radio Link Control (RLC)
  - ✓ transfer of upper layer PDUs, error correction through ARQ Concatenation, segmentation and reassembly of RLC SDUs



[1] LTE Tutorials, http://www.tutorialspoint.com/lte/index.htm

- Radio Resource Control (RRC)
  - ✓ broadcast of System Information
- Packet Data Convergence Control (PDCP)
  - ✓ Header compression and decompression of IP data,
  - ✓ Transfer of data (user plane or control plane)
  - ✓ Maintenance of PDCP Sequence Numbers (SNs)
  - ✓ Ciphering and deciphering of user plane data and control plane data
  - ✓ Integrity protection and integrity verification of control plane data
  - ✓ Timer based discard, duplicate discarding,



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[1] LTE Tutorials, http://www.tutorialspoint.com/lte/index.htm

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Virtualization

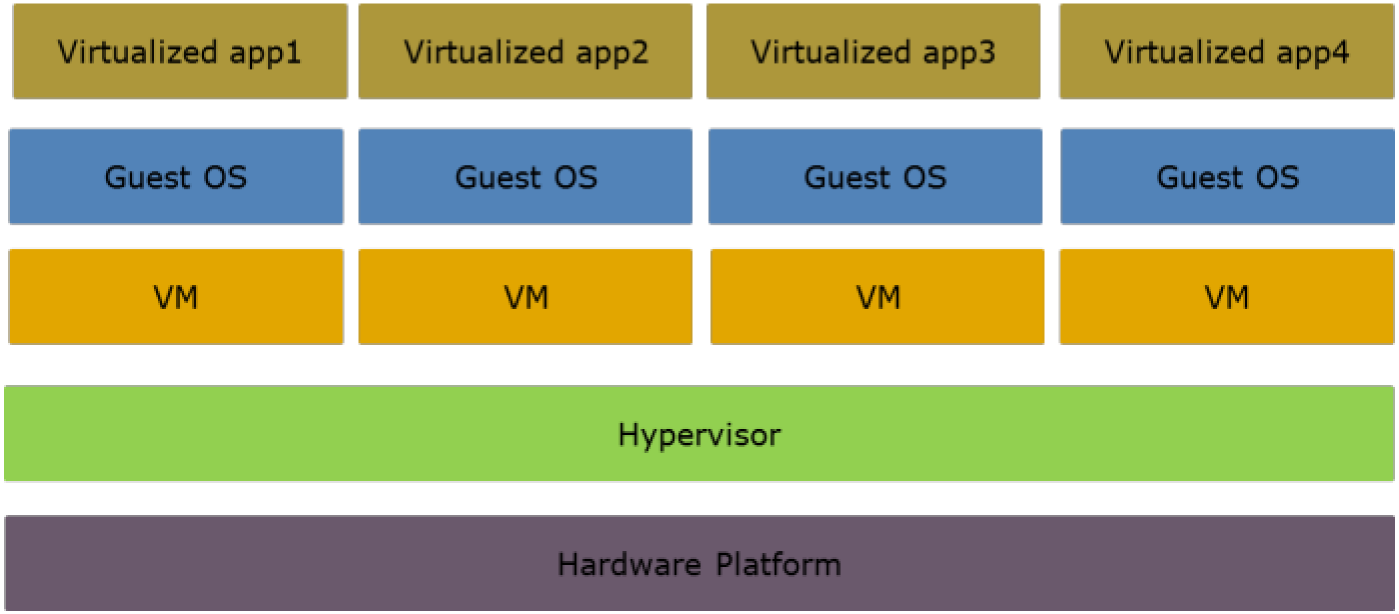


Figure 1-2 Virtualized environment

[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

CRAN Architecture

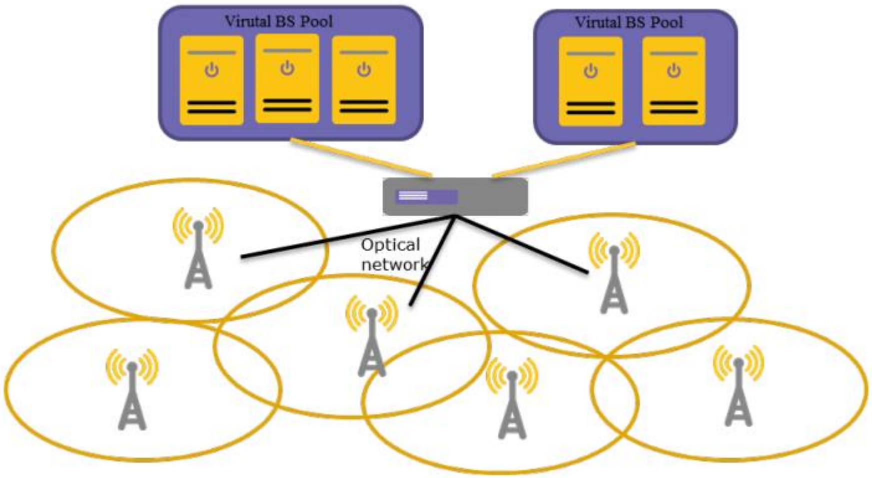


Figure 1-1 Cloud RAN Architecture

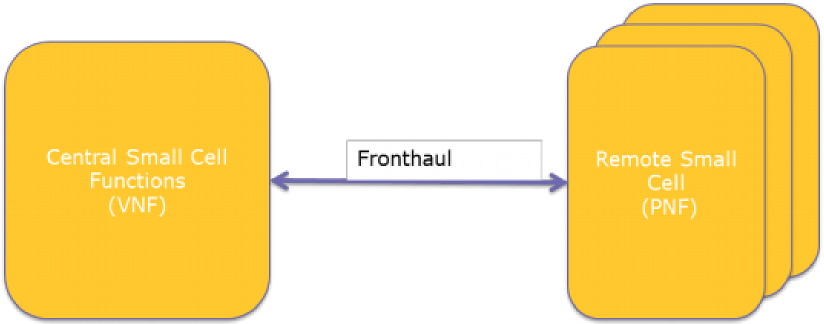


Figure 2-1 Virtualized small cell architecture

[2] Small Cell Forum, "Small cell virtualization: Functional splits and use cases", Release 6.0, 159.06.02, January 2016.

Split Architectures for different use cases

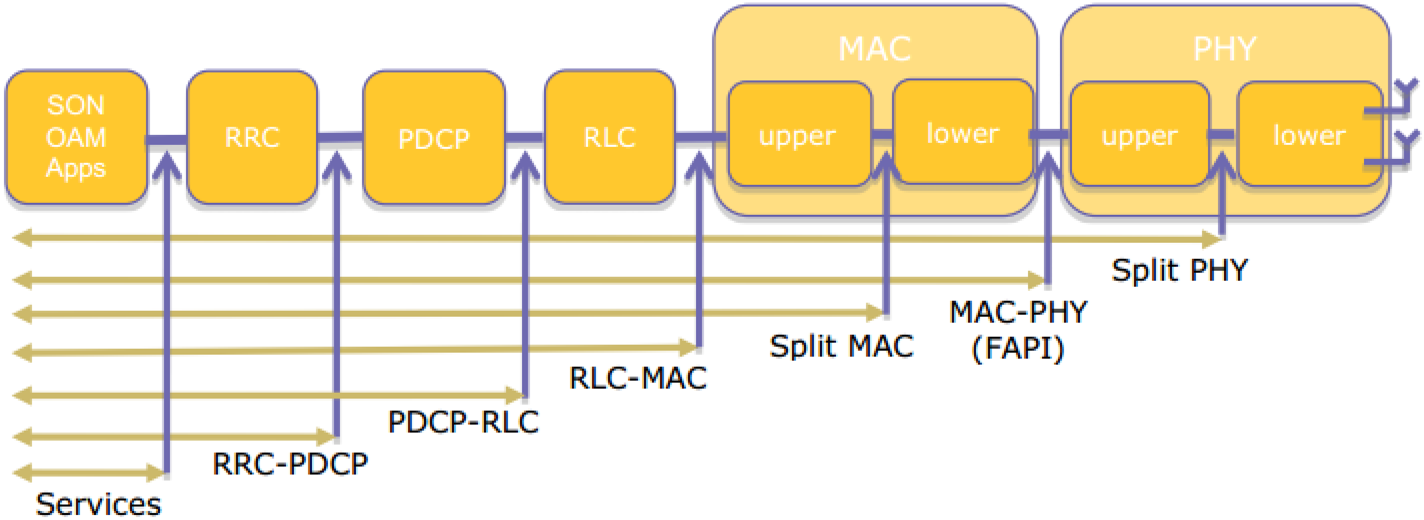


Figure 2-2 Use case architectures

[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

Split services

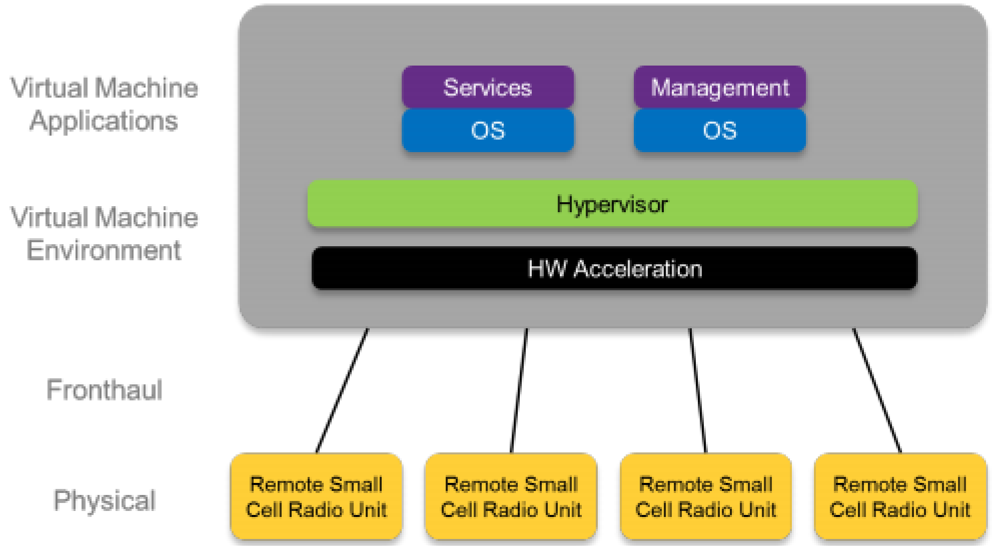


Figure 2-4 Virtualized small cell function for services use case

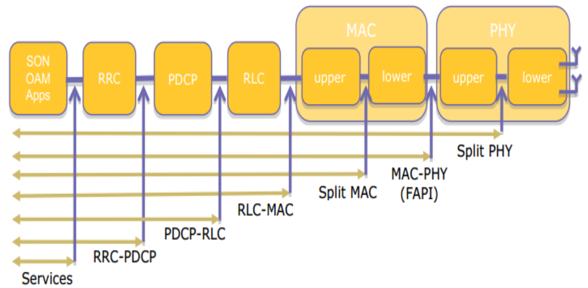
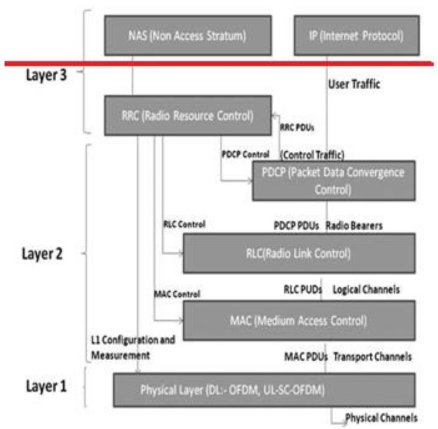


Figure 2-2 Use case architectures



Hardware requirement:

- Backhaul crypto acceleration
- True random number generators
- Integrated network interfaces

Benefits:

- Content cache (> L3)
- Wireless platform service (NTP, SON)

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[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

Split between RRC and PDCP

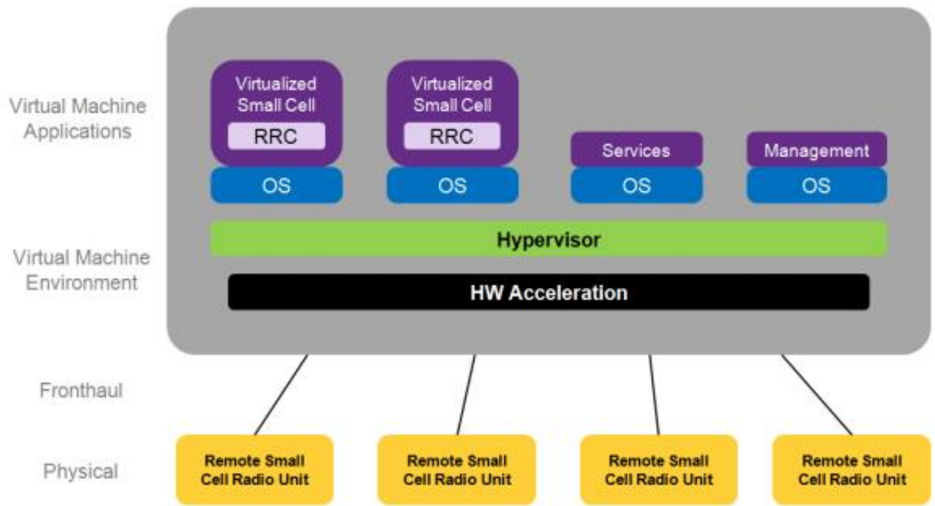


Figure 2-6 Virtualized small cell function for RRC-PDCP split

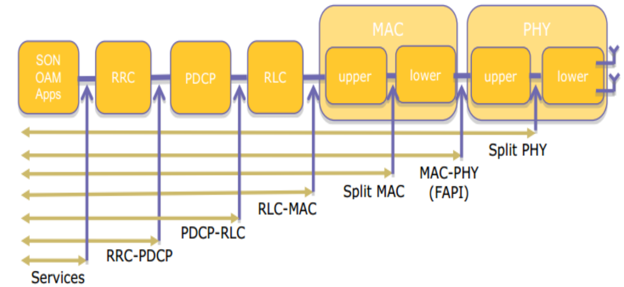
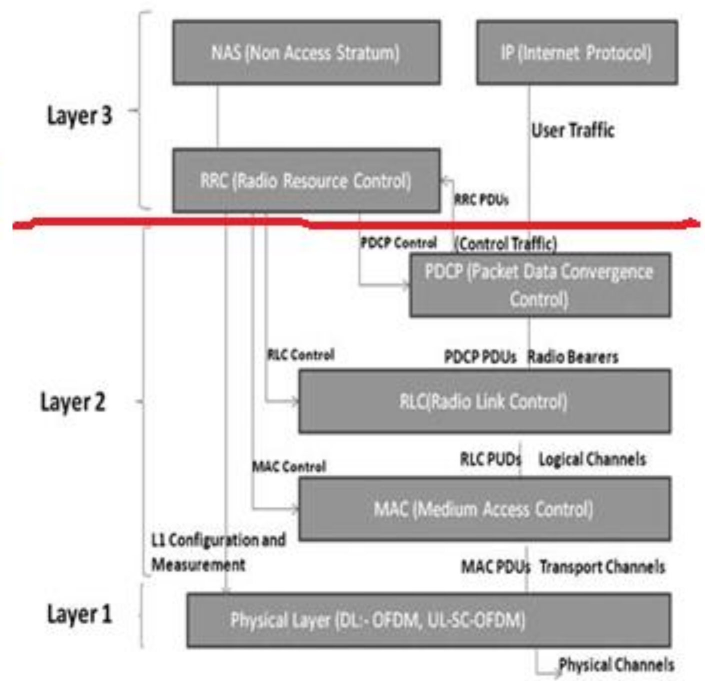


Figure 2-2 Use case architectures



Hardware requirement (same):

- Backhaul crypto acceleration
- True random number generators
- Integrated network interfaces

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[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

Split between PDCP and RLC

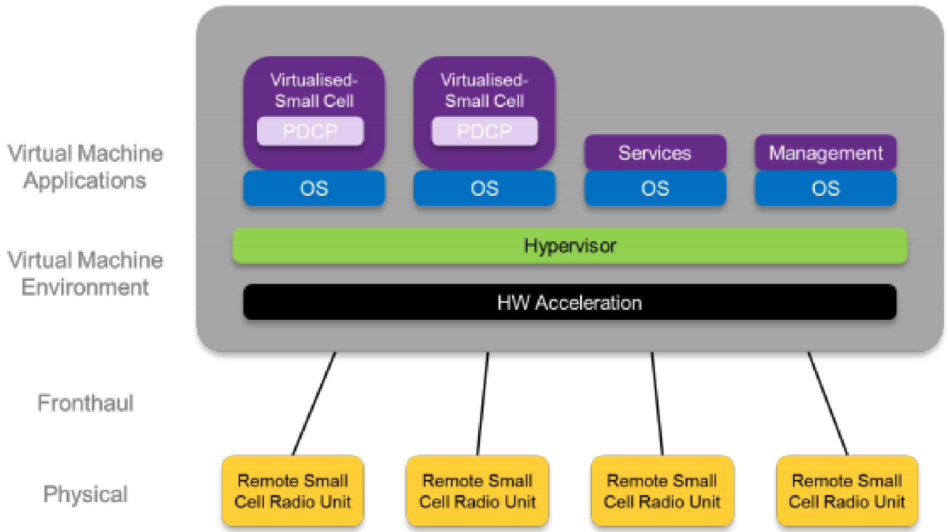


Figure 2-8 Virtualized small cell function for PDCP-RLC use case

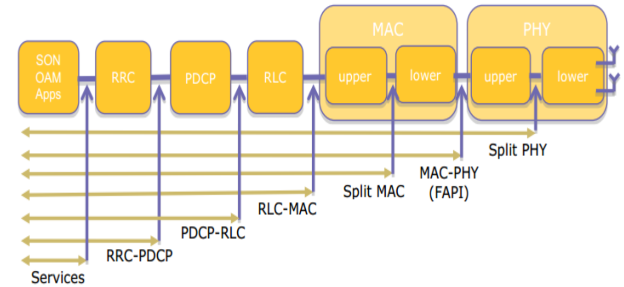
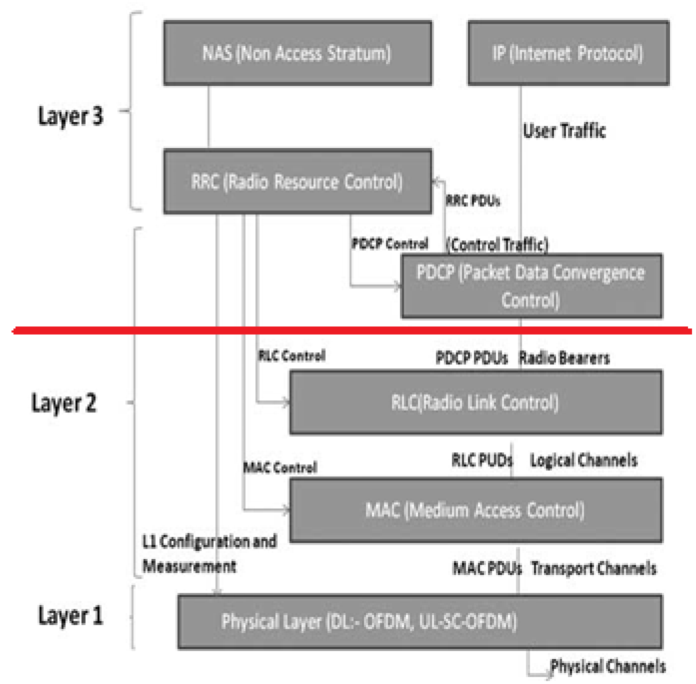


Figure 2-2 Use case architectures



Additional Hardware requirement:

- Air interface crypto acceleration

[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

Split between RLC and MAC

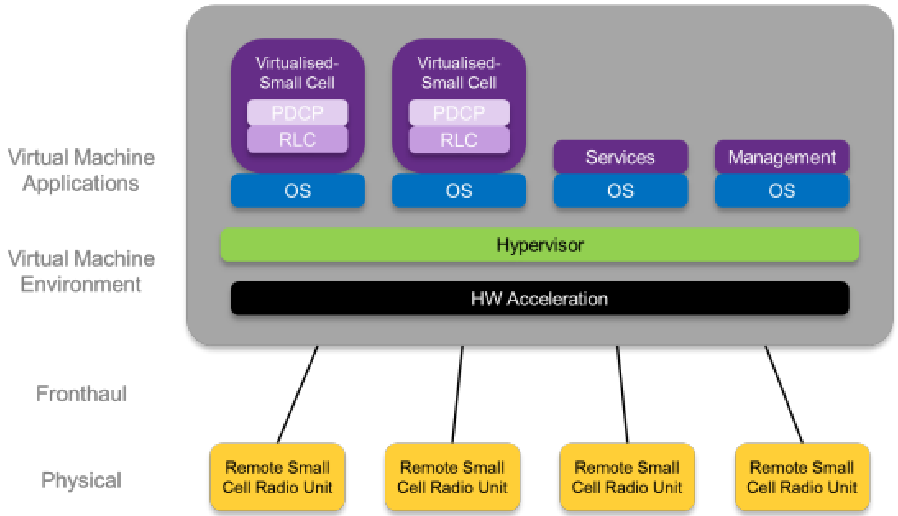


Figure 2-10 Virtualized small cell function for RLC-MAC use case

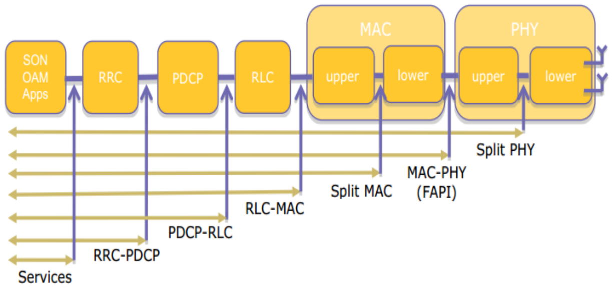
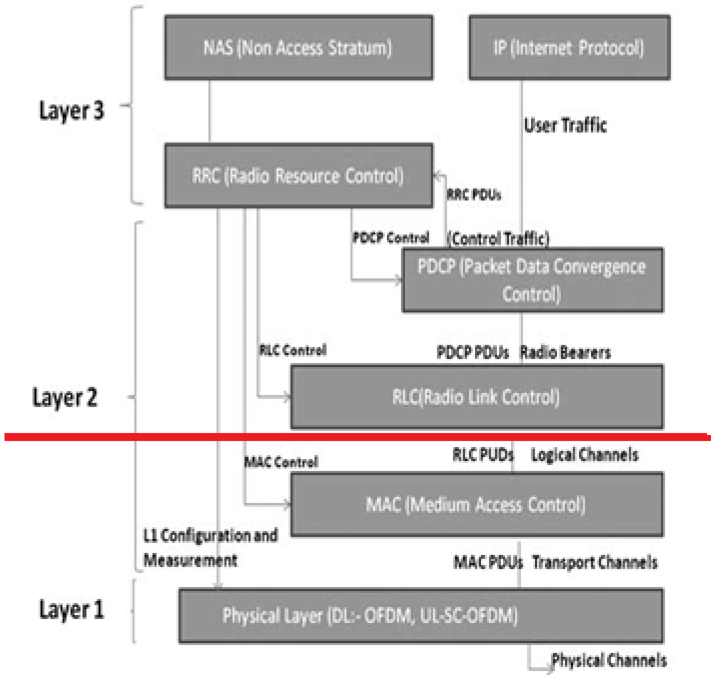


Figure 2-2 Use case architectures



Additional Hardware requirement:

- Packetization accelerators to support the segmentation and concatenation
- Scatter gather DMAs

[2] Small Cell Forum, "Small cell virtualization: Functional splits and use cases", Release 6.0, 159.06.02, January 2016.

Split MAC

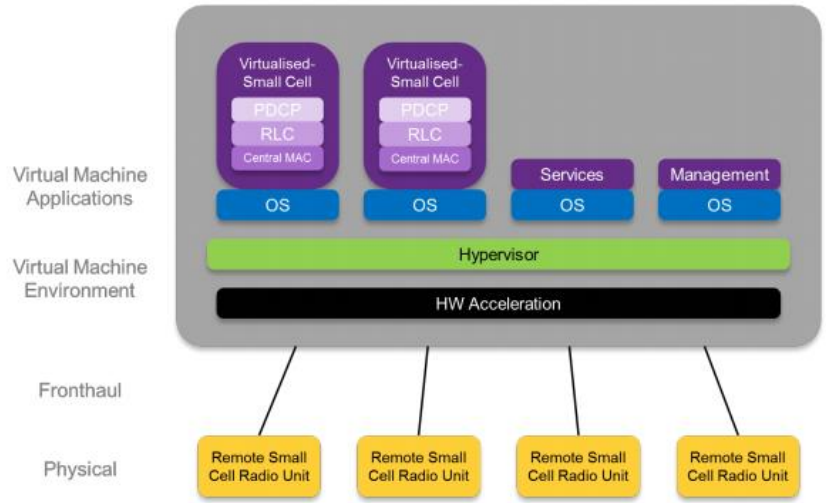


Figure 2-12 **Virtualized small cell function for split MAC use case**

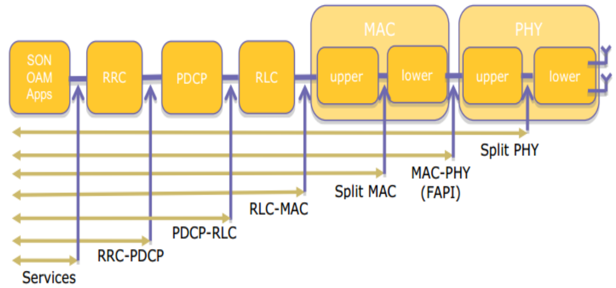
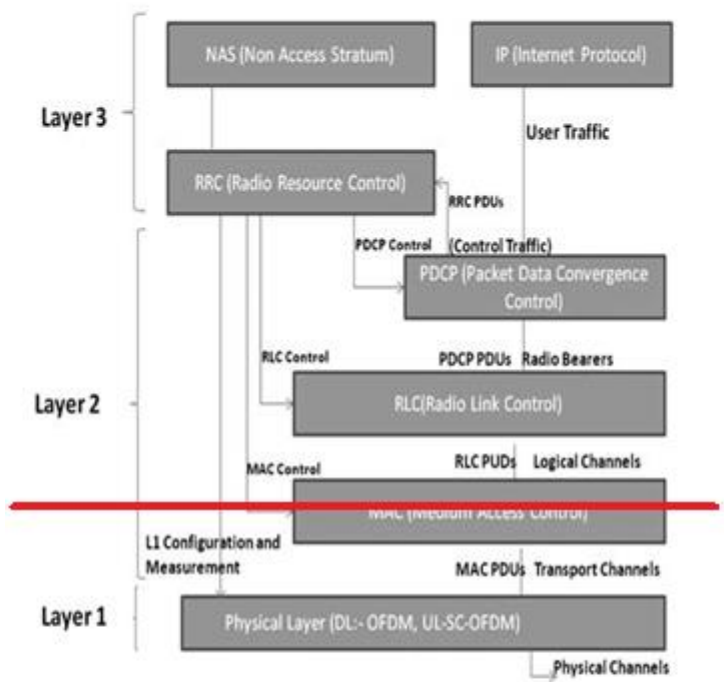


Figure 2-2 **Use case architectures**



Hardware requirement (same):

- Packetization accelerators to support the segmentation and concatenation
- Scatter gather DMAs

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[2] Small Cell Forum, "Small cell virtualization: Functional splits and use cases", Release 6.0, 159.06.02, January 2016.

Split between MAC and PHY

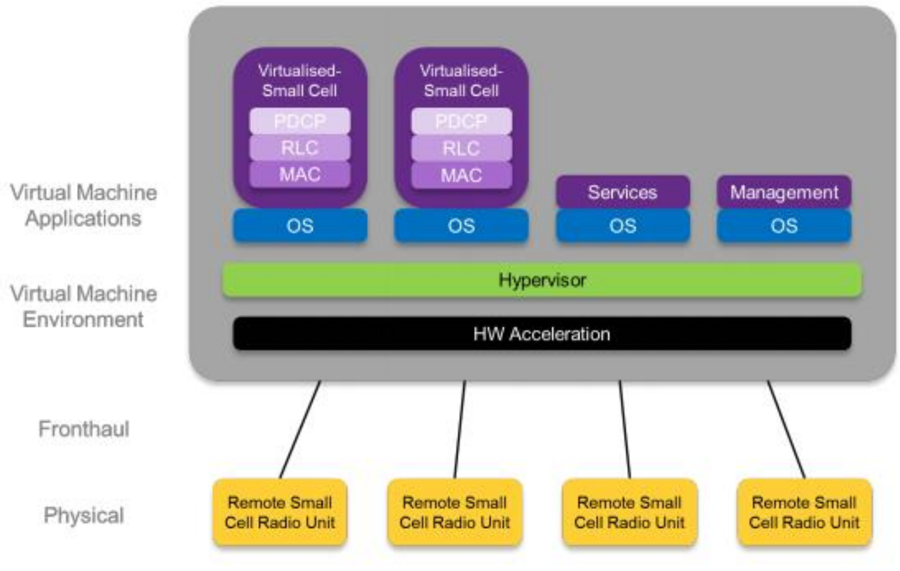


Figure 2-17 Virtualized small cell function for MAC-PHY use case

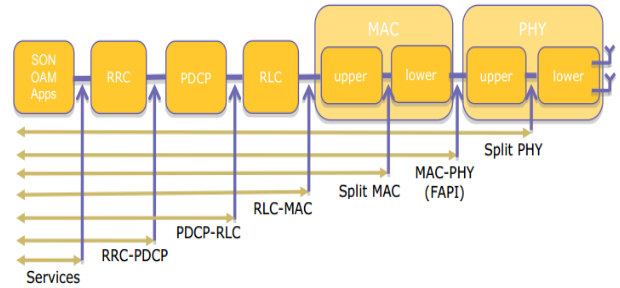
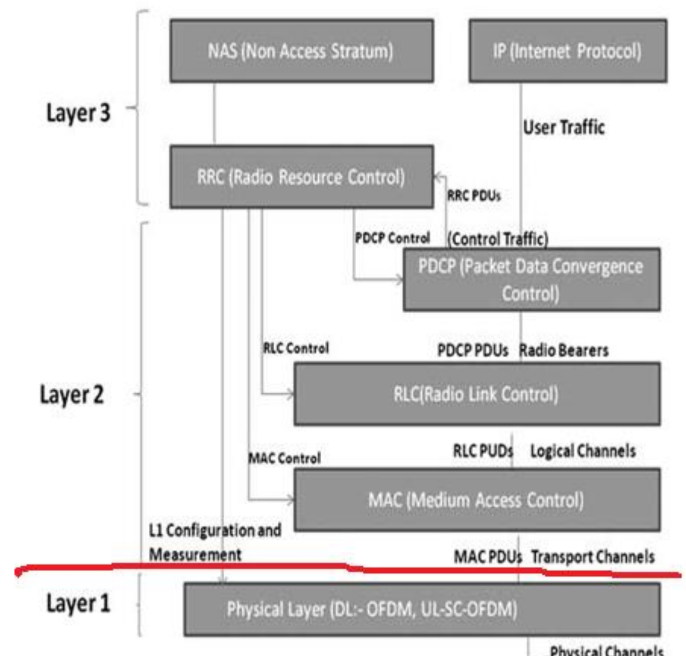


Figure 2-2 Use case architectures

Hardware requirement (same):

- Packetization accelerators to support the segmentation and concatenation
- Scatter gather DMAs



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[2] Small Cell Forum, "Small cell virtualization: Functional splits and use cases", Release 6.0, 159.06.02, January 2016.

Split PHY

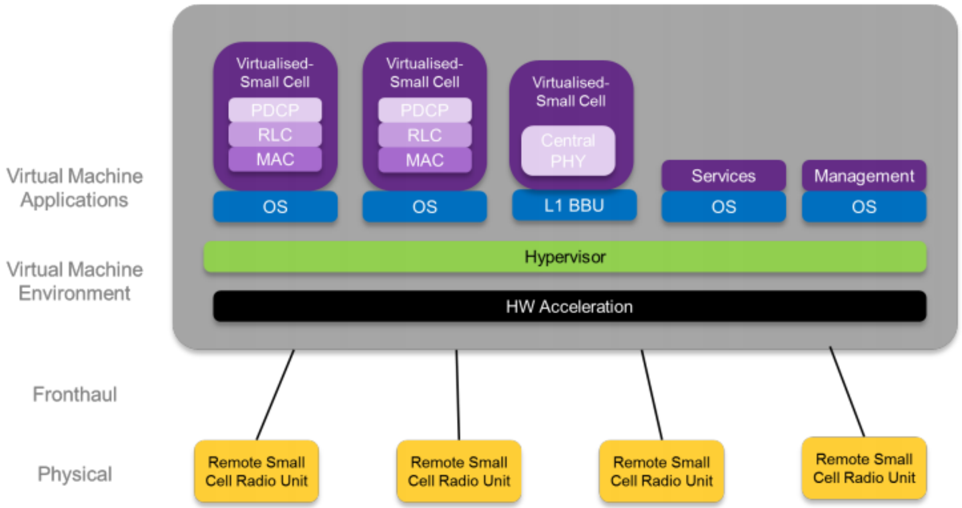


Figure 2-21 Virtualized small cell function for split PHY use case

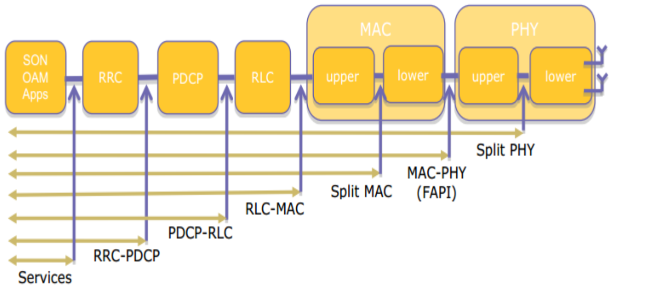
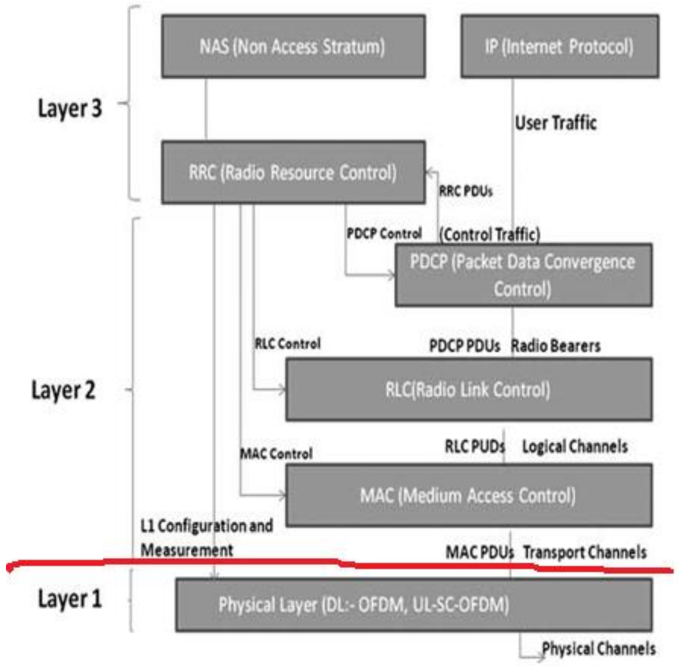


Figure 2-2 Use case architectures

Additional Hardware requirement:

- DSPs, FPGAs
- L1 hardware accelerators



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[2] Small Cell Forum, "Small cell virtualization: Functional splits and use cases", Release 6.0, 159.06.02, January 2016.

Different options for Split PHY

For the Interface I (and above):

- limits the support of some LTE advanced features (e.g. CoMP) and CRAN features
- drawbacks including L1 processing functions in RU
    - limit scalability for future features
    - Multi-vendor interoperability is more complex
    - There are interoperability issues with legacy systems

Interface II and III

- best potential in terms of DL throughput reduction, while fulfilling CRAN requirements
- this split allows all kinds of CoMP schemes

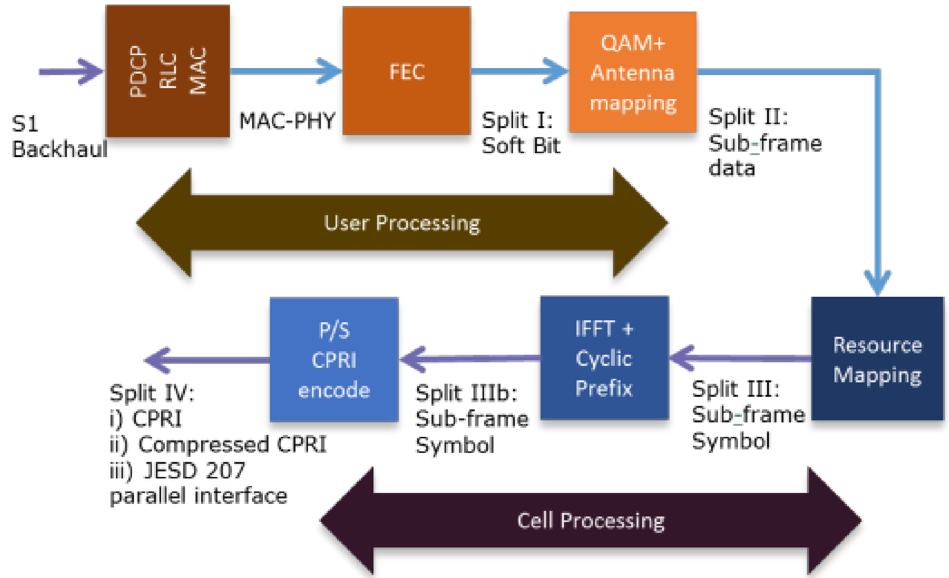

Figure 2-24 Possible L1 split locations

For the Interface I (and above):

- as for interface II, there is an opportunity of statistical MUX gains at the fronthaul interface

For the interface IV (CPRI):

- Very high data rate on DL and UL needed for the fronthauling interface

[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

Summary of function split

Use Case	One-way latency	DL bandwidth	UL bandwidth
RRC-PDCP	Non Ideal – 30ms[1]	151Mbps[2]	48Mbps[2]
PDCP-RLC	Non Ideal – 30ms[1]	151Mbps	48Mbps
RLC-MAC	Sub Ideal – 6ms	151Mbps	48Mbps
Split MAC	Sub Ideal – 6ms	151Mbps	49Mbps
MAC-PHY	Ideal – 250μs Near ideal – 2ms[3]	152Mbps	49Mbps
PHY split I	Ideal – 250μs Near ideal – 2ms[3]	173Mbps	452Mbps
PHY split II	Ideal – 250μs Near ideal – 2ms[3]	933Mbps	903Mbps
PHY split III	Ideal – 250μs Near ideal – 2ms[3]	1075Mbps	922Mbps
PHY split IIIb	Ideal – 250μs Near ideal – 2ms[3]	1966Mbps	1966Mbps
PHY split IV	Ideal – 250μs	2457.6Mbps	2457.6Mbps

1 Although centralized RRC could be made to run over a non-ideal (30ms) backhaul, certain key performance indicators may be degraded due to the extra delay in handling of RRC procedures.
2 Bandwidth when user plane data is routed via VNF. If user plane data has distributed routing the bandwidth is control only and <10Mbps
3 With 2ms latency the achievable throughput for a single UE will be halved

[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

Summary of function split

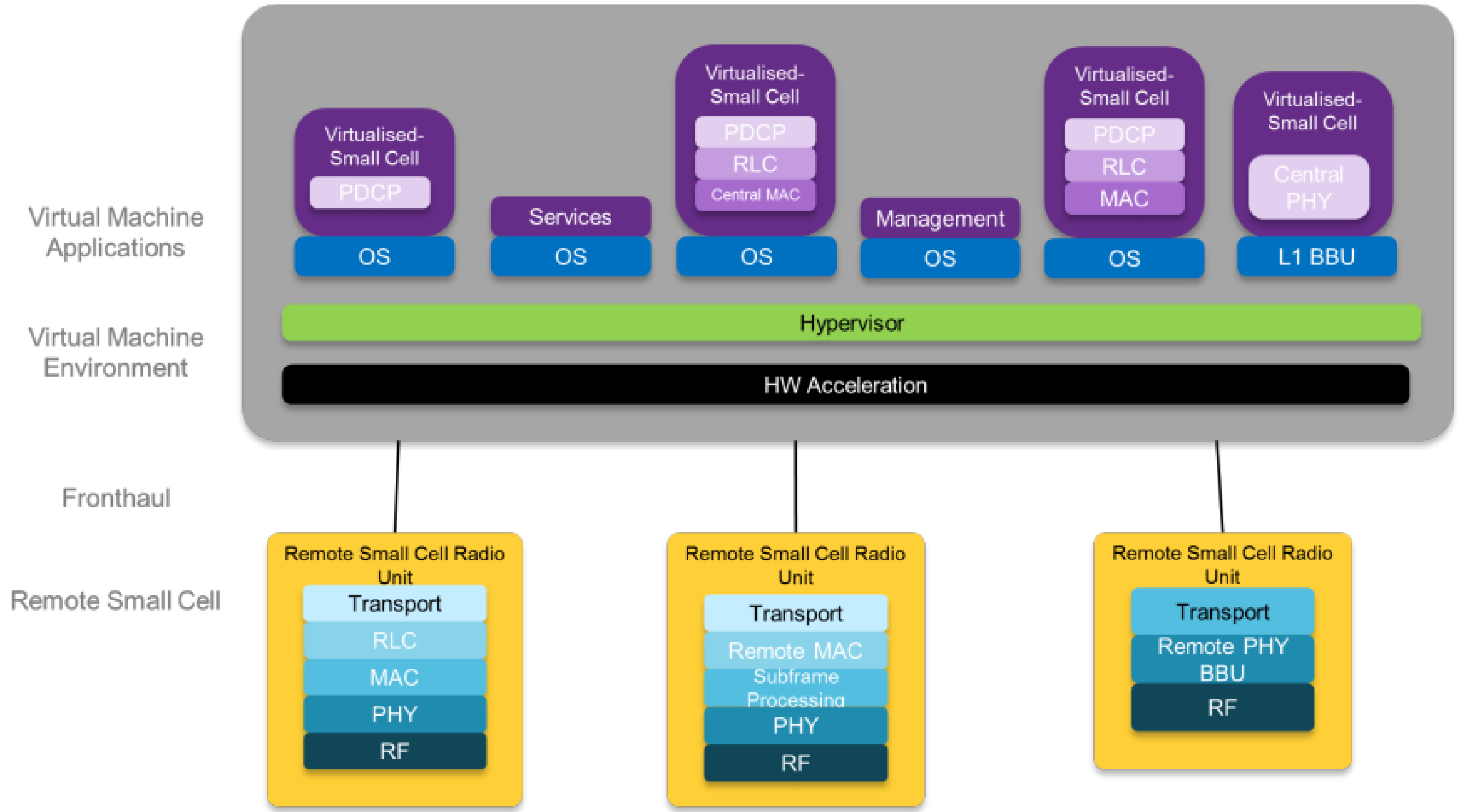

Figure 4-1 **Virtualized small cell network supporting multiple use cases**

[2] Small Cell Forum, “Small cell virtualization: Functional splits and use cases”, Release 6.0, 159.06.02, January 2016.

Technique supported by each split case

Use case	Carrier aggre-gation	Cross carrier scheduling	High order MIMO	DL CoMP			UL CoMP		
				JT	DPS	CS/CB	JR opt1	JR opt2	CS/CB
PDCP-RLC	o note 1	o note 1	o note 2			•			•
Split MAC	•	•	o note 2	o note 3	•	•	o note 3		•
MAC-PHY	•	•	o note 2	•	•	•	•		•
PHY split III	•	•	•	•	•	•	•	•	•

Table 5-1 Mapping of enhancement techniques to virtualization use cases splits

The bullets (•) denote that the technique may be implemented with that virtualization use case split between multiple remote small cells.
The bullets (o) denote that while the technique may be implemented directly in the Remote small cell, it is unaffected by the virtualization split for these use cases.
Note 1: Possible if the remote small cell contains all the carriers
Note 2: Possible if the remote small cell contains all the antenna ports
Note 3: Defining methods which may permit this CoMP mode to be supported and understanding the impact on CoMP performance is out of the scope of this document

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[3] Small Cell Forum, “Coverage and capacity impacts of virtualization”, Release 6.0, 160.06.01, June 2016.

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Different Fronthaul Technologies

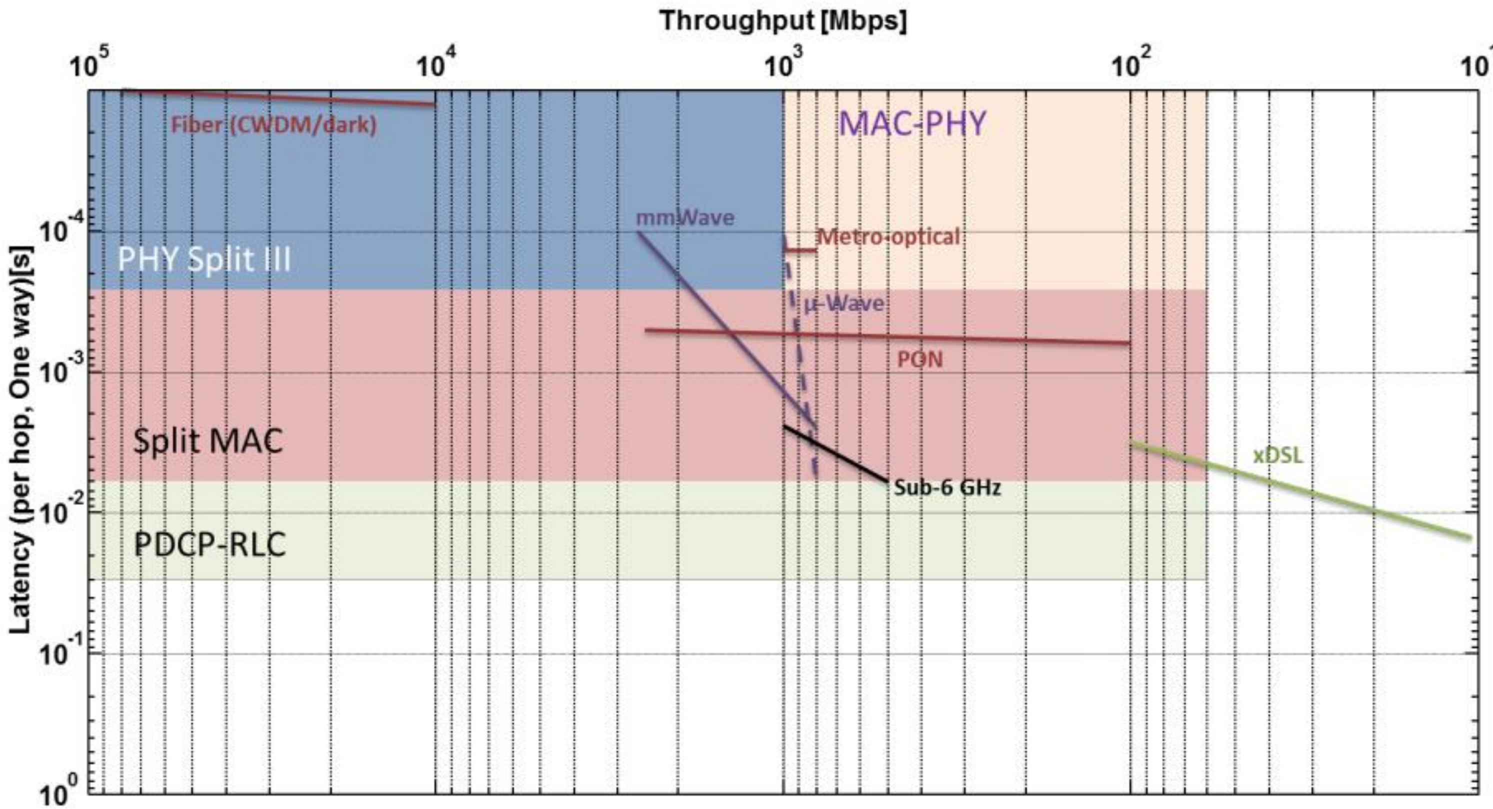

Figure 3-3 **Latency (one way) and throughput requirements for DL for RAN function splits vs. available fronthaul technologies**

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[4] Final Definition of iJOIN Requirements and Scenarios', iJOIN, Deliverable D5.2, November 2014

Different Fronthaul Technologies

BH technology		Latency (per hop, RTT)	Throughput	Topology
Millimeter wave	60GHz Unlicensed	≤5 ms	≤800 Mbit/s	PtP (LOS)
		≤200 µsec	≤1Gbps	PtP (LOS)
	70-80GHz Light licensed	≤200 µsec	≤2.5 Gbit/s	PtP (LOS)
Microwave (28-42 GHz) Licensed		≤200 µsec	≤1Gbps	PtP (LOS)
		≤10 ms	≤1Gbps	PtmP (LOS)
Sub-6 GHz Unlicensed or licensed		≤5 ms	≤500Mbps	PtP (NLoS)
		≤10 ms	≤500Mbps (shared)	PtmP (NLoS)
		≤5 ms	≤1 Gbit/s (per client)	PtmP (NLoS)
Dark Fibre		5 µs/km × 2	≤10 Gbps	PtP
CWDM		5 µs/km × 2	≤10·N Gbps (with N≤8)	Ring
Metro Optical Network		250 µs	≤1 Gbps	Mesh/Ring
PON (Passive Optical Networks)		≤1 ms	100M – 2.5Gbps	PtmP
xDSL		5-35 ms	10M – 100Mbps	PtP

Table 3-2 Fronthaul technologies classifications

[5] 'Network-layer algorithms and network operation and management: candidate technologies specification', iJOIN, Deliverable D4.2, November 2014

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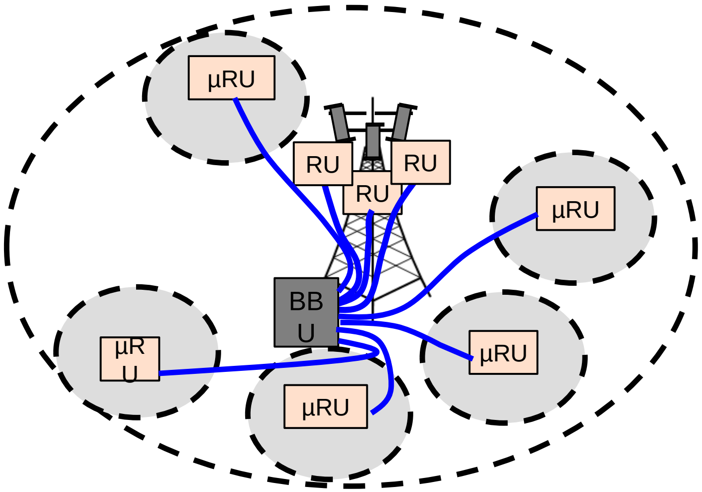
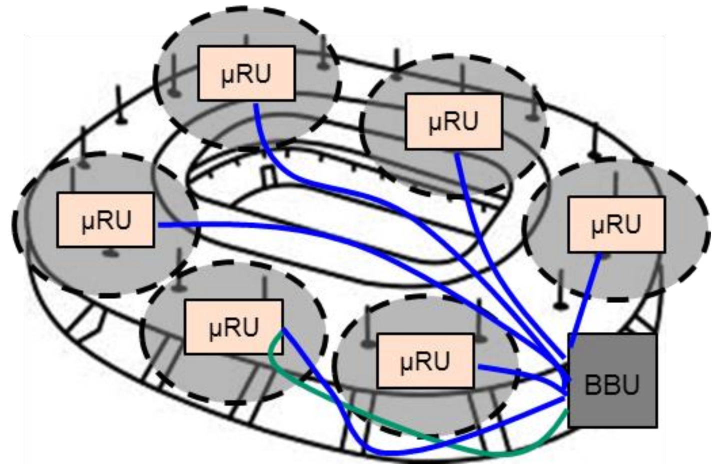
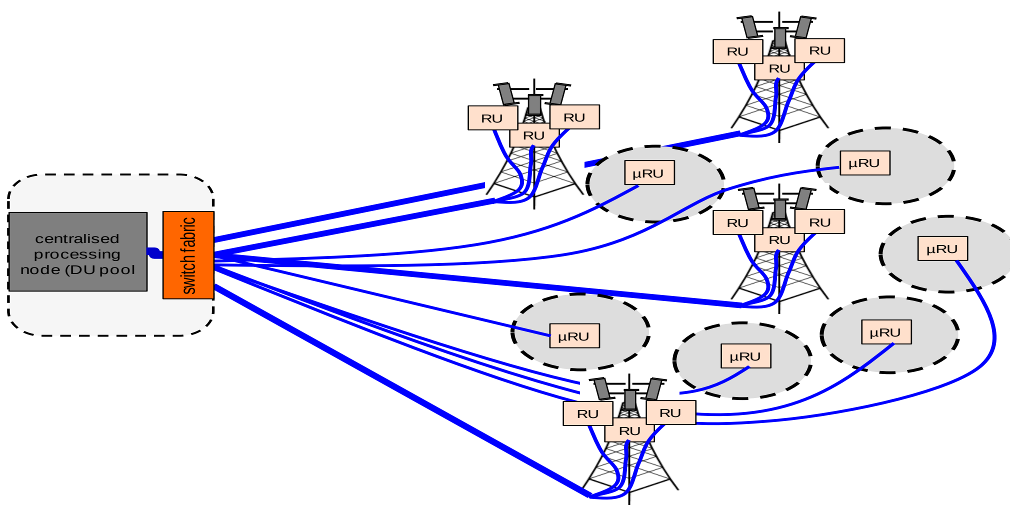
Centralize vs. Distribute (functions)

Items	Centralization	Distribution
Fronthaul Bandwidth		☺
Latency		☺
CoMP	☺	
Peak throughput (per UE)	☺	
Cell average throughput		
Economies of scale	☺	
Hardware upgrade	☺	
Efficiency in power consumption	☺	

Different levels of centralization







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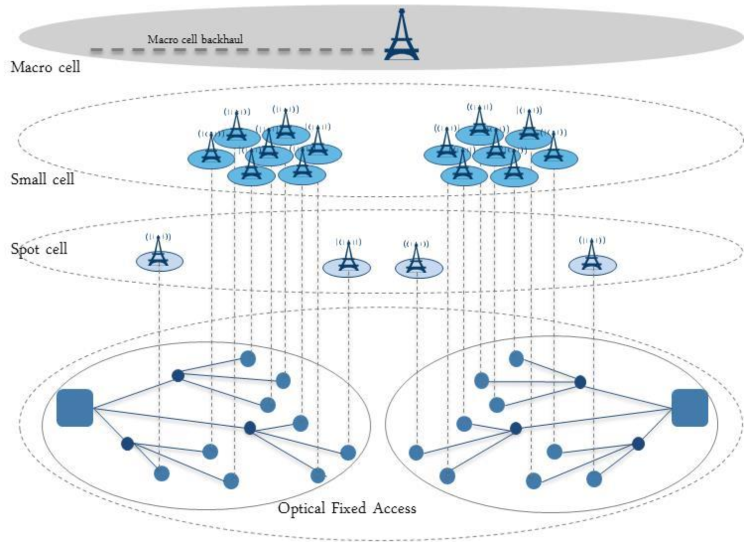
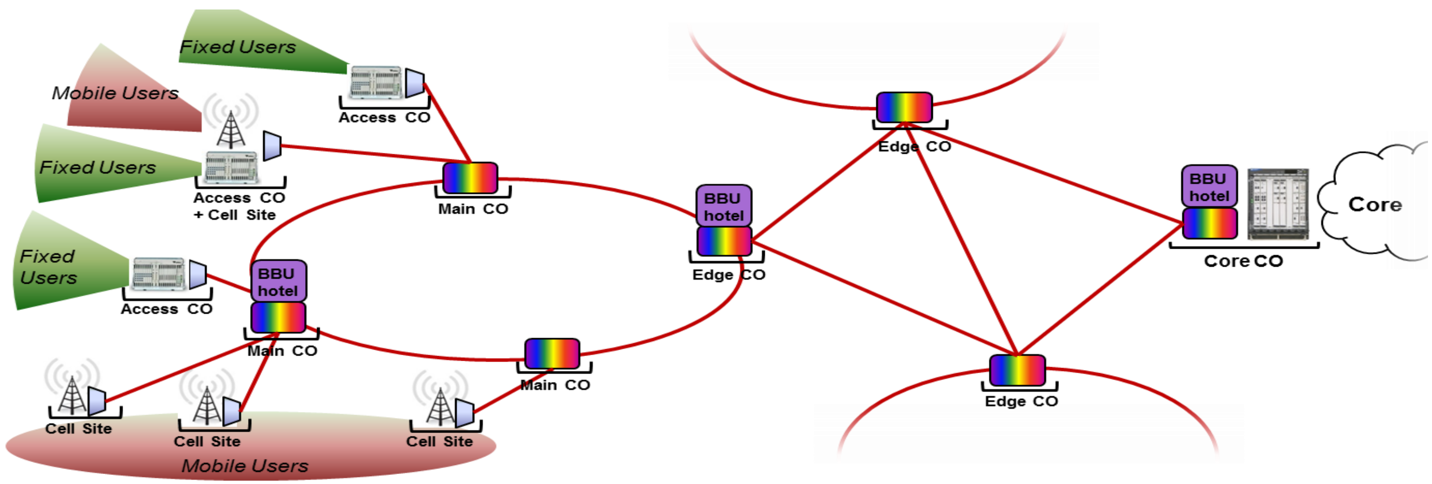
[6] COMBO project.

Multi-level DU placement





[6] COMBO project.

Mobile Edge Computing

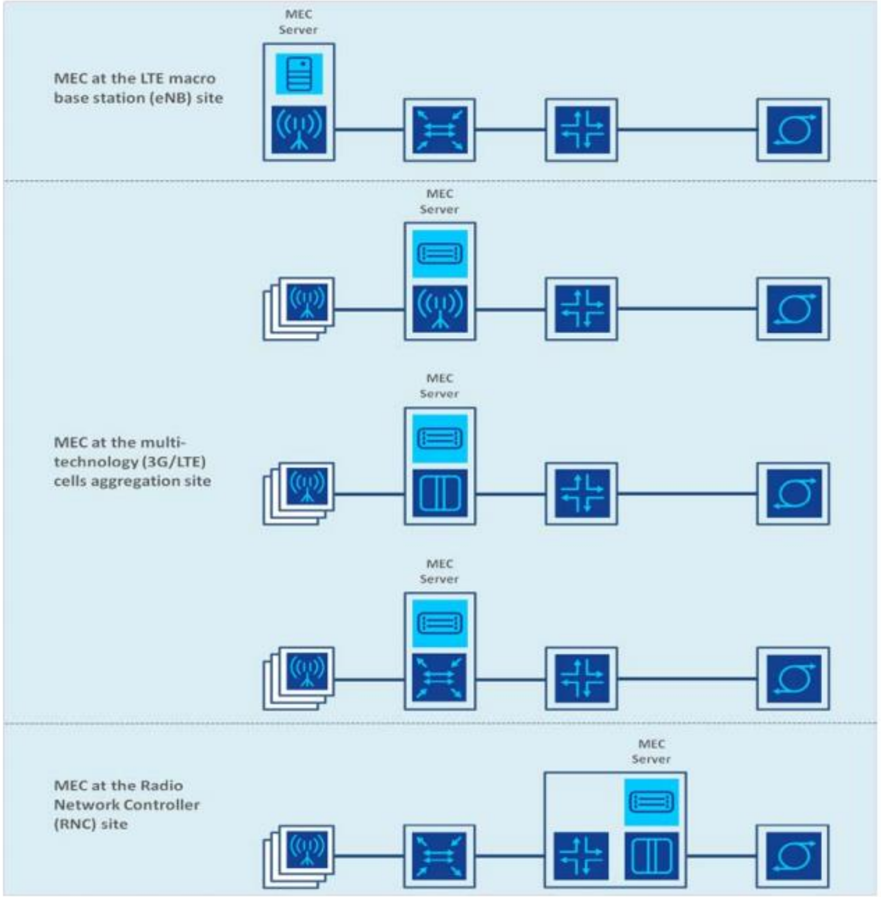


Figure 8: Deployment scenarios of the Mobile-edge Computing server

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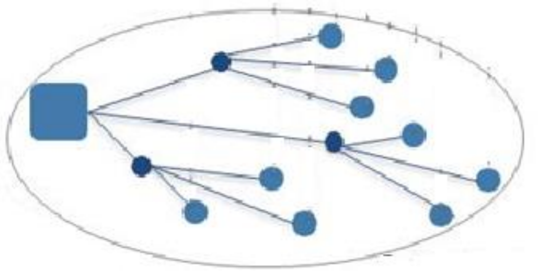
[7] Mobile-Edge Computing – Introductory Technical White Paper.

Research Idea: network breathing



Given:

- Network topology
  - ✓ node connectivity and links length
  - ✓ # fibers/link, #wavelengths/fiber, capacity/wavelength.
  - ✓ DU placement
- Capacity of a DU in terms of virtualized functions (VF)
- For each cell (user):
  - ✓ The ordered array of requested functions and content.
  - ✓ Bandwidth demand between any two VFs.
  - ✓ Maximum route length (latency budget) between any two VFs.
  - ✓ Set of contents needed by users in the cell.
- Coordinated-cell sets associated with the controlling VF.
- The power consumption of DU and VF.

Decide:

- How to split VFs for each cell
- Where to place VFs and contents for each cell
- The grooming, routing and wavelength assignment of traffic from all cells

Minimize:

- Network cost, defined as sum of
  - ✓ Power consumption (DU, wavelength)
  - ✓ Usage of content caches
  - ✓ Latency for each cell

centralization vs. distribution

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Research Idea: network breathing

Constraints:

- Aggregated traffic on a link cannot exceed the link's capacity.
- The VF associated with the coordinated set of cells must be put at a common ancestor of these cells.
- For each cell, the last VF must be located at or before the requested content.

Intuition:

- Minimizing power consumption of DU tends to centralize VFs.
- Minimizing cache usage tends to centralize contents.
- Minimizing latency tends to distribute VFs and cells.
- When latency is more valued, VFs and contents tend to be distributed towards network edge.
- When operational cost is more valued, VFs tend to be centralized towards the network core.

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Thank You !