Moving Optical Dynamicity to the Edge

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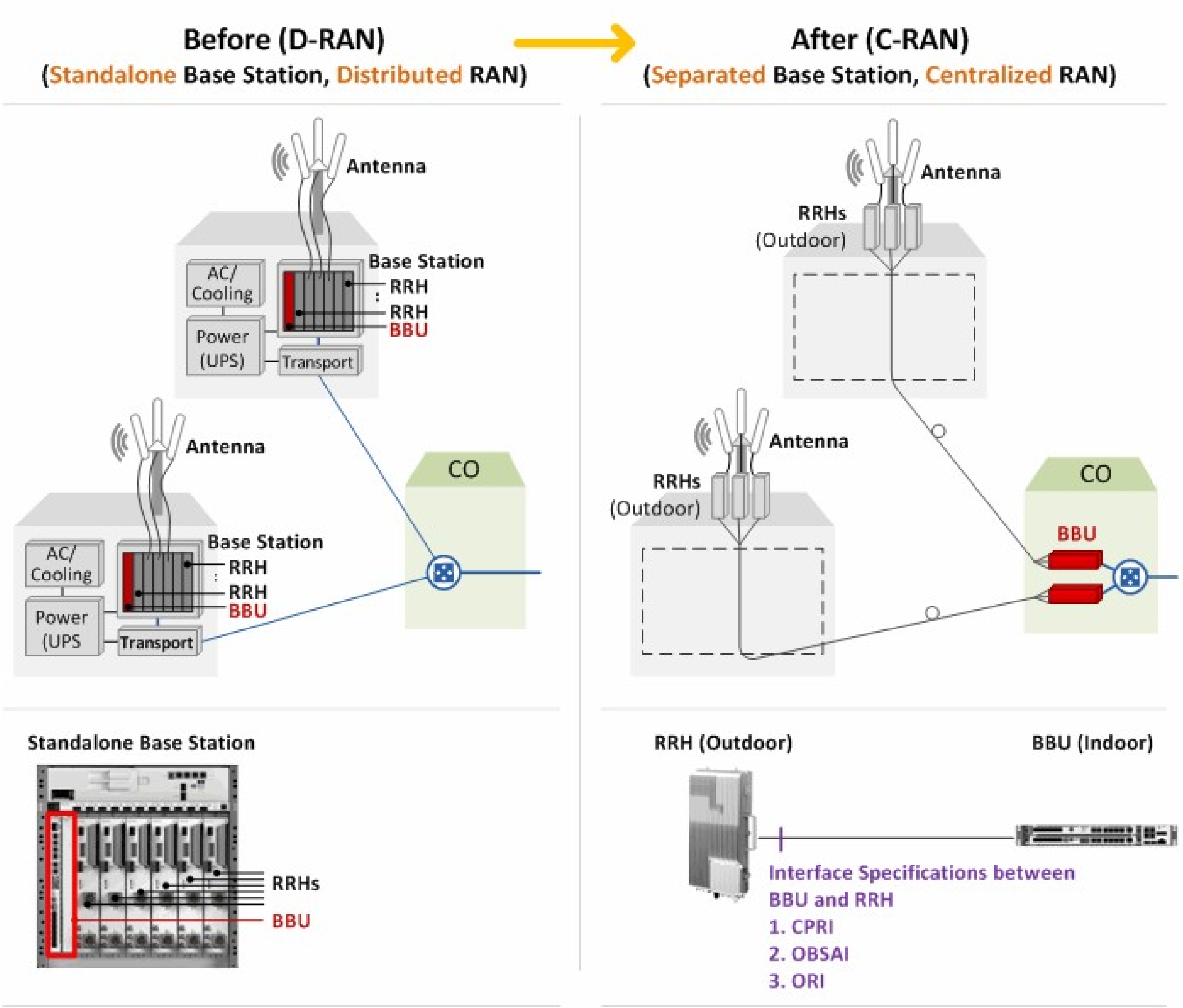
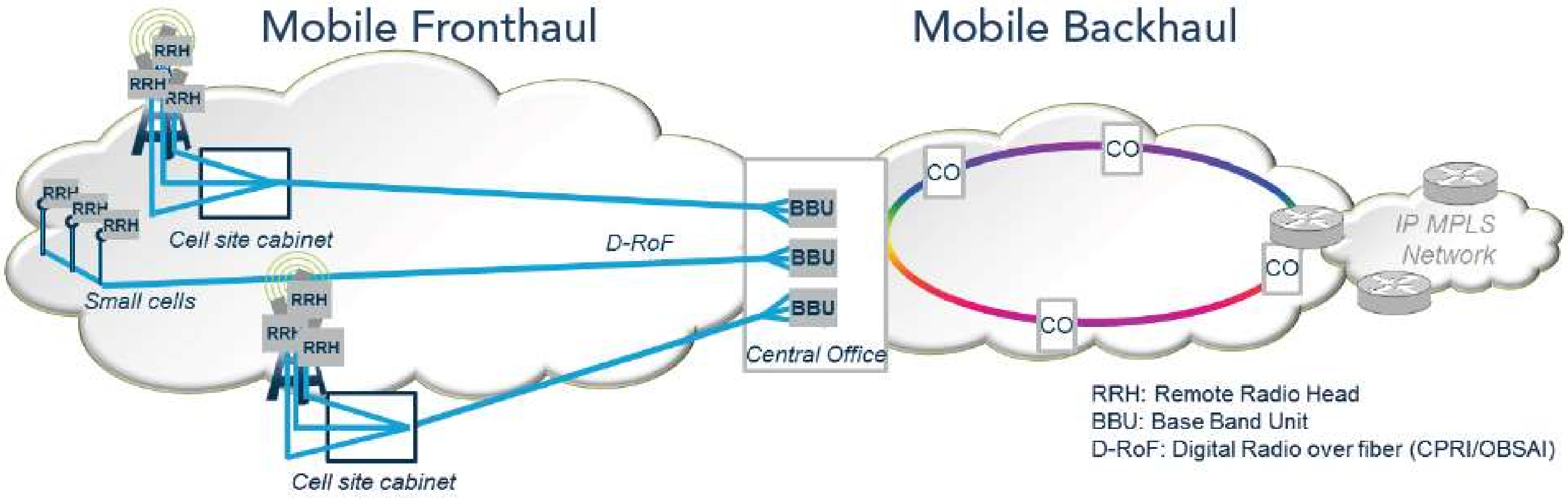
Cloud/Centralized RAN



Interface Specifications between BBU and RRH

1. CPRI
2. OBSAI
3. ORI

Centralized RAN in Argentina



RRH: Remote Radio Head
BBU: Base Band Unit
D-RoF: Digital Radio over fiber (CPRI/OBSAI)

Centralized RAN drivers

- **Faster deployment**. 2 days per RRU versus a conventional installation work 7 days (BBU + RRU).
- **Less space in remote sites** translate in savings in the installation of new cabinets, easier negotiation with owners by requiring less space and energy.
- **Lower rental costs in new places.** Simplifies model co location with other operators.
- **Maintenance BBUs** concentrated in one single place. FO network between farm and RRUS site.
- **Simplified transport architecture**. No GWT (switch or mini-router in the mobile site) in this architecture. The expansion of the backhaul network are necessary only GWD / GWC level.
- More **efficient use of energy and backups** in the BBUs farms.

Centralized RAN drivers-Construction impact

- The main driver for CRAN deployment in Argentina is the faster network deployment

	CRAN	Legacy LTE
Site Selection	24	65
BBU cabinet		35
Power Supply	20	20
Cellsite Router		15
Transmission	8	8
Equipment Installation a	3	20
TOTAL (reference units)	55	163

Construction Cycle comparison in Telefonica Argentina

Centralized RAN drivers

CRAN CAPEX is lower than distributed LTE in greenfield areas or brownfield when fibre is available

New sites				Brownfield	
Legacy LTE				Legacy LTE	
Fiber deployment	10			Fiber fusions	0,5
Cell Site Router	1,6			Cell site Router	1,6
Colored SFPs				Fibre pair	0,3
TOTAL	**11,6**			**TOTAL**	**2,4**
Centralized RAN				Centralized RAN	
Fiber deployment	10			Fiber fusions	0,5
Cell Site Router	0			Cell site Router	
CPRI SFPs	0,1			Fibre pair	0,3
TOTAL	**10,1**			CPRI SFPs	0,1
				TOTAL	**0,9**

Fiber. New sites and existing sites fiber deployment cost (reference units)

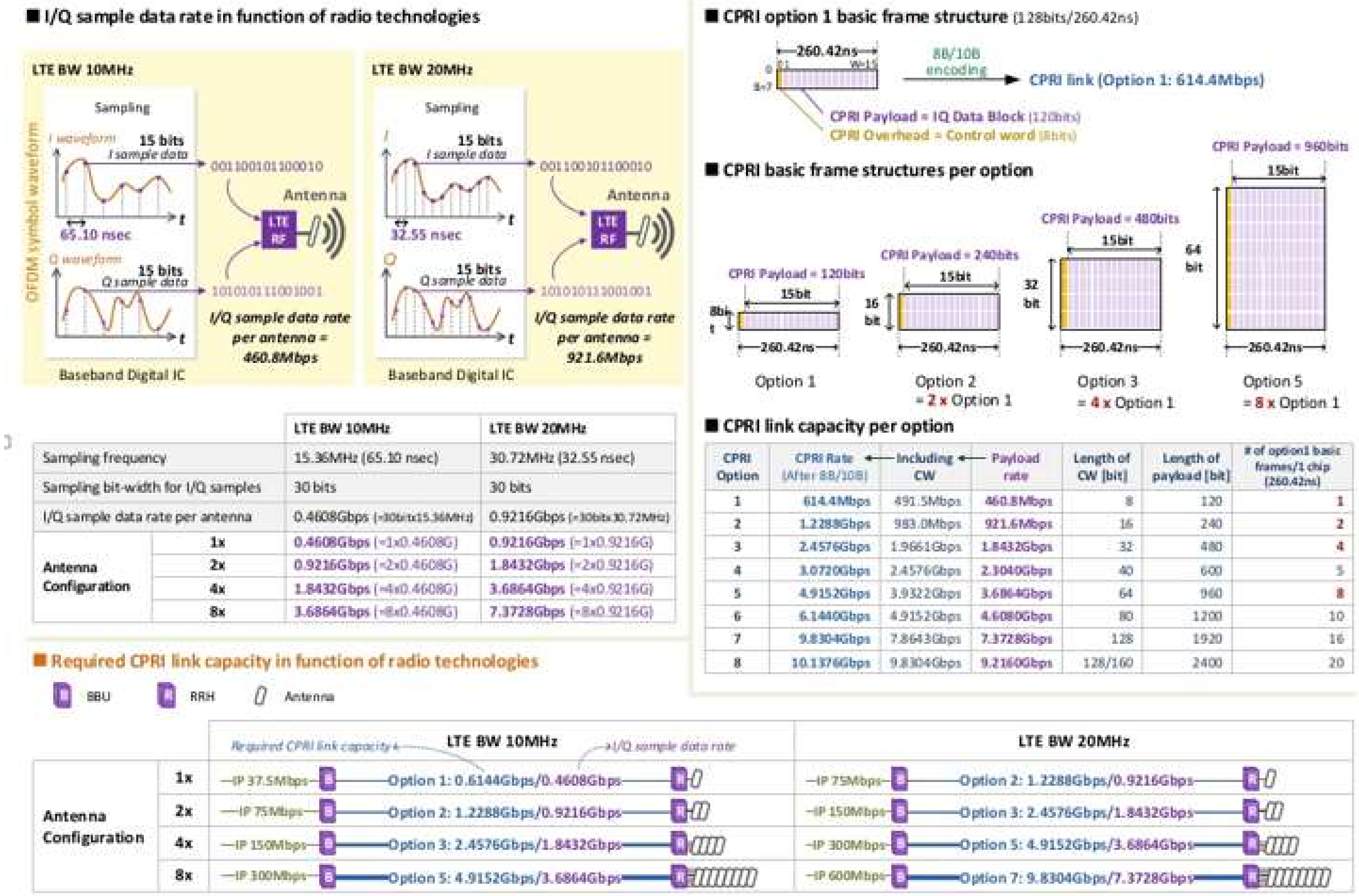
The cost of cabinet CRAN is 50% lower than DRAN (conventional) cabinet (BBU + RRUs).

Fronthaul

- The use of the CPRI (Common Public Radio Interface) interface (or other similar interfaces, like OBSAI or ORI) lead to the definition of the **fronthaul network**, as opposed to the backhaul network used in traditional mobile RAN architectures
  - As of lately, there are also some groups that also talk about midhaul
- Fronthaul network basically transports **analog signals in digital form**
- Two main characteristics differentiate backhaul and fronthaul networks
  - **Capacity, latency and frequency jitter requirements** are far more stringent than those of the backhaul networks
  - The capacity required in the fronthaul does not depend on the amount of user traffic that is being carried out, so there are **no statistical multiplexing gains** when aggregating several fronthaul links
- This fronthaul network is thus a very simple optical transmission network based on transparent point-to-point connections by using dark fiber or wavelength division multiplexing (WDM) technology
  - Although there are new wireless solutions, mainly based on the use of very high frequency bands, that are also able to support fronthaul requirements
- IEEE is now working on making feasible to support a CPRI like interface with Ethernet technology
  - E.g., IEEE P1904.3 - Standard for Radio Over Ethernet Encapsulations and Mappings

CPRI requirements - capacity

- Depending on the radio configuration (bandwidth, number of antennas,…), CPRI capacity requirements can be of the order of Gbit/s per site



		LTE BW 10MHz	LTE BW 20MHz
Sampling frequency		15.36MHz (65.10 nsec)	30.72MHz (32.55 nsec)
Sampling bit-width for I/Q samples		30 bits	30 bits
I/Q sample data rate per antenna		0.4608Gbps (=30bitx15.36MHz)	0.9216Gbps (=30bitx30.72MHz)
Antenna Configuration	1x	0.4608Gbps (=1x0.4608G)	0.9216Gbps (=1x0.9216G)
	2x	0.9216Gbps (=2x0.4608G)	1.8432Gbps (=2x0.9216G)
	4x	1.8432Gbps (=4x0.4608G)	3.6864Gbps (=4x0.9216G)
	8x	3.6864Gbps (=8x0.4608G)	7.3728Gbps (=8x0.9216G)

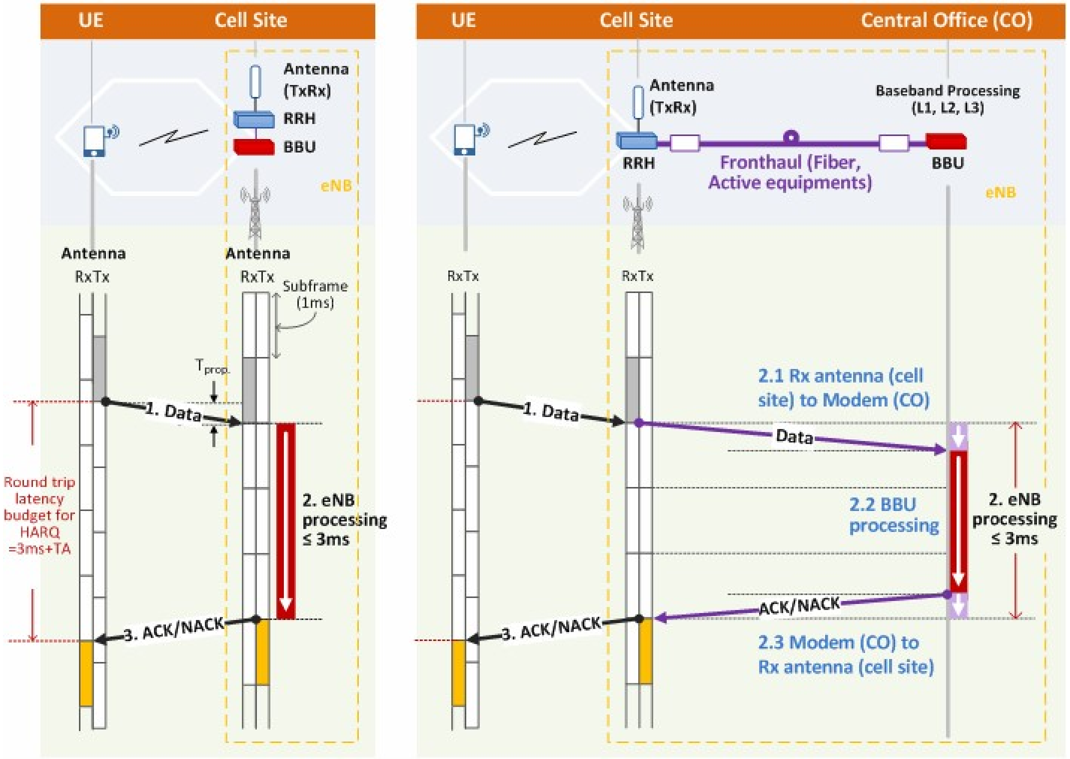
■ CPRI link capacity per option

CPRI Option	CPRI Rate (After 8B/10B) ←	Including CW ←	Payload rate	Length of CW [bit]	Length of payload [bit]	# of option1 basic frames/1 chip (260.42ns)
1	614.4Mbps	491.5Mbps	460.8Mbps	8	120	1
2	1.2288Gbps	983.0Mbps	921.6Mbps	16	240	2
3	2.4576Gbps	1.9661Gbps	1.8432Gbps	32	480	4
4	3.0720Gbps	2.4576Gbps	2.3040Gbps	40	600	5
5	4.9152Gbps	3.9322Gbps	3.6864Gbps	64	960	8
6	6.1440Gbps	4.9152Gbps	4.6080Gbps	80	1200	10
7	9.8304Gbps	7.8643Gbps	7.3728Gbps	128	1920	16
8	10.1376Gbps	9.8304Gbps	9.2160Gbps	128/160	2400	20

		LTE BW 10MHz	LTE BW 20MHz
Antenna Configuration	1x	IP 37.5Mbps – Option 1: 0.6144Gbps/0.4608Gbps	IP 75Mbps – Option 2: 1.2288Gbps/0.9216Gbps
	2x	IP 75Mbps – Option 2: 1.2288Gbps/0.9216Gbps	IP 150Mbps – Option 3: 2.4576Gbps/1.8432Gbps
	4x	IP 150Mbps – Option 3: 2.4576Gbps/1.8432Gbps	IP 300Mbps – Option 5: 4.9152Gbps/3.6864Gbps
	8x	IP 300Mbps – Option 5: 4.9152Gbps/3.6864Gbps	IP 600Mbps – Option 7: 9.8304Gbps/7.3728Gbps

CPRI requirements - latency

- For an LTE network the maximum separation distance between RRH and BBU is constrained by the timing requirement of Hybrid Automatic Retransmit reQuest (HARQ) protocol used as a retransmission mechanism between UE and eNB
- UE should receive ACK/NACK from eNB in three subframes after sending uplink data, i.e. in the fourth subframe. Otherwise, the UE retransmits the data
- So, eNB should complete eNB processing (UL CPRI processing, UL frame decoding, ACK/NACK creation, DL frame creation, DL CPRI processing) within 3 ms after receiving uplink data from UE in subframe n, and then send downlink ACK/NACK in subframe n+4 back to the UE



(a) Timing requirement of uplink synchronous HARQ processing

(b) Impact of fronthaul delay (expedited BBU processing needed) in C-RAN

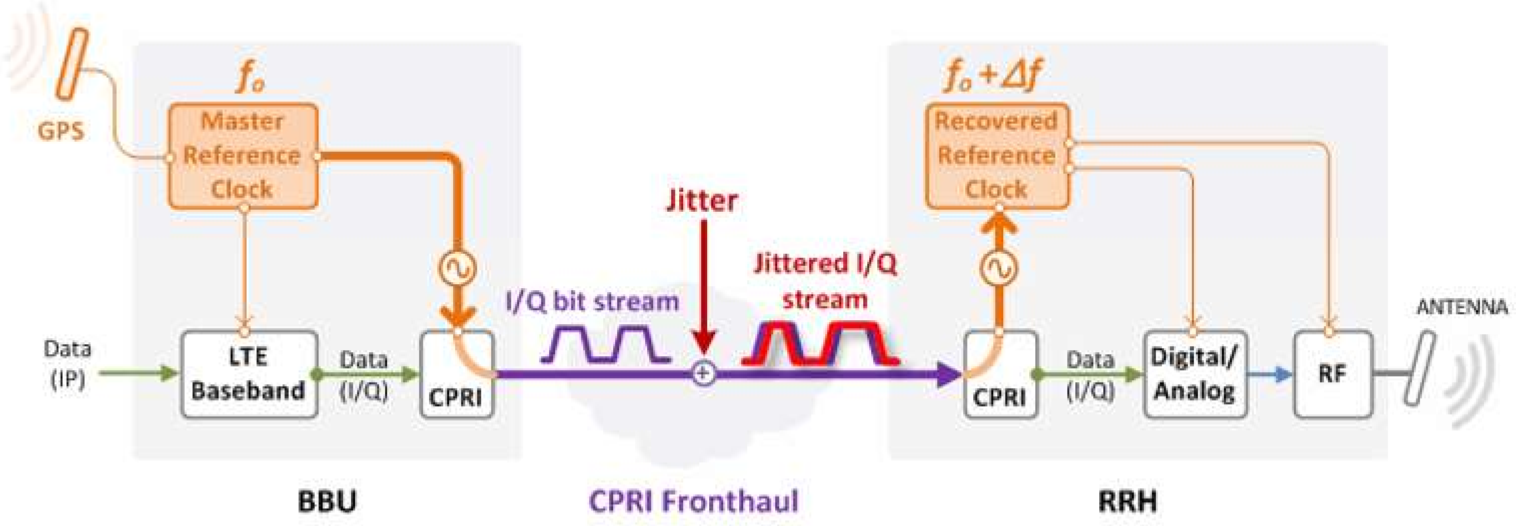
T_p: Propagation Delay TA: Timing Advance TA=$2T_p$

To secure UL/DL time alignment at a cell site (TX, Rx antenna), BBU allocates a TA value to UE after subtracting the fiber latency from the TA value.

LTE preamble format: 0

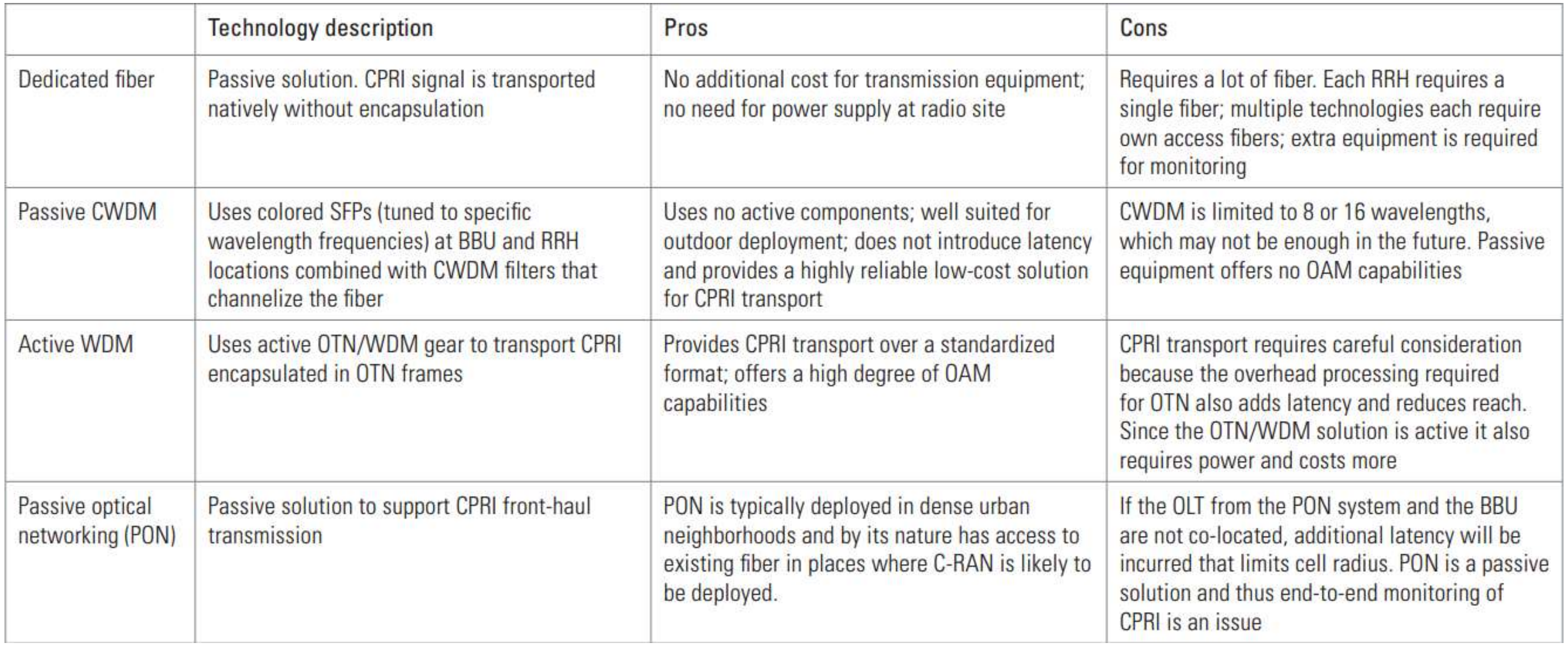
CPRI requirements - jitter

- The RRH should be synchronized with the BBU in the clock frequency, so in LTE C-RAN, a RRH must obtain a reference clock by recovering a timing clock from CPRI I/Q bit streams transmitted by BBU (having a separate reference clock for the RRH is not viable from an economic viewpoint)
- Degraded frequency accuracy of the reference clock recovered in RRH can affect the performance of all relevant components that use the reference clock; e.g., an inaccurate reference clock may cause errors in converting LTE digital signals (I/Q sample data) into LTE analog signals at DAC (Digital Analog Converter), and also lead to inaccurate frequency of carrier signals used for radio transmission of LTE analog signals
- It is specified that the maximum impact of jitter from the CPRI fronthaul on the frequency accuracy of RRH should be less than '±0.002ppm', '±2ppb
- This level of jitter is feasible using dark fiber, but using active equipment in a fronthaul network (e.g. Active WDM, PON, etc.) may comprise the jitter objective



Optical Fronthaul– implementation options

- Support of **fiber based** CPRI fronthaul can be carried out with different technological solutions, each of them with different pros and cons:

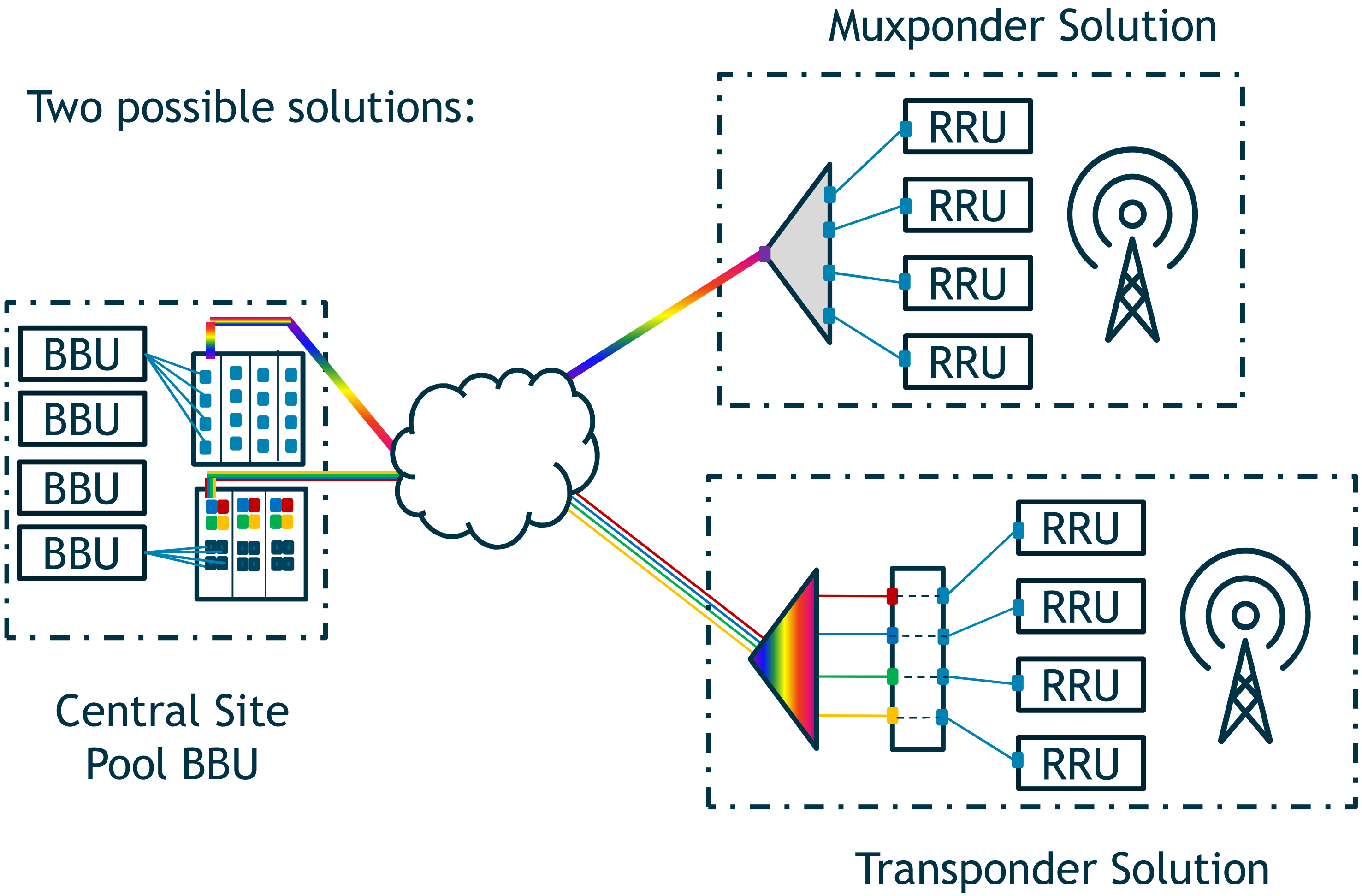


	Technology description	Pros	Cons
Dedicated fiber	Passive solution. CPRI signal is transported natively without encapsulation	No additional cost for transmission equipment; no need for power supply at radio site	Requires a lot of fiber. Each RRH requires a single fiber; multiple technologies each require own access fibers; extra equipment is required for monitoring
Passive CWDM	Uses colored SFPs (tuned to specific wavelength frequencies) at BBU and RRH locations combined with CWDM filters that channelize the fiber	Uses no active components; well suited for outdoor deployment; does not introduce latency and provides a highly reliable low-cost solution for CPRI transport	CWDM is limited to 8 or 16 wavelengths, which may not be enough in the future. Passive equipment offers no OAM capabilities
Active WDM	Uses active OTN/WDM gear to transport CPRI encapsulated in OTN frames	Provides CPRI transport over a standardized format; offers a high degree of OAM capabilities	CPRI transport requires careful consideration because the overhead processing required for OTN also adds latency and reduces reach. Since the OTN/WDM solution is active it also requires power and costs more
Passive optical networking (PON)	Passive solution to support CPRI front-haul transmission	PON is typically deployed in dense urban neighborhoods and by its nature has access to existing fiber in places where C-RAN is likely to be deployed.	If the OLT from the PON system and the BBU are not co-located, additional latency will be incurred that limits cell radius. PON is a passive solution and thus end-to-end monitoring of CPRI is an issue

- **Wireless fronthaul** is also an option, with several proprietary solutions already available
  - Based on the use of high frequency bands (e.g., E-Band or Free Space Optics)
- **Ethernet based** solutions are also being explored, e.g., IEEE P1904.3 Radio over Ethernet standard
  - This may become feasible due to the TSN developments to make Ethernet time-aware, like 802.1Qbu Preemption or 802.1Qcc Stream Reservation Protocol

Active solution

Two possible solutions:


Muxponder Solution

Central Site
Pool BBU

Transponder Solution

Passive vs. Active implementations

Passive:

- ✓ Does not require power supply
- ✓ Suitable for outdoor deployments
- ✓ Low footprint
- ✓ Low cost
- ✓ No extra latency

- X No OAM channel: no inventory, no supervision…
- X Colored pluggables supported at all RRUs/BBUs??

Passive vs. Active implementations

Active:

- ✓ OAM channel: inventory, supervision…
- ✓ Simultaneous support of backhaul, fronthaul and other networks
- ✓ Simplified operation: grey interfaces at BBU/RRU, tunable muxponder/transponder

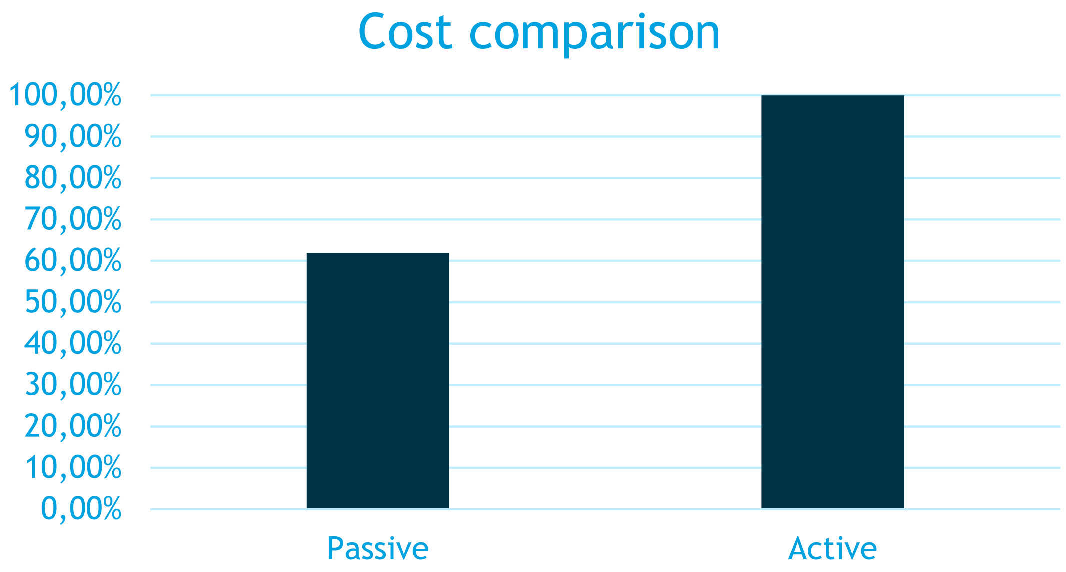
- X Extra latency insertion
- X Outdoor is not always possible
- X Requires power supply
- X Higher footprint
- X Higher cost

Passive vs. Active
preliminary cost evaluation

Assuming a protected ring architecture, with 4 RS, each one generating:

- 1 x CPRI 2 (1.229 Gbit/s)
- 7 x CPRI 3 (2.458 Gbit/s)
- 2 x CPRI 6/7 (6.144 Gbit/s – 9.830 Gbit/s)

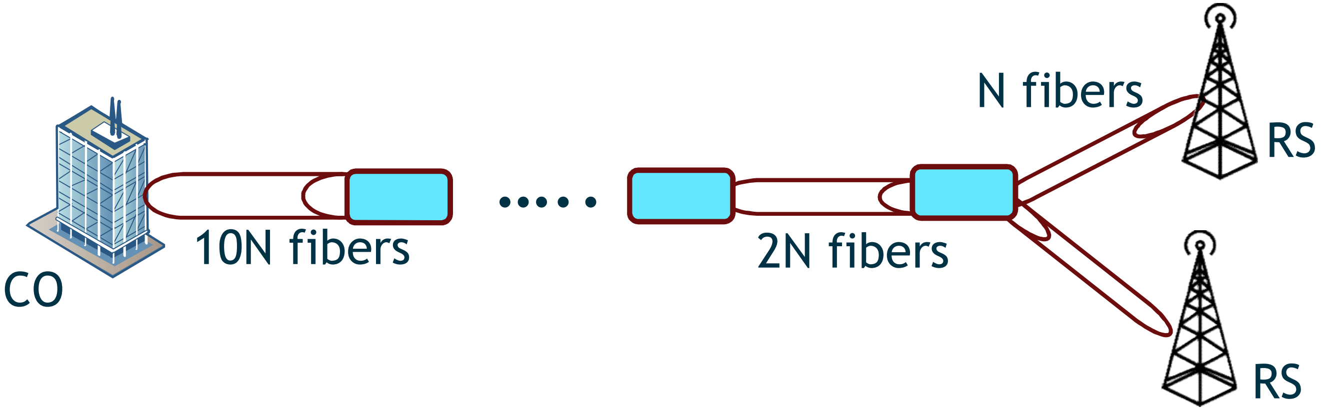
Rough estimation (hw+sw) active and passive costs.



Cost considerations

C-RAN (Passive & Active) vs C-RAN Dark Fiber

- Transport is interesting vs. dark fiber where cables are getting exhausted or ducts have no more room



Transport capacity is multiplied by λ (with λ=8,16,40,80)
Fiber needs transport = Fiber needs dark fiber/λ

Cost considerations

Greenfield scenarios: Higher cost is digging and trenching for fiber installation:

- 120$/m in urban areas, 100$/m in sub-urban areas, 88 $/m in rural areas[1]

Brownfield scenarios:

- Deploy new fiber over existent ducts: from 12.5%[2] to 25%[3] of the cost of digging and trenching
- Other cost considerations: if fiber can be leased, if there is enough capacity in the trench to deploy a new duct,…

Assuming for example that in the last 2 km of a sub-urban area new fiber and cable has to be deployed (**brownfield scenario**):

- Dark fiber cost= 25K$ - 50K$
- Transport Solution = Dark fiber cost/λ + equipment cost (muxponder/transponder/coloured SFPs costs)

1. J.R. Schneir, “Cost Analysis of Network Sharing in FTTH/PONs,” IEEE Comm. Mag, Aug. 2014
2. M. Tahon, “Improving the FTTH business case–A joint telco-utility network rollout model,” Telecomm. Policy, July 2014
3. A. Agata, “Suboptimal PON network designing algorithm for minimizing deployment cost of optical fiber cables,” ONDM 2012

Main technical challenges for 5G frinthauk

- The low-latency and strict synchronization requirements demanded in CPRI requires dedicated lambda per RRU.

- Existing optical fronthaul solutions provides static bandwith provisioning between BBU and RRU. This could be inefficient in dynamic 5G networks where optical fronthal bandwidth depends on the number of users connected to the cell site.

- The upcoming 5G RANs, where 100 MHz channels with massive MIMO are envisioned, may require several tens or even hundreds of gigabits per second capacity in the fronthaul

Key technologies for future 5G fronthaul

- RAN virtualization enabling an **alternative functional split between RRU and BBU** in order to enable more relaxed requirements in terms of latency and bandwidth

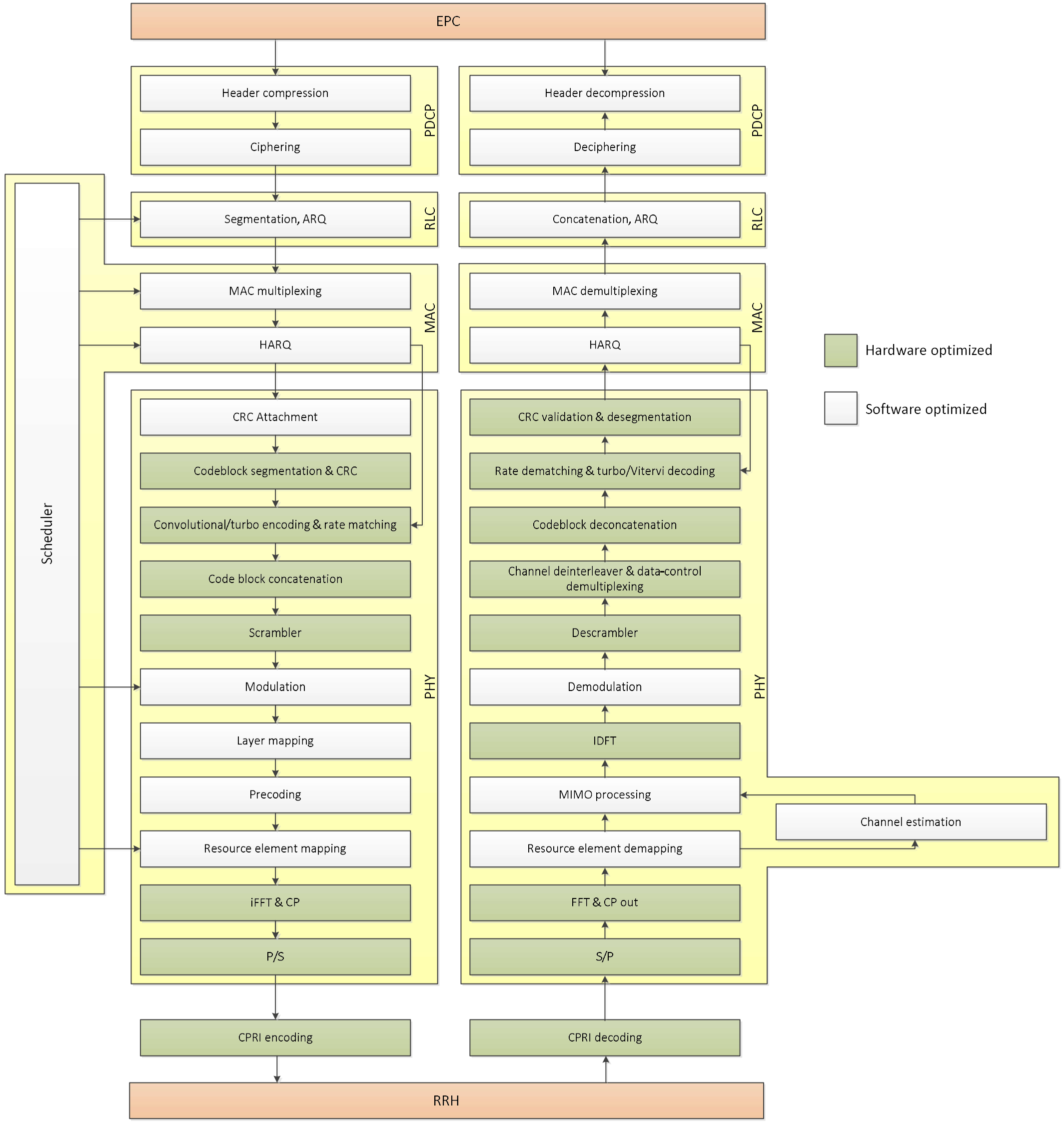
    - **IEEE 1904.3 Standard group** is exploring the possible gains of redefining the RE/REC functional split of C-RAN in the next-generation networks

- **Elastic Optical Networks** in the fronthaul enabling dynamic spectrum allocation among cell sites according to the real time traffic demands

Network virtualization and 5G

- For LTE and its evolution, virtualization is a different way of implementing an architecture that was designed not taking into account virtualization
- Core network virtualization is already a reality, with several commercial products deployed
  - E.g., virtualized EPCs have been deployed to support IoT services on LTE
- But there are good reasons to push for the extension of the virtualization to the Radio Access Network
  - To create an ecosystem of decoupled HW and SW vendors for RAN nodes, therefore reducing dependency on incumbents suppliers
  - To reduce costs, by means of sharing resources at a central site and reducing cost items at the remote locations
  - To improve network performance not compromising the cost reduction goal
  - To provide flexibility to adapt to standard evolutions and traffic demands
- In 5G, virtualization can be used to significantly change the way the network is designed
  - It is essential to implement the concept of network slice, which is expected to provide network operators a significant advantage over OTT players
  - But can also be used to change they way mobile communications are supported, e.g., moving towards a cell-less network architecture

Taxonomy of the functions



EPC

PDCP
Header compression
Ciphering

RLC
Segmentation, ARQ

MAC
MAC multiplexing
HARQ

PHY
CRC Attachment
Codeblock segmentation & CRC
Convolutional/turbo encoding & rate matching
Code block concatenation
Scrambler
Modulation
Layer mapping
Precoding
Resource element mapping
iFFT & CP
P/S

CPRI encoding

PDCP
Header decompression
Deciphering

RLC
Concatenation, ARQ

MAC
MAC demultiplexing
HARQ

PHY
CRC validation & desegmentation
Rate dematching & turbo/Vitervi decoding
Codeblock deconcatenation
Channel deinterleaver & data-control demultiplexing
Descrambler
Demodulation
IDFT
MIMO processing
Channel estimation
Resource element demapping
FFT & CP out
S/P

CPRI decoding

Scheduler

RRH

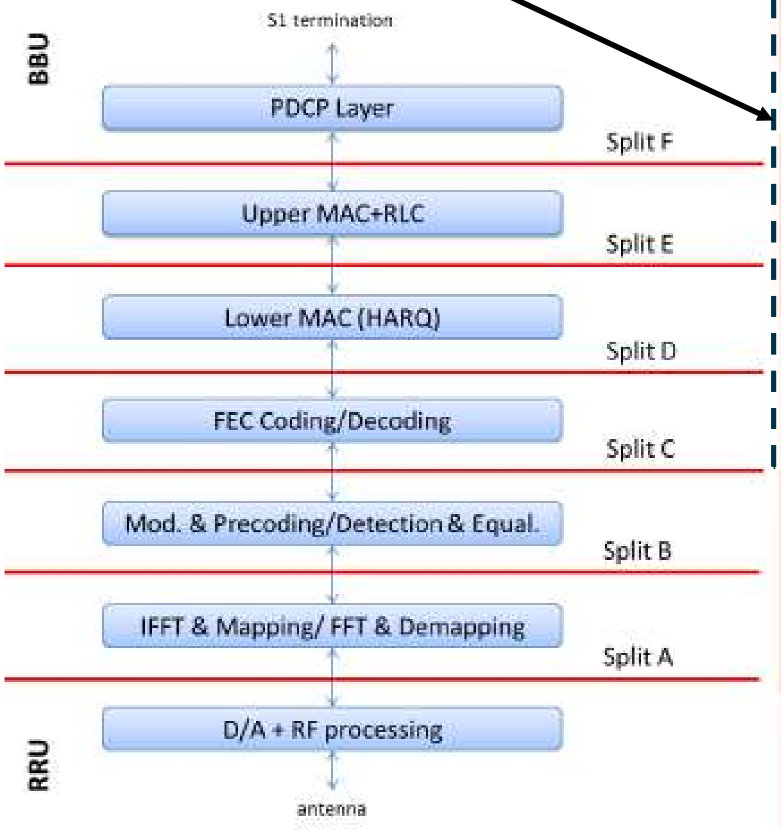
🟩 Hardware optimized

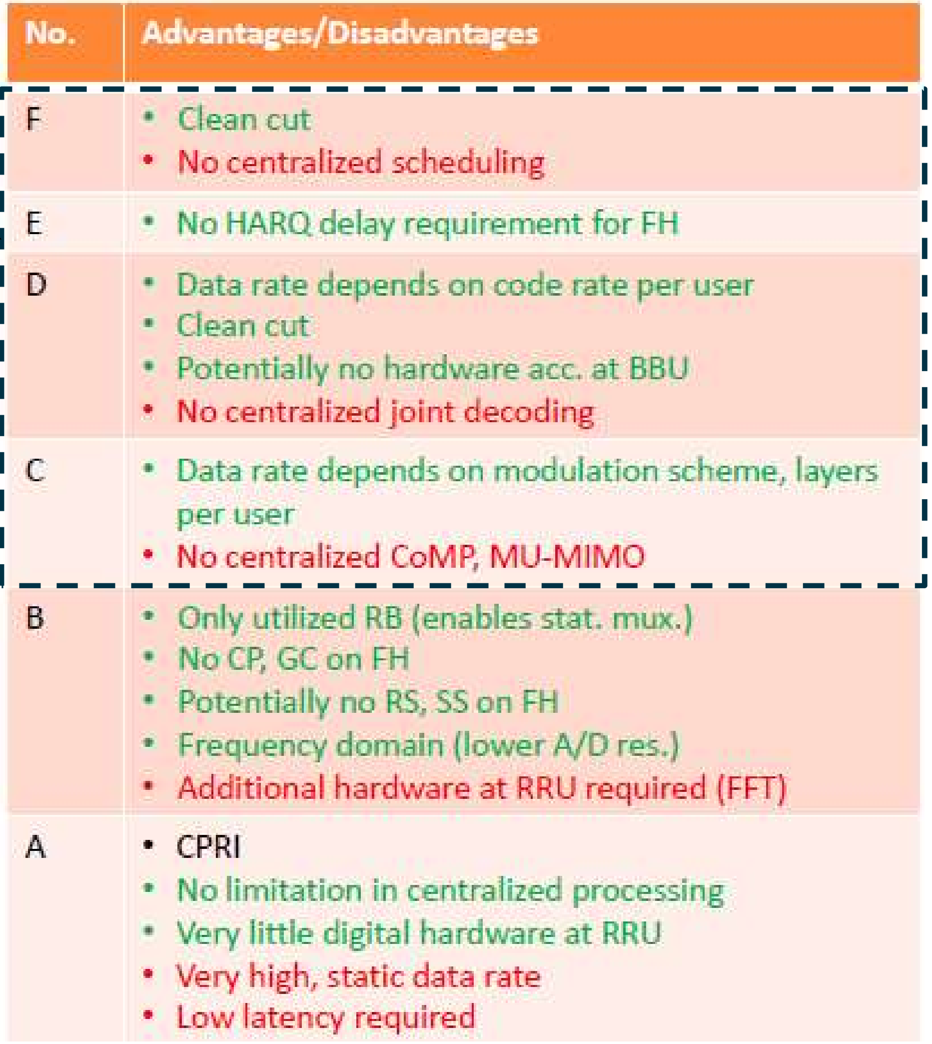
⬜ Software optimized

- Depending on the nature of each functionality that is being supported the most adequate platform is different
  - **Layer 2 and upper layers** are better implemented in **software over GPP**
  - **Iterative operations like FFT/iFFT and encoding/decoding** are better implemented with **specialized hardware components**, like DSPs or FPGAs
- However, it may be necessary to allow for some flexibility
  - **Encoding is a much less complex operation than decoding**, and can be implemented in GPP with no significant penalty
  - **IDFT after MIMO equalization can be implemented in software**, as this would facilitate the support of advanced interference cancellation receivers

Different functional splits have different implications

Optimum splits for dynamic Optical networks

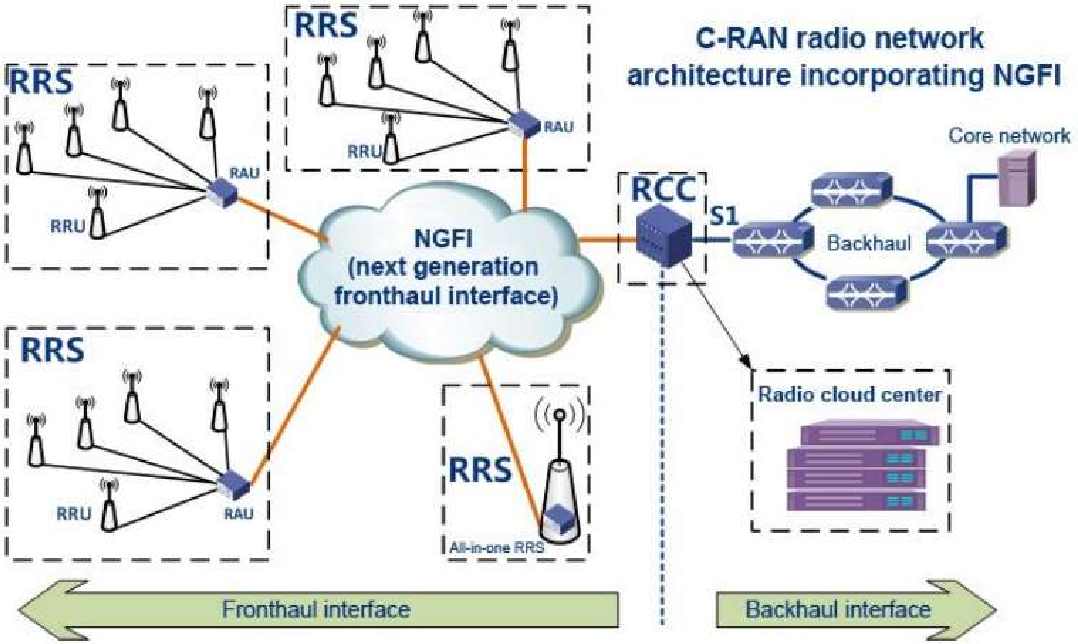




No.	Advantages/Disadvantages
F	🟢 Clean cut 🔴 No centralized scheduling
E	🟢 No HARQ delay requirement for FH
D	🟢 Data rate depends on code rate per user 🟢 Clean cut 🟢 Potentially no hardware acc. at BBU 🔴 No centralized joint decoding
C	🟢 Data rate depends on modulation scheme, layers per user 🔴 No centralized CoMP, MU-MIMO
B	🟢 Only utilized RB (enables stat. mux.) 🟢 No CP, GC on FH 🟢 Potentially no RS, SS on FH 🟢 Frequency domain (lower A/D res.) 🔴 Additional hardware at RRU required (FFT)
A	• CPRI 🟢 No limitation in centralized processing 🟢 Very little digital hardware at RRU 🔴 Very high, static data rate 🔴 Low latency required

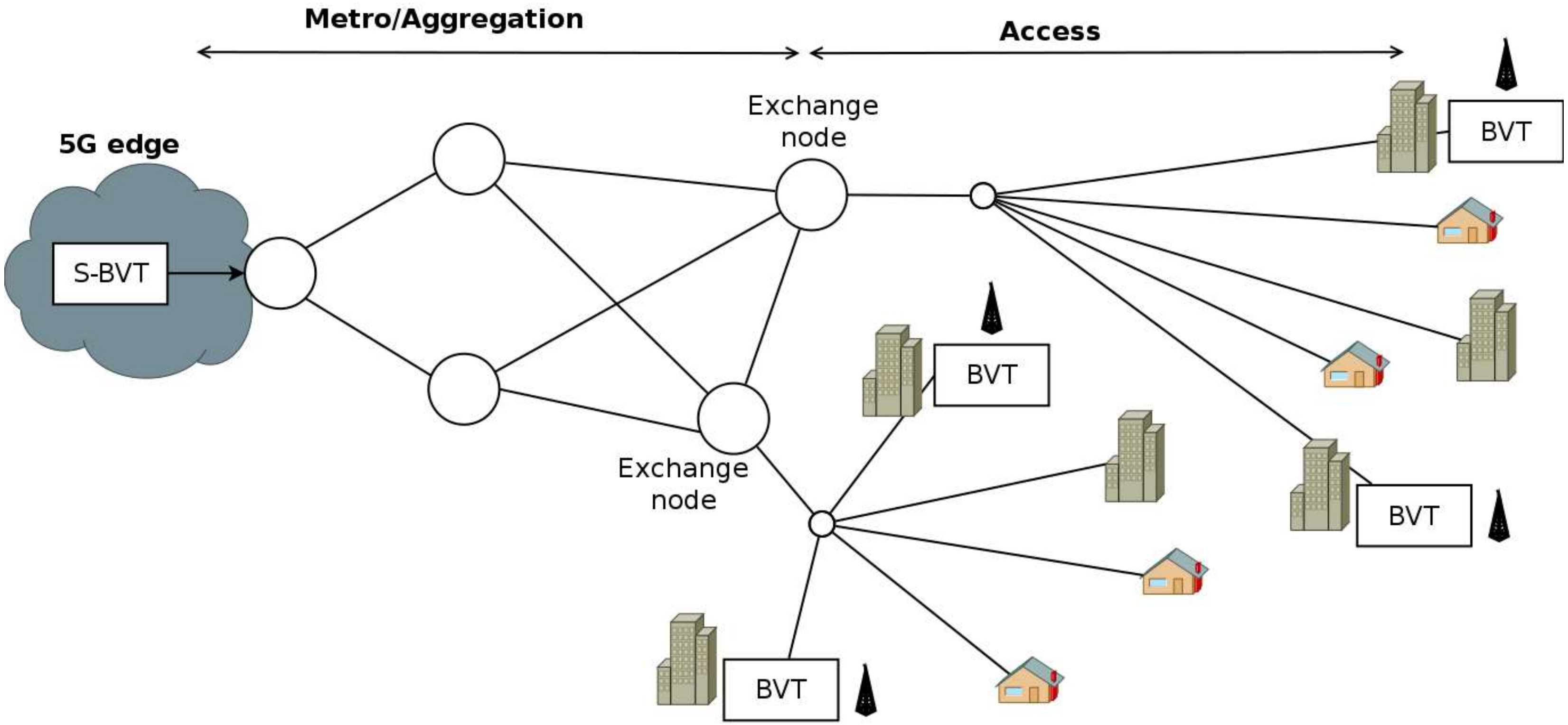
Next Generation Fronthaul Interface (NGFI)

- NGFI is an open interface possessing at least two key properties:
  - First, it redefines the functions of baseband units (BBUs) and remote radio units (RRUs), so some baseband processing functions are shifted to the RRU, which leads to a change in BBU and RRU architecture
    - As a result, the BBU is redefined as the Radio Cloud Center (RCC), and the RRU becomes the Radio Remote System (RRS)
  - Second, the fronthaul changes from a point-to-point connection into a multiple-to-multiple fronthaul network, using packet switch protocols.



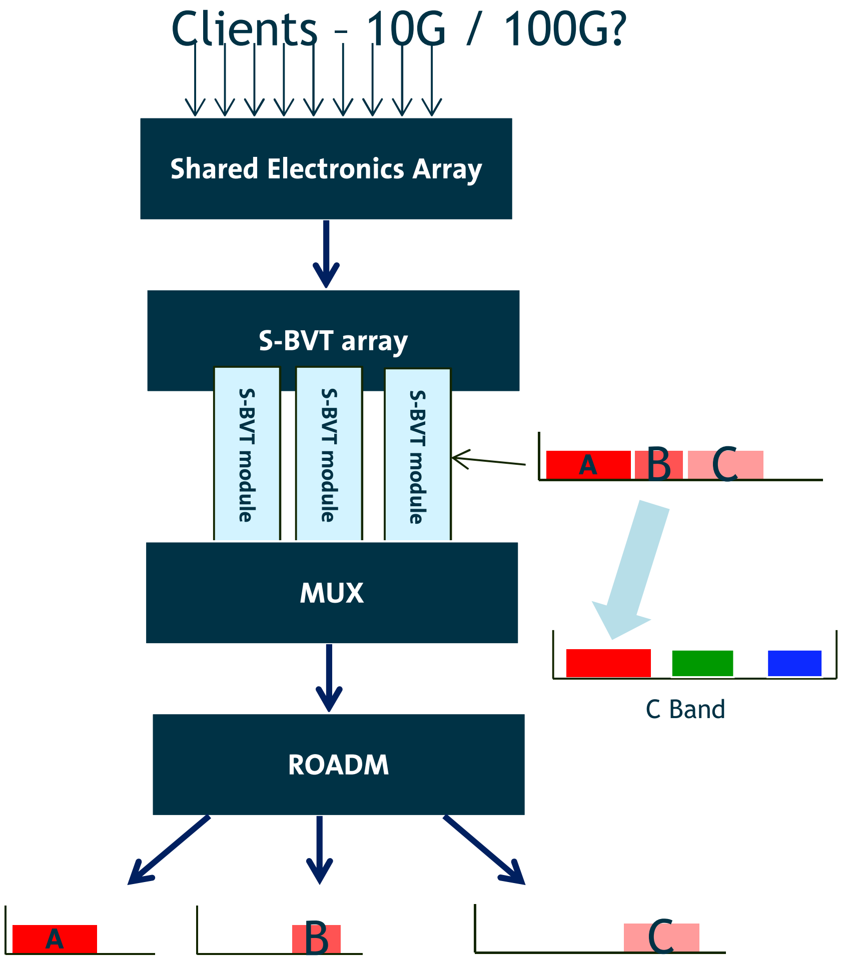
C-RAN radio network architecture incorporating NGFI

EON in the fronthaul



Main idea: Transparently and dynamically deliver mobile front-/back-haul in a converged metro/access environment, following the elastic networking paradigm while taking advantage of the already deployed fiber infrastructure

Sliceable Bit Rate Variable Transponder (S-BVT)

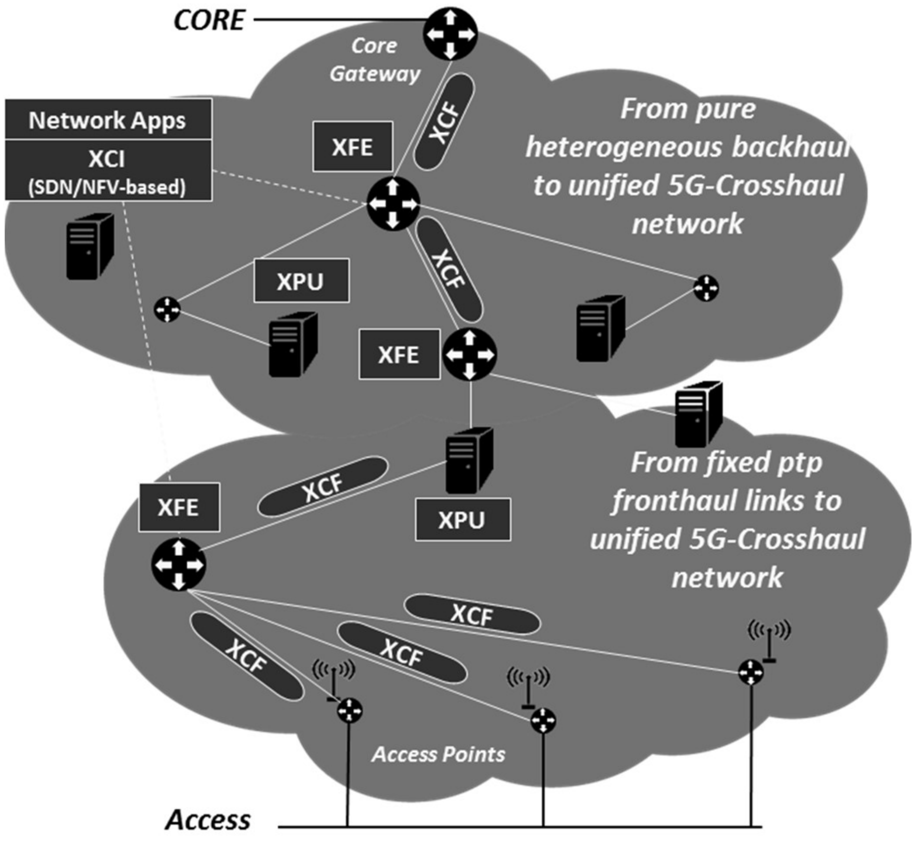


- S-BVT architecture treats spectrum generation as a resource
- Each S-BVT transponder generates a large amount of spectrum that can be modulated in distinct spectral blocks
- A ROADM further in the network slices these blocks and sends them to their different destinations
- Key parameters include spectrum width, and number of slices for each S-BVT

Taking action · 5G-Crosshaul project(1)
Converged SDN/NFV fronthaul/backhaul

5GXCrosshaul
the integrated fronthaul/backhaul

A high capacity low latency transport solution that lowers costs and guarantees flexibility and scalability



A holistic approach for converged Fronthaul and Backhaul under common SDN/NFV-based control, capable of supporting new 5G RAN architectures (V-RAN) and performance requirements

Main building blocks

- **XCF - Common Frame** capable of transporting the mixture of various Fronthaul and backhaul traffic
- **XFE - Forwarding Element** for forwarding the Crosshaul traffic in the XCF format under the XCI control
- **XPU - Processing Unit** for executing virtualized network functions and/or centralized access protocol functions (V-RAN)
- **XCI - Control Infrastructure** that is SDN-based and NFV-enabled for executing the orchestrator's resource allocation decisions
- **Novel network apps** on top to achieve certain KPIs or services

(1) http://www.5g-crosshaul.eu/

The 5G-Crosshaul Control Plane

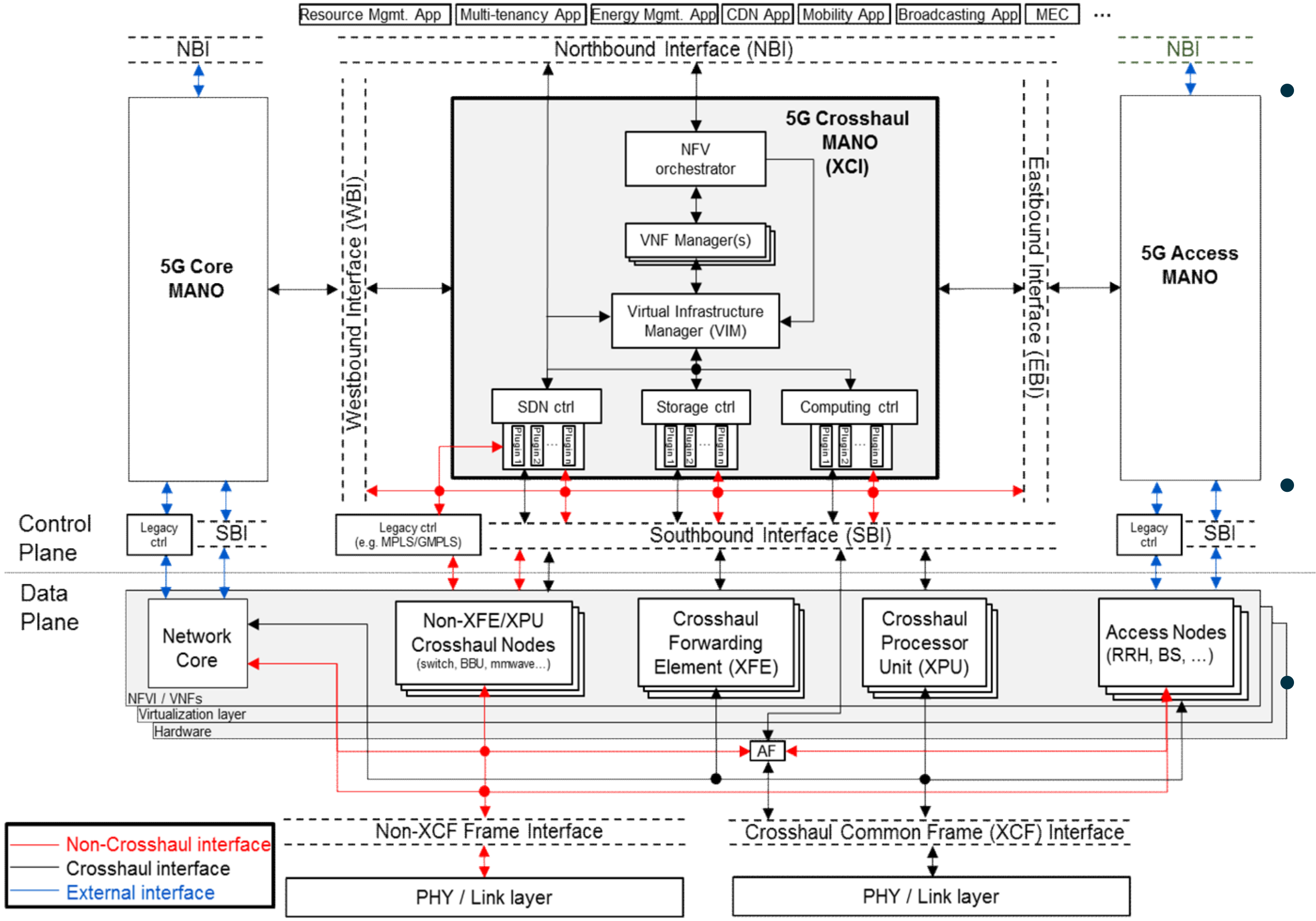


Figure 1: 5G-Crosshaul Architecture Illustration

- Unified control plane for the integrated fronthaul/backhaul transport network
- Leverages SDN/NFV technologies
- Specifically designed for multi-tenancy

5G fronthaul: Static CPRI vs dynamic optical frontahul

	STATIC HIGH CAPACITY CPRI	Dynamic Optical fronthaul
KEY TECNOLOGIES	Tunable SFPs up to 100Gbps and beyond	New Functional Split Low costs S-BVT up to 1 Tbps and BVT at 10Gbps and beyond Performance monitoring, big data analysis and dynamic SDN control
STRENGTHS	Simple architecture (no control plane)	Flexible BBU location (centralized or distributed) Lower capacity at RRU side is needed SBVT dimensioning at BBU side according to traffic patterns
WEAKNESSES	Distributed BBUs (20KM approx. between BBU and RRU) High capacity SFPs at both BBU and RRU sides No pooling at aggregation switches	Complex SDN control and SBVT and BVT designs

Conclusions

- Existing CRAN solutions impose strict transport requirements in terms of capacity and latency
- Future 5G networks will require new optical fronthaul solutions
- Two alternatives are foreseen:
  - Static CPRI
  - Dynamic optical networks
- We do not discard none but Telefonica research work is currently focused on the last one

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BE MORE_