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Can PON technologies accelerate 5G deployments?

Workshop
"Optical technologies in the 5G Era"
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Considerations

- what are possible use cases where PON is beneficial for backhaul or fronthaul?
- can we leverage FTTx network deployments for fiber links in 5G?
- what are critical technical requirements and how can PONs meet them?
- is it only about cost, or are PONs in specific cases even more performant for x-haul than other transport technologies?
- …

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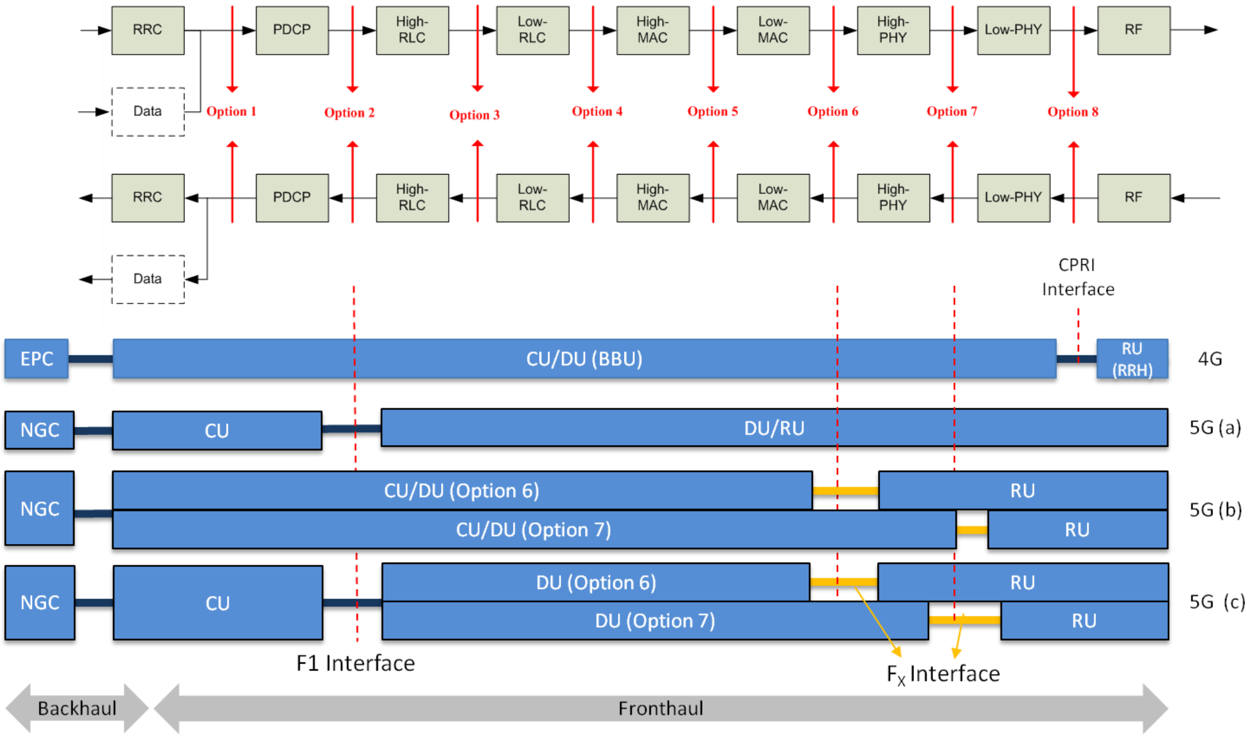
New functional split architectures of base satations

Reducing the general 3GPP model to few relevant split points

3GPP split architecture
(cf. TR 38.801)

reduced model accounting for the split points chosen by 3GPP for x-haul
(cf. G.sup.5GP)



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Bandwidth and latency requirements in NGFH architectures

3GPP Release 14, TR 38.801 V14.0.0 (2017-03)

Protocol Split option	Required DL bandwidth	Required UL bandwidth	Max. allowed one way latency [ms]
Option 1	4Gb/s	3Gb/s	1 – 10 ms
Option 2	***4016Mb/s***	***3024 Mb/s***	
Option 3	[lower than option 2 for UL/DL]		
Option 4	4000Mb/s	3000Mb/s	100 – few 100 μs
Option 5	3000 Mb/s	4000Mb/s	
Option 6	***4133Mb/s***	***5640 Mb/s***	
Option 7a	***10.1~22.2Gb/s***	***16.6~21.6Gb/s***	
Option 7b	***37.8~86.1Gb/s***	***53.8~86.1 Gb/s***	
Option 7c	***10.1~22.2Gb/s***	***53.8~86.1Gb/s***	
Option 8	157.3Gb/s	157.3Gb/s	

Latencies

„non-realtime“: msec, service related

„realtime“: μsec, RAT related

Bandwidths

- Split Option 2:
  few percent increase vs. backhaul
- Split Option 6, 7:
  order of magnitude decrease vs CPRI

Model calculation for high capacity scenario using LTE models:
100 MHz bandwidth, 256-QAM, 8 MIMO layers, 32 antennas,
2*(7-16) bit per IQ sample
(will be updated when 5G parameters are available)

Which transport solution for which architecture ?

- Future NGFH networks will have to meet widely differing requirements, depending on
  - RAT details: number of antennas, wireless capacity/RF bandwidth, MIMO layers, …
  - service types:
    latency, sporadic/continuous traffic, aggregation on radio and fixed network segment, …
  - chosen split point

- There will be a need for
  - big static pipes (cf. WDM-PON) for continuous traffic and for high aggregation in the radio segment
  - dynamic pipes (T(W)DM-PON) with statistical multiplexing for aggregating traffic from multiple sites
  - ultra-low latency on the RAT and on the services level (URLLC)
  - convergence with FTTx services on the same network

cost points (capex and opex) will be decisive …

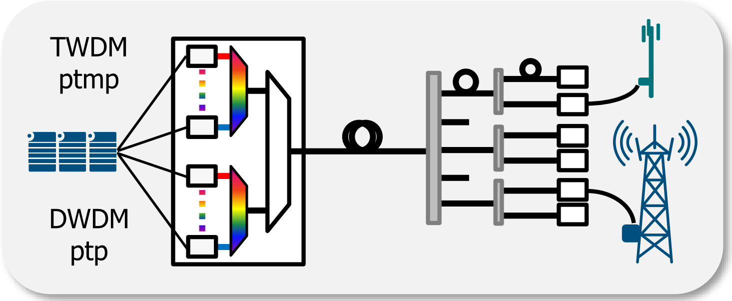
PON variants: state-of-the-art and future evolutions

Available today:

- XGS-PPON (G.9807), NG-PON2 (G.989.x), 10G-EPON (IEEE 802.3)

XGS-PON, NG-PON2: up to 10G per channel over 40 km

- ptmp: XGS-PON, TWDM-PON
  up to 10G/10G , 4 or 8 ch
- ptp: DWDM-PON
  any rate (up to about 11G spec'ed in G.989.2, including native CPRI as client)



tomorrow:

- IEEE, ITU: (1 … 4) x 25G
- research: tens of wavelengths, high power budgets (optically amplified), long reach (up to 100 km) (various EU projects, such as PIEMAN, SARDANA, DISCUS)

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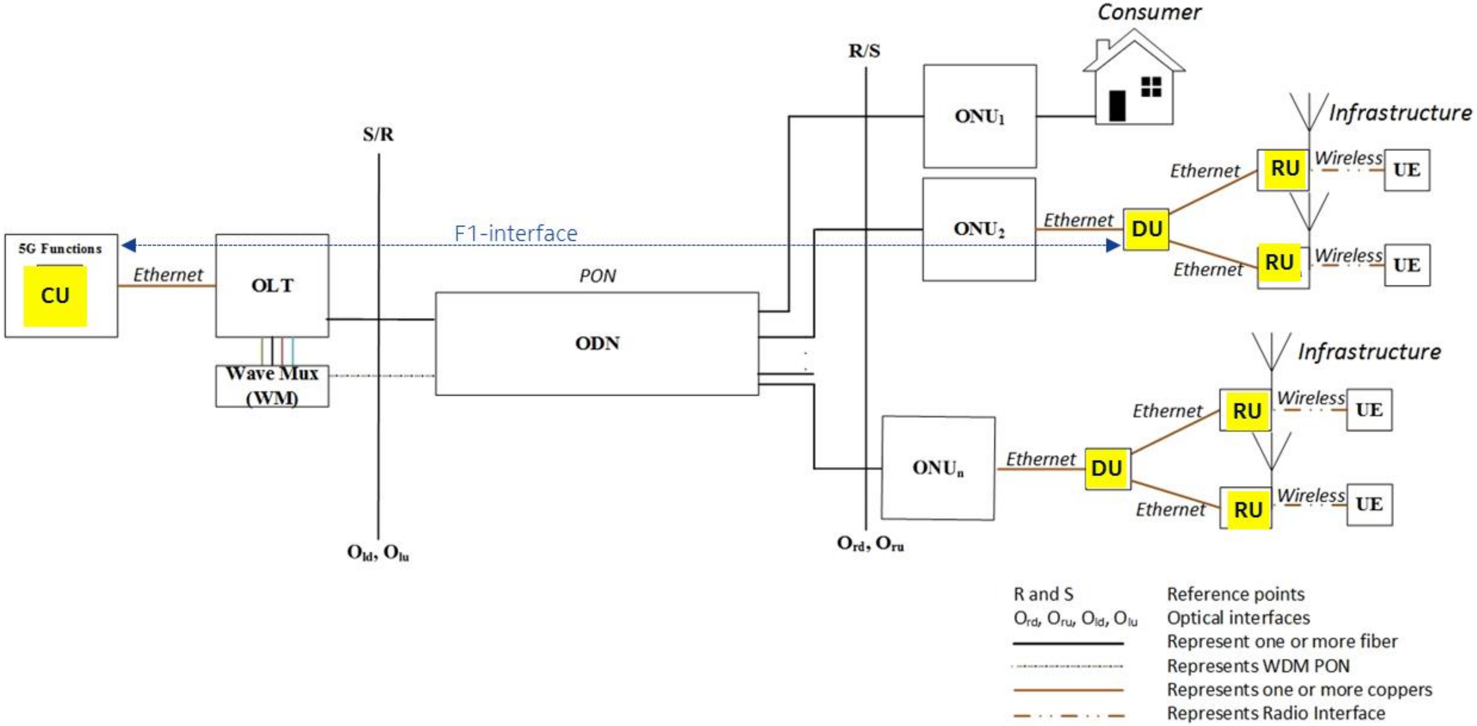
A) Obvious use case for PON: transport at F1 interface between CU and DU



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A) Sample calculation of capacities for air interface and F1 transport

Air interface quiet time peak data rate for 5G

(Assumptions:
- up to 100 MHz:
sub-6GHz, 256QAM; FDD with possibly different UL and DL BW
- above 100 MHz:
> 6GHz (256QAM; TDD with aggregated UL + DL bandwidths)

MIMO	Air Peak data rate (Mbps)						
16	718	1436	2872	7180	19008	38016	76032
8	359	718	1436	3590	9504	19008	38016
4	180	359	718	1795	4752	9504	19008
2	90	180	359	898	2376	4752	9504
1	45	90	180	449	1188	2376	4752
	10	**20**	**40**	**100**	**200**	**400**	**800**
							RF Bandwidth (MHz)

Aggregate F1 data rate; white, green, yellow cells indicate compliance with GPON, 10G PON, 25G PON

MIMO	aggregated F1 interface data rate from a single DU, serving 10 RUs (Mbps)						
16	1465	2930	5860	14649	38780	77560	155120
8	732	1465	2930	7324	19390	38780	77560
4	366	732	1465	3662	9695	19390	38780
2	183	366	732	1831	4848	9695	19390
1	92	183	366	916	2424	4848	9695
	10	**20**	**40**	**100**	**200**	**400**	**800**
							RF Bandwidth (in MHz)

B) Fx-fronthaul (Options 6/7) of small cells in ultra-dense radio networks

conventional Fx-FH C-RAN → *C-RAN with local Fx-FH for small cells*

distance from CO is limited by Fx-fronthaul latency (sub-msec)

distance from CO can be as much as allowed by F1-fronthaul latency (msec)

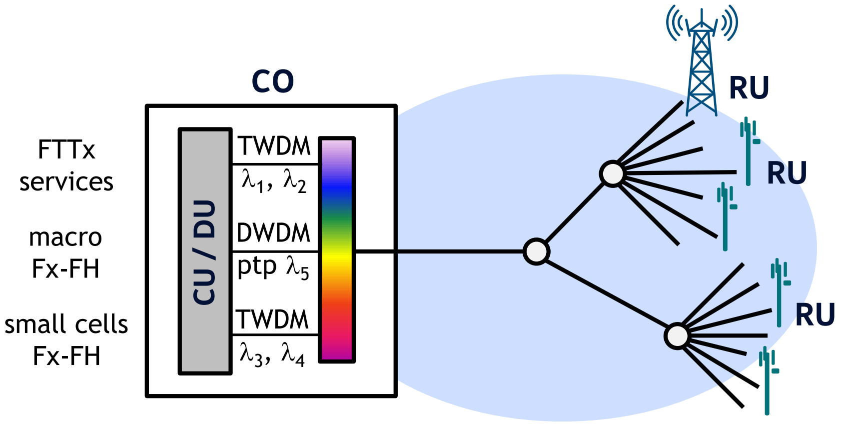
< 10 km

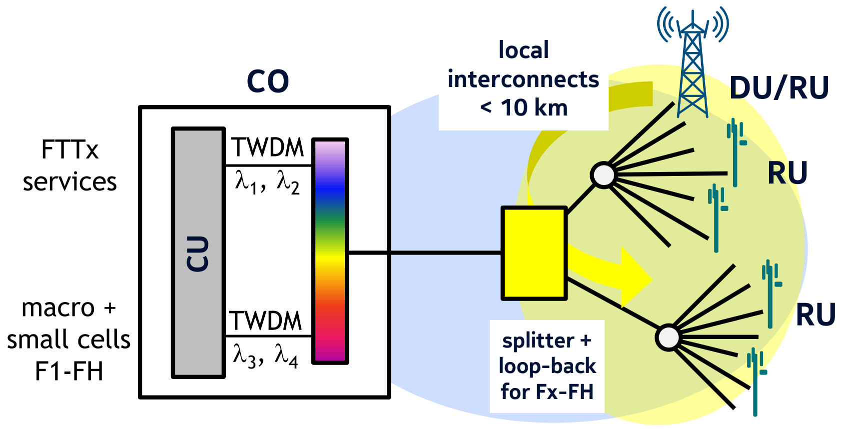
fronthaul from CO to macro + small cells

>> 20 km

F1-fronthaul from CO to macro cell

Fx-fronthaul from macro to small cells





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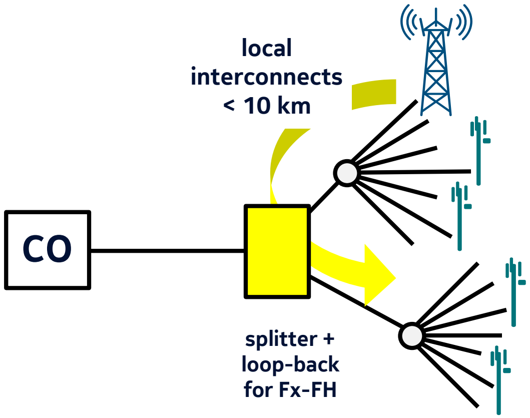
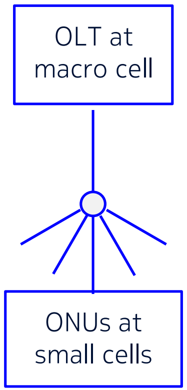
B) Local C-RAN: two independent PONs on the same ODN



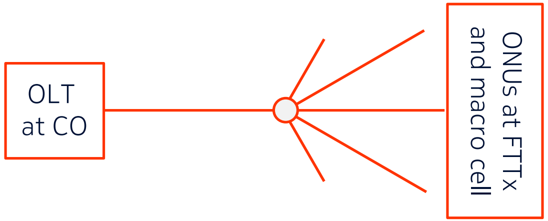


<u>short range PON</u>
for Fx-FH on
separate wavelength

blue ODN

reuses

drop section
of red ODN



<u>long range PON</u>
for FTTx and F1-FH

what's inside the
central splitter + loop-back box?

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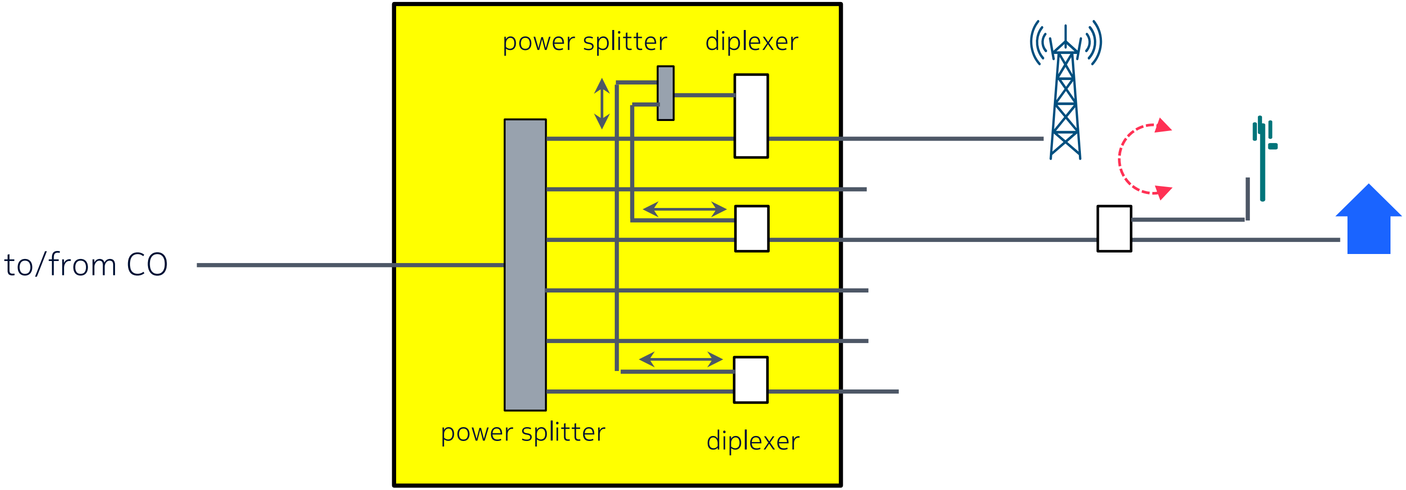
B) Splitter with additional loop-back for local Fx-FH in WDM overlay

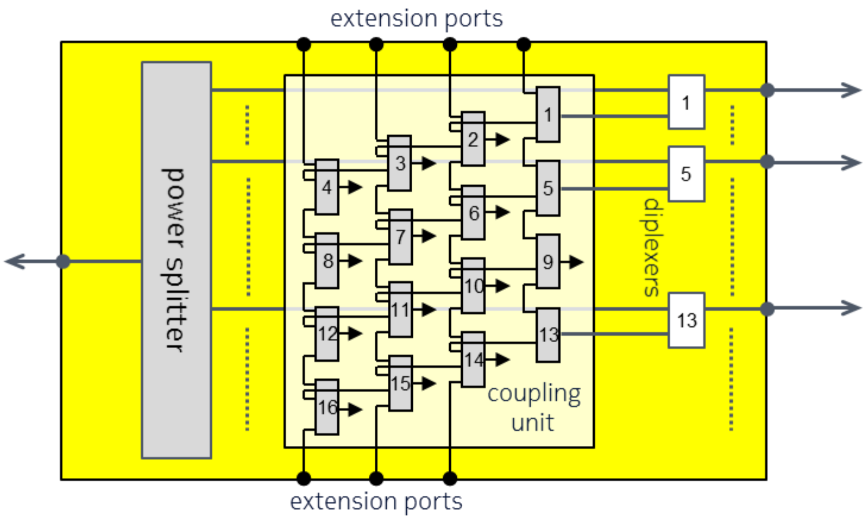


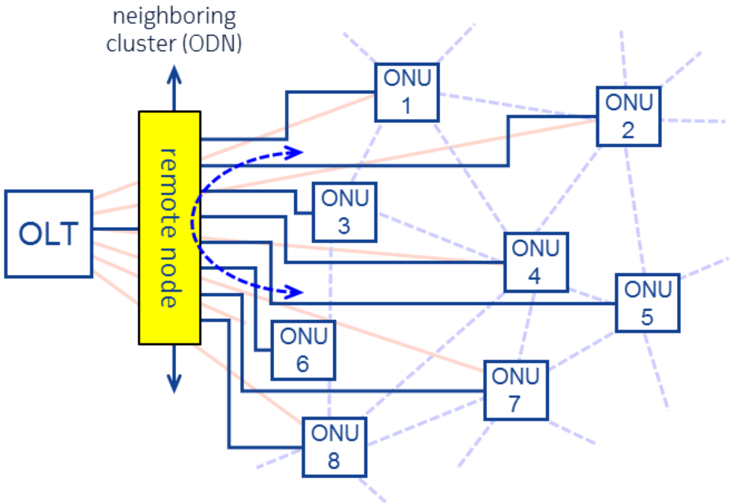
Splitting loss for single stage architecture:

local PON ~1/N_1 (<1/N)
long distance PON ~1/N
(N+N_1 nodes being served on 1/N ODN)

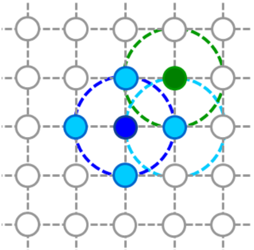
- needs N_1+2 additional elements
- port selection for small cells is not flexible

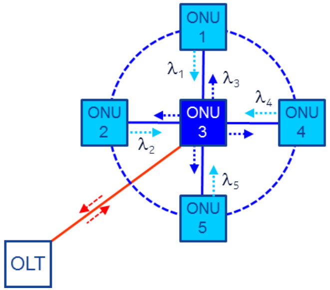
B) For more complex interconnects, with overlapping local clusters for CoMP





coupling unit establishes a square grid topology for the attached ONUs





elementary cell:

- each ONU broadcasts data to 4 local neighbours
- and is attached to the core node via common power splitter

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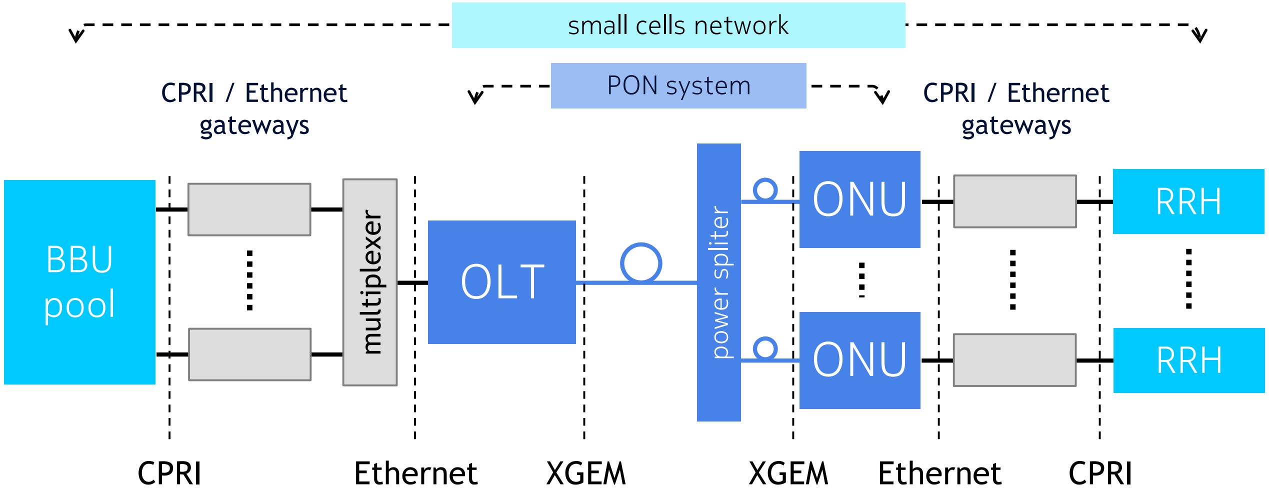
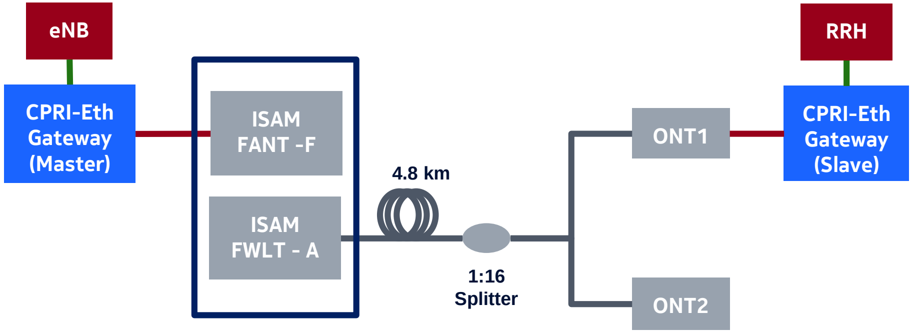
C) Minimizing (CPRI) fronthaul latencies over TDM-PON



Lowest latencies achievable by fixed bandwidth assignment on the TDM-PON network

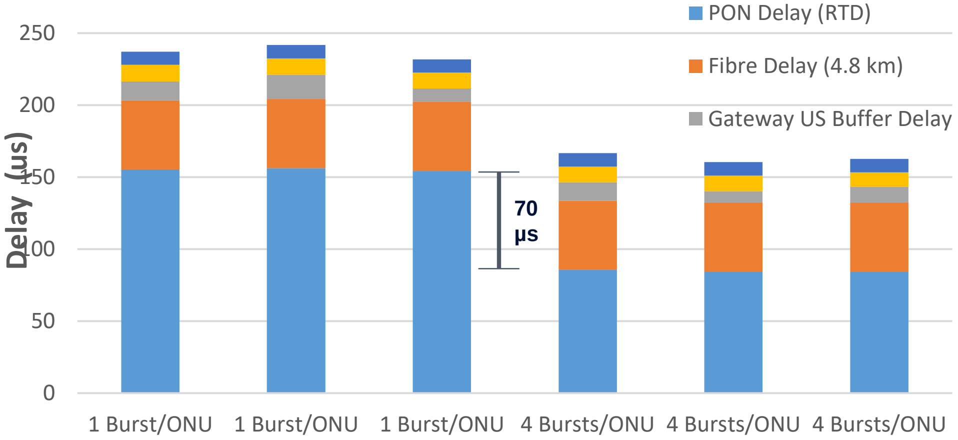
- option a): native CPRI-over-Ethernet:
  - chopping and encapsulating the CPRI stream as is
- option b): Radio-over-Ethernet (not shown)
  - IQ data and C&M data are encapsulated into Ethernet without CPRI framing

C) CPRI latency analysis of demo system using commercial TDM-PON



PON Upstream Burst Configuration		Master Gateway upstream buffer delay (µs)	PON round-trip delay w/o fiber (µs)	Measured CPRI Round-Trip Delay (µs)
1 burst per ONU	Measurement 1	13,02083333	155,341378	**237,1669962**
	Measurement 2	16,92708333	156,1193612	**241,688469**
	Measurement 3	9,440104167	154,1520198	**231,8435235**
4 bursts per ONU	Measurement 1	12,92317708	85,43718082	**166,4164449**
	Measurement 2	7,877604167	84,41343183	**160,9330605**
	Measurement 3	10,80729167	84,4341799	**162,4512044**

- gateway buffer latency is ≈ 10s µs
- 2 x gateway processing delay ≈ 10 µs
- estimated PON round trip delay is ≈ 85 µs
  with 4 bursts per ONU per 125 µs PON frame
- fiber round trip delay ≈ 48 µs



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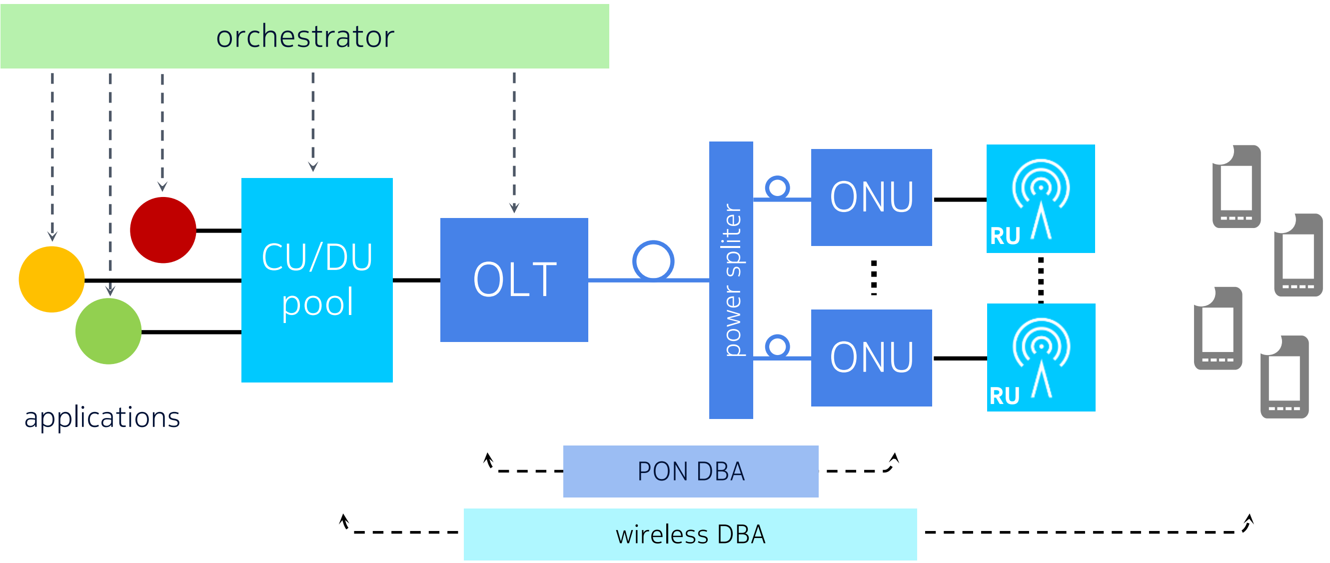
C) Minimizing (eCPRI) Next Generation Fronthaul latencies on TDM-PON

NGFH splits allow for taking advantage of statistical multiplexing gains

→ dynamic coordination of wireless and PON capacities according to scheduled traffic : Co-DBA
→ SDN type coordination of capacities across applications, radio and PON by a common orchestrator



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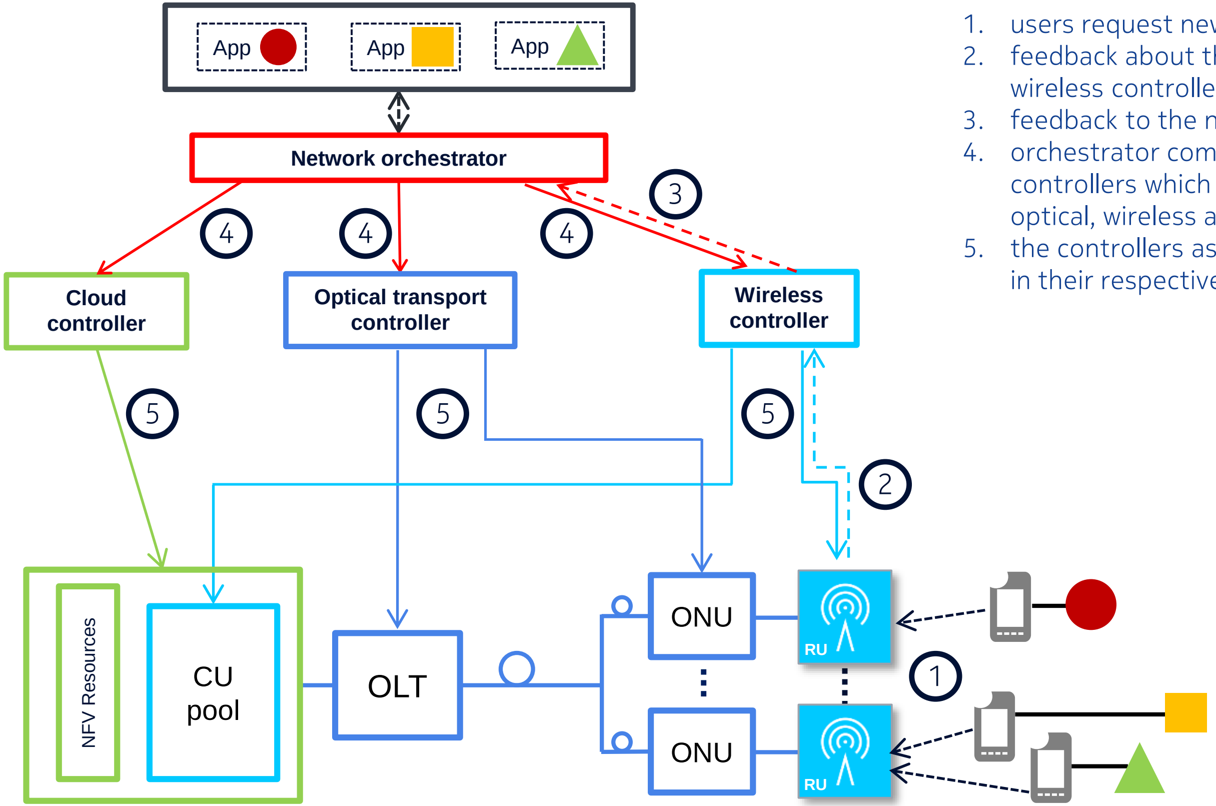
C) end-to-end coordinated dynamic bandwidth assignment



1. users request new bandwidth
2. feedback about the new requirement to the wireless controller
3. feedback to the network orchestrator
4. orchestrator communicates to the controllers which resources to assign in the optical, wireless and cloud domain
5. the controllers assign the required resources in their respective domain

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Summary

Specific use cases considered, particularly with focus on small cells

Bandwidth considerations:

- statistical multiplexing at F1 and Fx interface → TDM-PON
- high aggregate bandwidth on either interface → WDM-PON

Latency and jitter optimization for

- local CRAN in distant areas
- local interconnections for CoMP
- Cooperative DBA (Co-DBA)
- SDN-type orchestration across application – wireless – PON

5G is driving PON technologies towards 25G and beyond,
along with optimized architectures and control plane

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