Scenarios and Economic Analysis of Fronthaul

Andrea Di Giglio[1], Anna Tzanakaki[2, 3] and Dimtira Simeonidou[2]

1. Telecom Italia, Via Reiss Romoli, 274 – 10146 Torino (ITALY); University of Bristol, UK; 3. National and Kapodistrian University of Athens, Greece

Abstract: this work presents a comparison between C-RAN and emerging DA-RAN approaches for 5G networks. Main results show that DA-RAN and splitting alternative to CPRI bring economical and architectural advantages.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.4250) Networks.

1. Introduction

Coexistence with legacy (2-3G), Long Term Evolution (LTE / 4G) and Wi-Fi technologies, together with the improvement of spectral efficiency and throughput, represent important requirements for 5G networks. To fulfill those requirements operators are evaluating the migration from the traditional Distributed Radio Access Network (D-RAN) paradigm, where Base Band Units (BBUs) and Remote Radio Units (RRUs) are co-located, and the new Cloud/Centralized Radio Access Network (C-RAN) where RRUs are connected to one/few central units hosting a BBU pool through high bandwidth transport links, known as fronthaul. In fact the C-RAN approach can address some limitations of D-RAN, such as high costs, as well as limited scalability and flexibility. However, C-RAN may require huge transport bandwidth and impose strict latency and synchronization constraints [1]. The H2020 5G PPP project 5G-PICTURE [9] proposes a novel architecture exploiting flexible functional splits to address the limitations of C-RAN. In the project approach the optimal "split" can be flexibly decided, based on some factors such as transport and service requirements, yielding the ability of satisfying the challenging requirements set by emerging "verticals", such as high-speed train and industry 4.0 [2-4].

2. Network paradigm evolution

It has already been demonstrated in [5] and [6] that centralization of the base-band processing (C-RAN) reduces capital and operational costs by more than 30%. Furthermore it enables the implementation of advanced radio features such as Coordinated Multi-Point (CoMP). In addition, in C-RAN, the antenna sites are simplified with respect to D-RAN since no base-band processing is required, allowing significant installation and maintenance savings. However, C-RAN presents some disadvantages, since it requires huge bandwidth and ultra-low latency that make it unsuitable to satisfy 5G verticals requirements. 5G-PICTURE proposes a paradigm shift, from C-RAN to a novel concept adopting the notion of "disaggregation" of hardware and software components across wireless, optical and compute/storage domains. This approach, referred to as "Dis-Aggregated RAN" (DA-RAN), allows decoupling of hardware and software components creating a common "pool of resources" that can be independently selected and allocated on demand composing, in principle, any 5G service. Apart from increased flexibility, DA-RAN, due to its modular approach, offers enhanced scalability, upgradability and sustainability potential, particularly relevant to 5G, supporting huge and nonstop growing number of devices and services.

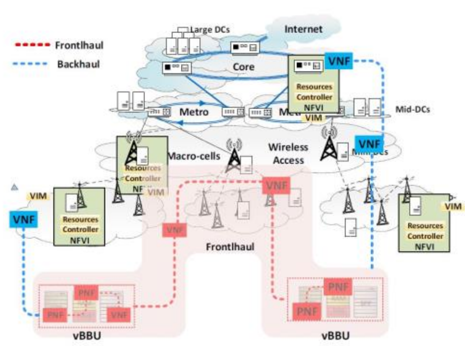

Fig. 1. DA-RAN network paradigm supporting integration of fronthauling and backhauling [9]

Fig. 1 depicts the DA-RAN architecture, highlighting the concept of flexible RAN functional splits and the integration of fronthaul and backhaul on the same transport network. An important aspect of the 5G-PICTURE architecture is hardware programmability and the adoption of distributed Physical/Virtual Network Functions

(PNFs/VNFs). These are controlled by Virtualized Infrastructure Managers (VIM), responsible of controlling computing, storage and network resources. FH and BH services are supported through a combination of PNFs and VNFs orchestrated by appropriate service chains.

3. Quantitative analysis

In this study a set of network planning simulations have been performed on C-RAN and DA-RAN aimed at comparing costs, energy consumption and some efficiency figures. A schematic view of the analyzed network is depicted in Fig. 2.

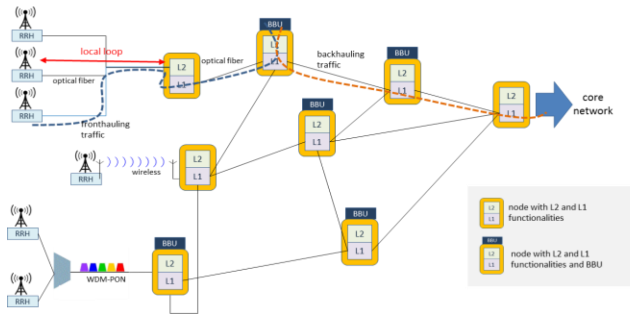

Fig. 2. Architecture of the network analyzed in the simulation

The local loop (i.e. the link between the antenna site and the edge node) can be based on point-to-point optical fiber, WDM-PON or wireless. Each edge node grooms, at layer 2, the traffic towards the same destination and splits the traffic into packet (L2) and optical (L1) services. L2 traffic is groomed with other traffic in the intermediated nodes, while L1 optical circuits are delivered to destination optical bypassing intermediate nodes. The lightpaths in the ROADM based network (Fig. 2) (40 wavelength per fiber) are defined by a Routing and Wavelength Assignment (RWA) algorithm. Each node is equipped by both L2 and L1 optical switching functionality. L2 is implemented by a MPLS-TP switch (the throughput ranges between 1.6T and 19.2T), while the ROADM consist of low-cost wavelength selective switches based on silicon photonics. The optical transceivers are 100G non-coherent (PAM4). In some cases, a combination of 10G, 40G and 100G optical channels is considered for transport cost optimization.

The network under analysis is similar to a metro/regional network (MAN) of northern Italy, with a very high user density distribution. It is composed by rings interconnected by a meshed core network to the hub nodes. Each ring is composed of a variable number of BBU sites and L1/L2 nodes. More than 1400 antennas sites are served by the MAN, and the local loop is based on mmWave radio links for 40 and on WDM-PON for 80 out of more 1400 antennas. Four areas are covered by small cells, offloading macro-cell traffic and the entire network serves more than 300.000 users. Massive MIMO is also considered in some cases. The adopted splitting option is (Common Public Radio Interface) CPRI, since it guarantees the best performance for C-RAN. Besides the requirement of about 24 km maximum distance between RRU and BBU [7], CPRI needs more than tenfold the bitrate of the end user bitrate, making it critical in geographical connections. In a 5G environment, especially with massive MIMO and beamforming, CPRI will quickly fall short. The new eCPRI [8], considered as an option in the following evaluation, is defined to overcome some CPRI limitations. The chosen option for eCPRI is the transport of frequency domain I/Q symbols (split II_d/I_u) [8], allowing more than 5-fold bandwidth saving in the fronthaul w.r.t. CPRI.

Tab. 1. Analyzed case studies

	Splitting option	Opt. bypass Threshold	Opt. interfaces
1	CPRI	45 Gbit/s	100G
2	CPRI	8 Gbit/s	10/40/100G
3	eCPRI	8 Gbit/s	10/40/100G

Tab. 1 reports the characteristics of the simulated use cases and in particular about the splitting option, the threshold to enable optical bypass and the adopted optical interfaces. For each use case C-RAN and DA-RAN networks have been dimensioned and compared w.r.t. costs, energy consumption and dimensioning parameters

Tab. 2. Synthesis of simulation results

	C-RAN					DA-RAN				
	YTCO (CU)	YTCO (CU) (transport)	Energy (MWh/year)	Max link size (parallel fibres)	Max nodal degree	YTCO (CU)	YTCO (CU) (transport)	Energy (MWh/year)	Max link size (parallel fibres)	Max nodal degree
1	15375	12079	2371	6	24	14729	11220	2529	5	17
2	17095	13557	3507	6	24	15635	12067	3360	5	22
3	12583	8871	2717	2	9	12390	8651	2655	1	2

The results of Tab. 2 clearly show that the introduction of a splitting option alternative to CPRI (e.g. eCPRI, currently under standardization) improves costs and energy consumption, especially in the transport segment. The costs are reported as Yearly Total Cost of Ownership (YTCO), calculated as $\boldsymbol{YTCO = \Sigma_i\,(CAPEX_i/AP_i) + \Sigma_j\,OPEX_j}$, where $CAPEX_i$ and $OPEX_j$ are the i-th and j-th components of CapEx and OpEx respectively. In order to harmonize the sum, each CapEx has to be annualized, distributing the investment on the appropriate amortization period (*AP*).

DA-RAN, in addition to the advantages listed above, also allows an economic saving, albeit of a minor extent. It is important to note that the maximum nodal degree (i.e. the number of fiber pairs entering in a node) is very high in particular for CPRI splitting in C-RAN architecture. This imposes either a cumbersome node architecture with many interconnections among elementary ROADM devices (that can individually manage a nodal degree up to 8-10 maximum), or the adoption of conventional WSS ROADM, greatly increasing costs.

Going into details considering the transport costs of the use case 3 it is possible to highlight that the fiber local loop is predominant, see Tab. 3. In order to lower this cost a massive use of WDM-PON would be necessary so that more RRHs can share the same fiber. This solution is only possible if the band for fronthauling is not huge, so not using CPRI, and if the savings on the fiber cost is not counterbalanced or even overtaken by costs for WDM-PON devices (OLT, ONU, ...).

Tab. 3. Costs results for use case 3

CAPEX	**Yearly cost**	
	(C-RAN)	**(DA-RAN)**
WDMPON	862.38	862.38
L2 matrix	170.11	79.61
10G interfaces	3.61	46.31
40G interfaces	31.32	57.42
100G interfaces	280.61	58.73
ROADM	102.41	125.16
wireless	386.75	382.83
Total CAPEX [CU]	**1837.19**	**1612.44**

OPEX	**Yearly cost**	
	(C-RAN)	**(DA-RAN)**
energy	350.86	431.56
fiber network	874.07	730.22
fiber local loop	4934.34	4934.34
space (racks)	97.68	113.10
maintenance	781.98	825.09
Total OPEX [CU]	**7038.93**	**7034.32**

Furthermore DA-RAN takes advantage of a lower peak traffic: this is highlighted by a lower usage of 100G interfaces and a reduced L2 aggregation capacity.

4. Conclusions

The DA-RAN architecture envisaged by the 5G-PICTURE project, has been designed to comply with the new 5G verticals' stringent requirements. In this work we demonstrated that DA-RAN allows cost and energy savings and a better traffic distribution in the optical fronthaul network. Furthermore it is confirmed that CPRI consumes a too large bandwidth when 5G advanced features are adopted (massive MIMO, beamforming,…). Alternative splitting (e.g. eCPRI) promises retrenches and lower network load.

5. Acknowledgement

The authors wish to thank Marco Schiano for ideas and comments that greatly improved the manuscript. This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 762057 (5G-PICTURE).

6. References

[1] D. Bladsjo et al., "Synchronization aspects in LTE Small Cells," IEEE Comm. Mag., vol.51, no.9, pp.70,77, Sep. 2013

[2] U. Dötsch et al., Quantitative Analysis of Split Base Station Processing and Determination of Advantageous Architectures for LTE, Bell

[3] D. Wubben et al., "Benefits and Impact of Cloud Computing on 5G Signal Processing: Flexible centralization through cloud-RAN," IEEE Signal Processing Magazine, vol.31, no.6, pp.35-44, Nov. 2014.

[4] A. Tzanakaki, "Wireless-Optical Network Convergence: Enabling the 5G Architecture to Support Operational and End-User Services", *IEEE Commun. Magazine*, 55 (10), 184-192, 2017

[5] C. Raack et al., "Centralised versus Distributed Radio Access Networks: Wireless integration into Long Reach Passive Optical Networks", Conference of Telecommunication, Media and Internet Techno-Economics (CTTE), Nov. 2015

[6] A. De La Oliva et al., "Final 5G-Crosshaul system design and economic analysis", 5G-Crosshaul public deliverable, Dec. 2017

[7] H. J. Son et al., "Fronthaul Size: Calculation of maximum distance between RRH and BBU", NETMANIAS, Apr. 2014

[8] eCPRI, "V1.0 Common Public Radio Interface: eCPRI Interface Specification," Ericsson AB, Huawei Technologies Co. Ltd, NEC Corporation and Nokia, Aug. 2017

[9] 5G-PICTURE, http://www.5g-picture-project.eu/index.html