H2020 5G PPP 5G-Crosshaul project
Grant No. 671598

D6.2: Year 2 achievements and plan for Year 3

Abstract

This deliverable (D6.2) reports on all the activities undertaken in WP6 in the second year of the project, i.e. from 1st of July 2016 to 30th of June 2017. It also provides an outline of the work plan for the remaining six months of project execution, i.e. from 1st of July 2017 to 31st of December 2017.

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List of Acronyms

Acronym	Description
3GPP	Third Generation Partnership Project
5G PPP	5G Public Private Partnership
API	Application Program Interface
BBF	Broadband Forum
BBU	Baseband Unit
BoF	Birds of a Feather (IETF Pre-Working Group efforts)
BPON	Broadband Passive Optical Network
BSS	Base Station Subsystem
CDN	Content Delivery Network
CNF	Conference dissemination
CP	Cyclic Prefix
CPRI	Common Public Radio Interface
CSA	Coordination and support Action
CU	Centralized Unit
DetNet	Deterministic Networking (IETF)
DL	Downlink
DU	Distributed Unit
eCPRI	Enhanced CPRI
eMBB	Enhanced Mobile Broadband
EPC	Evolved Packet Core
ETP	European Technology Platform
ETSI	European Telecommunications Standards Institute
FFT	Fast Fourier Transform
FSAN	Full Service Access Network
GSM	GSM Association
GPON	Gbit/s-capable PON
HetNet	Heterogeneous Networks
ICT	Information and Communication Technology
IEEE	Institute of Electronics and Electrical Engineering
IETF	Internet Engineering Task Force
iFFT	Inverse Fast Fourier Transform
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
IPR	Intellectual Property Rights
IRTF	Internet Research Task Force
ISG	Industry Specification Group (ETSI)
IT	Information Technology
ITU-R	International Telecommunications Union – Radiocommunication sector
ITU-T	International Telecommunications Union – Telecommunications standardization sector

JRN	Journal dissemination
LAN	Local Area Network
LTE / -A	Long Term Evolution / -Advanced (3GPP)
MAC	Medium Access Control
MAG	Magazine dissemination
MEC	Mobile Edge Computing
mMTC	Massive Machine Type Communications
MPLS	Multiprotocol Label Switching
MWC	Mobile World Congress
mWT	Millimetre Wave Transmission (ETSI)
NFV	Network Functions Virtualization
NFVRG	NFV Research Group (IRTF)
NGFI	Next Generation Fronthaul Interface
NGMN	Next Generation Mobile Networks
NG-PON	Next Generation Passive Optical Network
OAM	Operation, Administration and Maintenance
ODL	OpenDayLight
OF	Open-Flow (ONF)
ONF	Open Networking Foundation
ONT	Optical Network Terminal
OTN	Optical Transport Network
OSS	Operations Support System
PAR	Project Authorization Request
PDCP	Packet Data Convergence Protocol
PHY	Physical Layer
PoC	Proof of Concept
PON	Passive Optical Network
PRACH	Physical Random Access Channel
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RE	Radio Equipment
RLC	Radio Link Control
RNC	Radio Network Controller
RoE	Radio Over Ethernet
RoF	Radio Over Fibre
RRC	Radio Resource Control
RRH	Remote Radio Head
RRU	Remote Radio Unit
SCF	Small Cells Forum
SDN	Software Defined Networks
SDNRG	SDN Research Group (IRTF)
SDO	Standard Development Organization
SLA	Service Level Agreement
TCO	Total Cost of Ownership

TDM	Time Division Multiplexing
THES	Thesis dissemination
TTA	Telecommunications Technology Association
TSN	Time Sensitive Networking
UL	Uplink
URLLC	Ultra-Reliable Low-Latency Communications
VIM	Virtual Infrastructure Manager
VNF	Virtual Network Function
WDM	Wave Division Multiplexing
WG	Working Group
XCI	Xhaul Control Infrastructure
XGPON	10Gbit/s-capable PON

Executive Summary

Building on the momentum achieved in Year 1, the second year followed with key achievements for the dissemination and exploitation activities accompanying the accelerated technology development in Year 2. These activities are highlighted below:

- A noticeable presence at Mobile World Congress 2017, with a full programme including demonstrations, panel, invited talks, videos, leaflet, and press release.
- An active communication and dissemination through 25 talks and panels, and 5 organized workshops, in addition to press releases, videos, and interviews.
- A good record of scientific peer-reviewed publications with 46 articles published or accepted for publication (and several others submitted) in reputed scientific journals/magazines and conference/workshop proceedings.
- A significant boost in the number of contributions submitted to standardization forums, with 19 contributions submitted in various groups, such as IEEE, ONF, IETF, and eCPRI.
- A proactive identification of key innovations from the project together with pre-commercial proof-of-concepts, and a new product (AnyHaul) from 5G-Crossaul partner Nokia, which all bear a good potential for further exploitation.

In addition to what listed above, an outline of the work plan for the remaining six months of the project execution (Jul. 2017 to Dec. 2017) has been developed and shared in this deliverable.

1 Introduction

This document reports on the achievements of the 5G-Crosshaul project in Year 2 for all communication, dissemination, standardization and exploitation activities. It also outlines a work plan for these activities in the remaining six months of the project execution (Jul. 2017 to Dec. 2017).

The document is structured into four main chapters, namely, (1) communication and public activities, (2) dissemination and collaboration activities, (3) standardization activities, and (4) exploitation activities.

Chapter 2 reports on the communication and public activities undertaken in Year 2. These activities are steered towards ensuring an up-to-date communication on the project to the large public through various channels including portal, social networks, videos, and press releases.

Chapter 3 reports on the dissemination activities including talks, workshops, and peer-reviewed scientific articles. It also reports on related collaboration activities undertaken in the framework of the 5G-PPP including its projects and working groups. The goal of such activities is mainly to promote the project to the Research & Development (R&D) stakeholders, and raise opportunities for collaboration or synergy with other projects and activities.

Chapter 4 reports on latest developments of related standard bodies such as 3GPP, IETF, eCPRI, and ITU-T. In addition, standardization activities undertaken by the consortium, including both dissemination and contributions are presented. These activities are aimed at creating an influence from/to ongoing or future standardization activities so that the technology developed in the project can find an easier path for exploitation into future products.

Chapter 5 reports on the exploitation activities undertaken with the aim to identify key innovations from different technical work packages within the project, as well as the proof-of-concepts and products from the partners that are correlated to 5G-Crosshaul.

The document ends with conclusions summarizing the work done in Year 2, and insights on the next steps planned for the remaining six months.

2 Communication and Public Activities

This chapter reports all the communication activities undertaken during Year 2.

2.1 Press releases

Three press releases were issued in Year 2, two in relation to the trials conducted in Berlin from September through November 2016, and an additional press release accompanying the MWC 2017 show.

Table 1: Press releases.

#	Month	Description	Lead partners
1	Sep'16	**InterDigital Demonstrates Integrated Fronthaul and Backhaul Over Millimeter Wave System** H2020 5GPPP 5G-Crosshaul Project uses InterDigital's EdgeLink™ in first proof-of-concept demonstration http://ir.interdigital.com/file/Index?KeyFile=36022570	IDCC
2	Nov'16	**5G-Crosshaul Partners Announce Successful Result of 5G Integrated Fronthaul-Backhaul Extended Outdoor Trial** Month-plus trial in real-world conditions, a first of its kind, delivers sub-millisecond latency, Gbps throughput; integrated fronthaul/backhaul sets stage for cost saving, flexibility in real-world deployable 5G architecture http://ir.interdigital.com/file/Index?KeyFile=36613495	IDCC, HHI, CND
3	Feb'17	**InterDigital Headlines GSMA 5G Showcase Alongside Industry Leaders at Mobile World Congress** Company's Crosshaul project featured on mainstage alongside 5G demos by Ericsson, Qualcomm, Intel http://ir.interdigital.com/file/Index?KeyFile=38231311	IDCC

2.2 Interviews

The project coordinator provided 4 interviews on the project as summarized below.

Table 2: Interviews.

#	Month	Description	Lead partners
1	Sep'16	Interview in Radio Exterior de España (15 minutes). https://www.youtube.com/watch?v=rlN4et8VnpY&feature=youtu.be	UC3M
2	Sep'16	Interview in SER Madrid Sur (14 minutes). http://play.cadenaser.com/audio/1473327004_983007/	UC3M
3	Mar'17	Interview at the program "World Ecommerce" in Radio Internacional de España. https://www.youtube.com/watch?v=LhwOyG2It2M&feature=youtu.be	UC3M
4	Jun'17	Interview on the project demonstrations at the EuCNC 2017 (link not available at the time of writing of this deliverable)	UC3M

2.3 Leaflet

A leaflet highlighting the progress of the project, trials, and programme at MWC 2017 was prepared and distributed at the MWC 2017 show. This is shown below.

Figure 1 The Project leaflet for MWC 2017

2.4 Videos

Videos on project demonstrations and trials were filmed and posted on the web.

Table 3 Videos.

#	Month	Description	Lead partners
1	Sept'16	**Video demonstration on the Berlin trial** was taken and published on YouTube, the project portal (http://5g-crosshaul.eu/5g-crosshaul-demonstrates-integrated-fronthaul-and-backhaul-over-millimeter-wave-system/), and partners' portals (e.g. http://www.interdigital.com/videos/5g-crosshaul). This video demonstration was also shown at the 5G-Global Event in Rome, November 2016.	IDCC, HHI, CND
2	Feb'17	**MWC17: 5G-Crosshaul with EdgeLink™ Platform** (http://www.interdigital.com/videos/mwc17-)	IDCC
3	Mar'17	**Video on the MWC 2017 panel: Crosshaul – The Fusion of Fronthaul and Backhaul in 5G** (http://5g-crosshaul.eu/watch-crosshaul-panel-at-mwc17/)	IDCC

2.5 Blogs/Newsletters/Social media

A blog article was published in July 2016 by IDCC in the international magazine NetworkWorld: **Fronthaul and backhaul: Look out, a fusion is coming!**

http://www.networkworld.com/article/3096788/virtualization/fronthaul-and-backhaul-look-out-a-fusion-is-coming.html

Also, VISIONA has posted the news relating to 5G-Crosshaul demos at EuCNC'17 on Twitter: https://twitter.com/VisionaIP/status/874541070092316672

Inputs were provided to the 5G-PPP Euro-5G group on 5G-Crosshaul participation in the 2nd 5G Global event, published at https://5g-ppp.eu/5g-crosshaul-2nd-global-5g-event-in-rome/ and in the newsletter https://5g-ppp.eu/newsletter-6/;

In addition, the project coordinator (UC3M) and WP6 manager (IDCC) kept the project portal updated and the social media posted on news and events from the project. They also kept attending the 5G-PPP communication and dissemination working group.

2.6 Work Plan for Year 3 (6 months)

The project has agreed the following plan for the next 6 months of the project lifetime:

- Press release announcing the completion of the project and its key innovations.
- Final leaflet summarizing the key achievements of the project. The leaflet will be distributed by partners present at MWC 2018 show.
- Videos, interviews, webinars and blog articles focused on the overall project achievements during the project lifetime.
- Continuous communication through the project portal, the social networks, and the 5G-PPP communication and dissemination working group.

3 Dissemination and Collaboration Activities

In Year 2, dissemination and collaboration activities have been conducted in accordance with the plan set in D6.1. This chapter presents all achievements for the dissemination and collaboration activities during Year 2.

3.1 Scientific (peer-reviewed) Publications

Error! Reference source not found. Table 4: Journal/Magazine Papers Publications lists all peer-reviewed journals and magazines publications as they are published or accepted for publication in Year 2. Table 5: Conference Papers Publications in Year 2., on the other hand, provides a list of papers that have been published in scientific conference proceedings. As reported, in total 46 peer-reviewed articles from the project have been published (or accepted for publication) in Year 2, including 14 journal/magazine papers and 32 conference papers. Such an achievement is more than double of the target set for Year 2.

Table 4: Journal/Magazine Papers Publications in Year 2.

#	Type	Month	Description	Leading Partner
1	MAG	Jul'16	"5G-Crosshaul: An SDN/NFV Integrated Fronthaul/Backhaul Transport Network Architecture", by X. Costa-Pérez, A. Garcia-Saavedra, X. Li, A. de la Oliva, P. Iovanna, T. Deiß, A, di Giglio, and A. Mourad, *IEEE Wireless Communications Magazine*, Vol. 24, No. 1, Feb. 2017.	NEC, UC3M, TEI, NOKIA, TI, IDCC
2	JRN	Sep'16	"5G-Crosshaul: An SDN/NFV Control and Data Plane Architecture for the 5G Integrated Fronthaul/Backhaul", by S. González, A. de la Oliva, X. Costa, A. Di Giglioz, F. Cavalierex, T. Deiss, X. Li, A. Mourad, *Transactions on Emerging Telecommunications Technologies*, Vol. 27, No. 9, Sept. 2016	NEC, UC3M, IDCC, NOKIA
3	JRN	Nov'16	"An LPC-Based Fronthaul Compression Scheme," L. Ramalho, M. N. Fonseca, A. Klautau, C. Lu, M. Berg, E. Trojer, and S. Höst, *IEEE Communications Letters*, November 2016.	EAB
4	JRN	Dec'16	"Future Proof Optical Network Infrastructure for 5G Transport", by P. Iovanna et al., *Journal of Optical Communications and Networking*, Vol. 8, Issue 12, pp. B80-B92 (2016)	TEI
5	JRN	Dec'16	"Quasi-Passive Optical Infrastructure for Future 5G Wireless Networks: Pros and Cons", by A.S. Gowda, L.G. Kazovsky, K. Wang, and D. Larrabeiti, *Journal of Optical Communications and Networking*, Vol. 8, Issue 12, pp. B111-B123 (2016)	UC3M
6	JRN	Dec'16	The Impact of Vehicular Traffic Demand on 5G Caching Architectures: a Data-Driven Study, by F. Malandrino, C.-F. Chiasserini, and S. Kirkpatrick,	POLITO

			Elsevier Vehicular Communications Journal, Dec. 2016	
7	JRN	Dec'16	Trade-off between Power and Bandwidth Consumption in a Reconfigurable Xhaul Network Architecture, by V. Eramo, M. Listanti, F. G. Lavacca, P. Iovanna, G. Bottari, and F. Ponzini, *IEEE Access*, Vol. 4, pp. 9053-9065, Dec. 2016.	TEI
8	JRN	Jan'17	"The Need of a Transport API in 5G for Global Orchestration of Cloud and Networks through a Virtualised Infrastructure Manager and Planner (Invited)" by A. Mayoral, R. Muñoz, R. Vilalta, R. Casellas, R. Martínez, and V. López, *Journal of Optical Communications and Networking (JOCN*), vol 9, pp: A55-A62 (2017), special OFC2016 issue;	CTTC, TID
9	JRN	Mar'17	"Towards a unified fronthaul-backhaul data plane for 5G, The 5G-Crosshaul project approach," F. Cavaliere, P. Iovanna, J. Mangues, J. Baranda, J. Núñez, K. Lin, H. Chang, P. Chanclou, P. Farkas, J. Gomes, L. Cominardi, A. Mourad, A. de La Oliva, J. Alberto Hernández, D. Larrabeiti, A. Di Giglio, A. Paolicelli, P. Ödling, *Elsevier Computer Standards & Interfaces*, Vol. 51, pp. 56-62, March 2017.	TEI, CTTC, ITRI, ORANGE, HHI, IDCC, UC3M, TI
10	JRN	Mar'17	"Low Delay Random Linear Coding and Scheduling Over Multiple Interfaces", by A. Garcia-Saavedra, M. Karzand, and D. J. Leith, in *IEEE Trans. on Mobile Computing*, Mar. 2017	NEC
11	JRN	Mar'17	"Delay analysis of mixed fronthaul and backhaul traffic under strict priority queueing discipline in a 5G packet transport network", by A. Gowda, J. A. Hernández, D. Larrabeiti, and L. Kazovsky, in *Transactions on Emerging Telecommunications Technologies*, Vol. 28, No. 6, June 2017	UC3M
12	JRN	Apr'17	"Distributed Mobility Management solutions for next mobile network architectures", by L. Cominardi, F. Giustc, C. J. Bernardos, A. De La Oliva, *Elsevier Computer Networks*, Vol. 121, July 2017.	UC3M
13	MAG	Jun'17	"Advertisement Delivery and Display in Vehicular Networks", by F. Malandrino, C.-F. Chiasserini, and M. Sereno, accepted by *IEEE Magazine on Vehicular Technology*	POLITO
14	MAG	Jul'17	"Enabling Multi-Tenancy in 5G Transport Networks through Network Slicing", by X. Li, R. Casellas, G. Landi, A. de la Oliva, X. Costa, A. Garcia-Saavedra, T. Deiß, L. Cominardi, R. Vilalta, accepted by *IEEE Communications Magazine*, series May 2017/5G Network Slicing	NEC, CTTC, NXW, UC3M, NOKIA, IDCC

Table 5: Conference Papers Publications in Year 2.

#	Month	Description	Leading

			Partner
1	Jul'16	"SDN/NFV Orchestration of Multi-technology and Multi-domain Networks in Cloud/Fog Architectures for 5G Services", by Ricard Vilalta, Arturo Mayoral, Ramon Casellas, Ricardo Martínez, Raul Muñoz, in Proc. *OECC/PS-2016*, Niigata, Japan	CTTC
2	Jul'16	"The Price of Fog: a Data-Driven Study on Caching Architectures in Vehicular Networks", by F. Malandrino, CF. Chiasserini, S. Kirkpatrick, in Proc. *ACM MobiHoc Workshop on Internet of Vehicles and Vehicles of Internet (IoV-VoI),* July 2016, Paderborn, Germany.	POLITO
3	Aug'16	"FPGA-Based Testbed for Synchronization on Ethernet Fronthaul with Phase Noise Measurement," by I. Freire, I. Sousa, I. Almeida, C. Lu, M. Berg and A. Klautau, in Proc. *1st International Symposium on Instrumentation Systems, Circuits and Transducers (INSCIT)*, August 2016, Brazil. (Best paper award)	EAB
4	Sep'16	"On-Demand Allocation of Control Plane Functions via SDN/NFV for Monitoring-enabled Flexi-grid Optical Networks with Programmable BVTs", by R. Casellas, J. M. Fàbrega, R. Muñoz, L. Nadal, R. Vilalta, M. S. Moreolo, and R. Martínez, in Proc. *ECOC 2016*, Dusseldorf, Germany.	CTTC
5	Sep'16	"Experimental Investigation of Compression with Fixed-length Code Quantization for Convergent Access-Mobile Networks", by L. Anet Neto, P. Chanclou, Z. Tayq, B. C. Zabada, F. Saliou, G. Simon, in Proc. *ECOC 2016*, Dusseldorf, Germany.	ORANGE
6	Sep'16	"Experimental Real Time AMCC Implementation for Fronthaul in PtP WDM-PON", by Z. Tayq, L. Anet Neto, P. Chanclou, C. Aupetit-Berthelemo, in Proc. *ECOC 2016*, Dusseldorf, Germany.	ORANGE
7	Sep'16	"Performance Demonstration of Real Time Compressed CPRI Transport", Z. Tayq, A. Quere, L. Anet Neto, P. Chanclou, F. Saliou, K. Grzybowski, C. Aupetit-Berthemelot, S. K. Yoo, S. E. Hong, in Proc. *ECOC 2016*, Dusseldorf, Germany.	ORANGE
8	Sep'16	"Efficient Multimedia Broadcast for Heterogeneous Users in Cellular Networks", by C. Singhal, CF. Chiasserini, CE. Casetti, in Proc. *12th IEEE International Wireless Communications & Mobile Computing (IWCMC 2016),* Paphos, Cyprus.	POLITO
9	Oct'16	"Experimental Evaluation of an SDN-based Distributed Mobility Management Solution", by M. I. Sanchez, A. de la Oliva and V. Mancuso, in Proc. *MobiArch 2016*, October 2016, New York, USA.	UC3M
10	Nov'16	"Innovative TV Broadcasting-related Media Use Case in 5G-Crosshaul H2020 Project", by D. Jiménez, F. Álvarez, N. Sánchez, in Proc. *New European Media Summit*, Porto, 23-24 November, 2016.	VISIONA
11	Dec'16	"Analysis and Evaluation of End-to-End PTP	EAB

		Synchronization for Ethernet-based Fronthaul“, by Igor Freire, Ilan Sousa, Igor Almeida, Chenguang Lu, Miguel Berg and Aldebaro Klautau, in Proc. *GLOBECOM'16*, Dec. 2016, Washington DC, USA.	
12	Dec'16	“How close to the edge? Delay/utilization trends in MEC”, by F. Malandrino, C.F. Chiasserini, S. Kirkpatrick, in Proc. *ACM Cloud-Assisted Networking 2016 co-located with ACM CoNEXT 2016*, USA.	POLITO
13	Mar'17	"Switch-On/Off Policies for Energy Harvesting Small Cells through Distributed Q-Learning", by M. Miozzo, L. Giupponi, M. Rossi and P. Dini, in Proc. *IEEE Wireless Communications and Networking Conference (WCNC) 2nd Workshop on Green and Sustainable 5G Wireless Networks (GRASNET 2)*, 19-22 March, 2017, San Francisco (CA), USA	CTTC
14	Mar'17	“A network sharing mechanism based on multi-operator core network”, by Chia-Lin Lai, Shahzoob Bilal Chundrigar, Samer T. Talat, and Hsien-Wen Chang, in Proc. *38th WWRF Meeting*, Hsinchu, Taiwan.	ITRI
15	Mar'17	“Real Time Demonstration of the Transport of Ethernet Fronthaul based on vRAN in Optical Access Networks”, by Z. Tayq, L. Anet Neto, B. Le Guyader, A. De Lannoy, M. Chouaref, C. Aupetit-Berthelemot, M. N. Anjanappa, S. Nguyen, K. Chowdhury, and P. Chanclou, in Proc. *Optical Fiber Communication Conference (OFC)*, Los Angeles, USA, Mar. 2017.	ORANGE
16	Mar'17	“Mobile Fronthaul Architecture and Technologies: a RAN Equipment Assessment”, by P. Chanclou, L. Anet Neto, K. Grzybowski, Z. Tayq, F. Saliou, and N. Genay, in Proc. *Optical Fiber Communication Conference (OFC)*, Los Angeles, USA, Mar. 2017.	ORANGE
17	May'17	“An FPGA-based Design of a Packetized Fronthaul Testbed with IEEE 1588 Clock Synchronization”, by I. Freire, C. Lu, M. Berg, and A. Klautau, in Proc. *European Wireless 2017*, Dresden, Germany, May 2017.	EAB
18	May'17	“Enabling 5G network slicing over heterogeneous optical networks”, by R. Casellas, R. Vilalta, R. Martínez, and R. Muñoz, in Proc. *Workshop Optical networks for data centres in the 5G era, within the 21st International Conference on Optical Networks Design and Modelling (ONDM2017),* Budapest, Hungary, May, 2017.	CTTC
19	May'17	“Novel Resource and Energy Management for 5G Integrated Backhaul/Fronthaul (5G-Crosshaul)”, by X. Li, R. Ferdous, C. F. Chiasserini, C. E. Casetti, F. Moscatelli, G. Landi, R. Casellas, K. Sakaguchi, S. B. Chundrigar, R. Vilalta, J. Mangues, A. Garcia-Saavedra, X. Costa-Pérez, L. Goratti, D. Siracusa, in Proc. *IEEE International Conference on Communications (ICC)- 3rd International Workshop on 5G RAN design*, May 2017, Paris, France	NEC, NXW, CTTC, CREATE-NET
20	Jun'17	“Energy Monitoring and Management in 5G Integrated	HHI, ITRI,

		Fronthaul and Backhaul", by O. I. Abdullaziz1, M. Capitani, C. E. Casetti, C. F. Chiasserini, S. B. Chundrigar, G. Landi, X. Li, F. Moscatelli, K. Sakaguchi, and S. T. Talat, in Proc. *European Conference on Networks and Communications (EuCNC'17),* June 2017, Oulu, Finland	NEC, NXW, POLITO
21	Jun'17	"Experimental Evaluation of Hierarchical Control over Multi-Domain Wireless/Optical Networks", by J. Mangues-Bafalluy, J. Núñez-Martínez, R. Casellas, A. Mayoral, J. Baranda, J. X. Salvat, A. Garcia-Saavedra, R. Vilalta, I. Pascual, X. Li, R. Martinez and R. Muñoz, in Proc. *European Conference on Networks and Communications (EuCNC'17),* June 2017, Oulu, Finland	CTTC NEC
22	Jun'17	"Millimeter Wave for 5G Mobile Fronthaul and Backhaul", by P.-H. Kuo and A. Mourad, in Proc. *European Conference on Networks and Communications (EuCNC'17),* June 2017, Oulu, Finland	IDCC
23	Jun'17	"Energy-Efficient 5G Networks: Optimization Meets SDN", by G. Avino, C. Casetti, C. F. Chiasserini, F. Malandrino, M. Malinverno, Poster presentation at *CLEEN 2017*, June 2017, Turin. Italy.	POLITO
24	Jun'17	"Dataplane measurements on a Fronthaul and Backhaul integrated network", by T. Deiß et al., Poster presentation at *CLEEN 2017*, June 2017, Turin. Italy.	NOK-N
25	Jun'17	"The 5G-Crosshaul Packet Forwarding Element pipeline: measurements and analysis", by N. Molner, S. González, T. Deiß, and A. de la Oliva, in Proc. *CLEEN 2017*, June 2017, Turin. Italy	UC3M
26	Jun'17	"Understanding the Present and Future of Cellular Networks through Crowdsourced Traces", by F. Malandrino, C.-F. Chiasserini, and S. Kirkpatrick, in Proc. *IEEE WoWMoM*, June 2017, Macao, China	POLITO
27	Jul'17	"Energy Consumption Measurements in Docker", by S. Semu Tadesse, C.-F. Chiasserini, and F. Malandrino, to appear in Proc. *IEEE COMPSAC*, July 2017, Turin, Italy	POLITO
28	Jul'17	"Sharing of Crosshaul Networks via a Multi-Domain Exchange Environment for 5G Services", by L. M. Contreras Murillo, C. J. Bernardos Cano, A. Oliva, and X. Costa-Pérez, to appear in *Proc. MPNSV workshop, 3rd IEEE Conf. on Network Softwarization (NetSoft'17)*, Jul. 2017, Bologna, Italy.	TID, UC3M, NEC
29	Jul'17	"Real Time Demonstration of Fronthaul Transport over a Mix of Analog & Digital RoF", by Z. Tayq, L. Anet Neto, F. Saliou, C. Aupetit-Berthelemot, J. Gomes, T. Haustein, M. Lacouche, J. Plumecoq, L. Bellot, and P. Chanclou, to appear in Proc. *International Conference on Transparent Optical Networks (ICTON)*, July 2017, Girona, Spain.	ORANGE
30	Jul'17	"Mobile Front-/Back-Haul Delivery in Elastic Metro/Access Networks with Sliceable Transceivers based on OFDM Transmission and Direct Detection" by J.M. Fabrega, M. Svaluto Moreolo, L. Nadal, F.J. Vílchez, J.P. Fernández-	CTTC, TID

		Palacios, and L.M. Contreras, to appear in Proc. *International Conference on Transparent Optical Networks (ICTON)*, July 2017, Girona, Spain.	
31	Aug'17	"Characterizing Docker Overhead in Mobile Edge Computing Scenarios", by G. Avino, M. Malinverno, F. Malandrino, C. Casetti, C.F. Chiasserini, to appear in Proc. *ACM SIGCOMM HotConNet*, Aug. 2017, Los Angeles, USA.	POLITO
32	Sept'17	"Transport Network Design for FrontHaul", by P. Sehier, A. Bouillard, F. Mathieu and T. Deiß, to appear in Proc. *3rd IEEE Workshop on Next Generation Backhaul/Fronthaul Networks (BackNets)*, Sept. 2017, Toronto, Canada.	NOK-N

3.2 White Papers

The consortium has provided contributions to 5 white papers as shown in Table 6: White Papers published in Year 2..

Table 6: White Papers published in Year 2.

#	Month	Description	Leading Partner
1	Jul'16	5G PPP Architecture Working Group White paper "View on 5G Architecture"	NEC
2	Jan'17	5G-PPP vision white paper at MWC 2017 "5G innovations for new business opportunities"	TEI
3	Mar'17	5GPPP Network Management & Quality of Service Working Group – Cognitive Network Management for 5G	POLITO
4	Apr'17	ETSI White Paper "Crosshauling - The convergence of fronthaul and backhaul through softwarization and virtualization", submitted for ETSI internal review (expected for release in September 2017)	UC3M, IDCC
5	Jun'17	ONF mobile networks WG White Paper - "SDN-Based Network Architecture for 3GPP 5G" (expected for release in December 2017)	UC3M

3.3 Talks/Panels/Webinars

Table 7: Talks and panels delivered in Year 2. lists all presentation activities delivered including talks, panels and webinars. As reported, 28 activities are delivered during this period, which exceeds the target for Year 2 which as set as 20 talks.

Table 7: Talks and panels delivered in Year 2.

#	Month	Description	Leading Partner
1	Sep'16	"Industrial perspective in 5G optical transport", by T. Deiss, at Tyrrhenian International Workshop on Digital Communication 2016, Livorno, Italy	NOK-N
2	Oct'16	"Fronthaul and Backhaul for 5G and Beyond", by A. Mourad at the 2nd COST IRACON meeting, Durham, UK	IDCC

3	Oct'16	"SDN in the H2020 5G-Crosshaul project", by Antonio de la Oliva at Workshop on OpenDayLight and NFV/SDN Orchestration	UC3M
4	Oct'16	"SDN for Microwaves PoCs Overview and Demo", by Luis Miguel Contreras Murillo at Workshop on OpenDayLight and NFV/SDN Orchestration	TID
5	Oct'16	"European 5G scientific mission to South Korea", by Arturo Azcorra	UC3M
6	Nov'16	"5G-Crosshaul: mmW Transport Trial at 5G-Berlin Testbed", by A. Mourad and R. Gazda at 5G-Summit in Berlin	IDCC
7	Nov'16	"5G Crosshaul Media Use Case" by D. Jiménez, 5G Networks for Media and Entertainment Session, NEM Summit, 23-25 November 2016, Porto	VISIONA
8	Nov'16	"NFV & SDN innovations for 5G and Telco business", by G. Carrozzo, 87th TechDay@AlticeLabs – "ICT Industry Evolution Lines", 30 Nov 2016, Aveiro, Portugal	NXW
9	Dec'16	"Energy efficient orchestration of virtual services in 5G integrated fronthaul/backhaul infrastructures", by G. Landi presented at "End-to-end service orchestration for 5G and beyond" workshop, co-located with the 15th International Conference on Ubiquitous Computing and Communications (IUCC-2016), Granada, December 14th-16th, 2016	NXW
10	Dec'16	"Generalized Orchestration of IT/Cloud and Networks for SDN/NFV 5G Services", by R. Casellas, R. Vilalta, R. Muñoz, R. Martínez, at "End-to-end service orchestration for 5G and beyond" workshop, co-located with the 15th International Conference on Ubiquitous Computing and Communications (IUCC-2016), Granada, Spain, December 14th-16th, 2016	CTTC
11	Feb'17	"Network Slicing in Transport - Definition and implementation", by A. Garcia-Saavedra at 5GPPP Workshop, Athens, Greece	NEC
12	Feb'17	Crosshaul (Xhaul) Panel – The fusion of Fronthaul and Backhaul in 5G, Mobile World Congress (MWC) 2017, Barcelona, Spain	IDCC
13	Feb'17	NFV: A Re-Examination, Mobile World Congress (MWC) 2017, Barcelona, Spain	IDCC
14	Feb'17	5G Impact, Mobile World Congress (MWC) 2017, Barcelona, Spain	IDCC
15	Mar'17	"5G-Crosshaul Architecture Overview", by X. Costa-Pérez at 5GPPP Architecture Workshop	NEC
16	Mar'17	"Mobile Internet on Taiwan High Speed Rail", by H.-W. Chang at 38th WWRF Meeting, Hsinchu, Taiwan	ITRI
17	Mar'17	"On the Slicing of Crosshaul Transport Network", by P.-H. Kuo at 5G PPP Workshop on 5G Architecture and RAN Integration, Chertsey, UK	IDCC
18	Mar'17	"ETSI White Paper on Crosshauling", by A. de la Oliva at 5G PPP Workshop on 5G Architecture and RAN Integration, Chertsey, UK	UC3M

19	Mar'17	SDN and NFV for mobile networks, Scavenge ETN Marie Curie action school - "5G cellular networks and Internet of Things"	CTTC
20	May'17	IEEE ComSoc Webinar: SDN/NFV – Time for Real Innovations. http://event.lvl3.on24.com//event/14/16/84/1/rt/1/documents/resourceList1495556524256/webinarpowerpoint.pdf	IDCC, UC3M
21	Jun'17	"Hierarchical multi-domain fronthaul/backhaul orchestration in the 5G-Crosshaul Control Infrastructure", by J. Mangues-Bafalluy at EuCNC'17 Workshop - Software Networks and 5G: from network programmability to SDN/NFV combination for effective network slicing, Oulu, Finland	CTTC
22	Jun'17	"Packet network virtualization in 5G-Crosshaul", by T. Deiß, at EuCNC'17 Workshop - New x-haul solutions for the 5G transport challenge, Oulu, Finland	NOK-N
23	Jun'17	"5G-Crosshaul applications: Resource orchestration for the integrated fronthaul and backhaul", by X. Li at EuCNC'17 Workshop - New x-haul solutions for the 5G transport challenge, Oulu, Finland	NEC
24	Jun'17	"The 5G-Crosshaul testbed: Experimental validation of an integrated fronthaul and backhaul", by J. Mangues-Bafalluy at EuCNC'17 Workshop - New x-haul solutions for the 5G transport challenge, Oulu, Finland	CTTC
25	Jun'17	5G-Crosshaul Project overview and Demo Activity, by C. Casetti, 5G Focus Day, at Flex5Gware workshop, Turin, Italy	POLITO
26	Jun'17	"Key technologies for a 5G ready metro network", by J.P. Fernández-Palacios at Next Generation Optical Networking, Nice, France	TID
27	Jun'17	"The ingredients of the new networks - SDN, NFV and Slicing in the evolution towards 5G", by Luis M. Contreras at the University of Tokyo, Tokyo, Japan	TID
28	Jun'17	"Architecture and next steps", by A. De La Oliva Delgado at EU-Taiwan 5G Workshop, Brussels, Belgium	UC3M

3.4 Workshops

Table 8: Workshops organized. lists the workshops organized in Year 2. A total of 5 workshops have been organized, exceeding the target of 2 workshops set for Year 2.

Table 8: Workshops organized.

#	Month	Workshop	Country
1	Jul'16	On-the-fly services in on-the-fly mobile infrastructures (OSOMI)	Germany
2	Dec'16	End-to-end service orchestration for 5G and beyond within the 15th International Conference on Ubiquitous Computing and Communications (IUCC-2016).	Spain
3	Dec'16	5G RAN design workshop at IEEE Globecom 2016.	USA
4	Mar'17	5G PPP Workshop on 5G Architecture and RAN Integration (A joint workshop co-organised by	UK

		mmMAGIC, METIS-II, 5G-Crosshaul, 5G NORMA)	
5	Jun'17	EuCNC'17 Workshop: New x-haul solutions for the 5G transport challenge (A joint workshop of the iCIRRUS, 5G-Crosshaul and 5G-XHaul projects)	Finland

3.5 Demonstrations

Table 9: Demonstrations exhibited.**Error! Reference source not found.** lists the demonstration activities exhibited by the project in Year 2. A total of 12 demonstrations were exhibited, much higher than the target set with 2 demos.

Table 9: Demonstrations exhibited.

#	Month	Description	Leading Partners
1	Sep'16	mmWave integrated FH/BH – Live demo from Berlin to Brussels (at the project review meeting)	IDCC, HHI, CND
2	Nov'16	5G Crosshaul: mmW Integrated Fronthaul and Backhaul (for 5G Global Event)	IDCC, HHI, CND
3	Nov'16	Energy monitoring and management for network paths (for 5G Global Event)	NXW, POLITO
4	Nov'16	SDN-based TV Broadcasting Service (for 5G Global Event)	VISIONA
5	Nov'16	Silicon Photonic Reconfigurable Add Drop Multiplexer for Crosshaul networks (for 5G Global Event)	TEI
6	Nov'16	Next Generation Frounthaul Interface over LED-based Optical Wireless Link	HHI, CND
7	Feb'17	5G Impact (MWC'17) – Demonstration of 5G-Crosshaul solution with a remote surgery application	IDCC
8	Feb'17	MWC'17 Demonstration at InterDigital Stand - 5G-Crosshaul solution over InterDigital's EDGELINK platform, featuring demanding low-latency traffic from a remote surgery application.	IDCC
9	Feb'17	MWC'17 Demonstration at CTTC Stand - Demonstration by CTTC of an SDN- based management of a heterogeneous wireless Crosshaul, featuring automated technology and link selection over 802.11ac/ad links.	CTCC
10	Jun'17	"Flex5Gware - Joint demo with 5G-Crosshaul project: Network split with integrated fronthaul and backhaul", at CLEEN'17 Workshop	CTTC, UC3M, NXW, Nokia
11	Jun'17	"Flexibility of 5G-Crosshaul Technologies", at 5G-Crosshaul booth of EuCNC'17	VISIONA, NXW, CTTC, HHI, NEC
12	Nov'17	"Resource Management in a Hierchically Controlled Multi-domain Wireless/Optical Integrated Fronthaul and Backhaul Network", proposed for demo at 3rd IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN'17)	CTTC

3.6 5G-PPP Collaborations

5G-Crosshaul has continued its collaboration within the 5G-PPP, through joint work with 5G-PPP projects and participation in the 5G-PPP working groups. In this period, the following activities are particularly worth noting:

- Collaboration with 5G-PPP consortia (such as Fantastic 5G, Speed 5G, Selfnet, 5G Ensure, METIS II, and SESAME) for a white paper targeted at MWC 2017, covering how technologies developed by different projects can be employed to resolve challenges foreseen for 5G in various aspects.
- Participation by NEC in the "Golden Nuggets" activity by the 5G-PPP Technology Board meeting held in Brussels (Oct'16), with the aim to identify potential synergy between 5G-Crosshaul and the other projects.
- Contribution by NEC to the "5G PPP Architecture Working Group White paper - View on 5G Architecture, version 1.0".
- Contribution by NEC to the "5G PPP Architecture Working Group White paper - View on 5G Architecture, version 2.0".
- Contribution by TI to 5G-PPP CSA Working Groups, notably in support of the 5G-PPP activities at MWC 2017.
- Contribution by IDCC to the 5G PPP Pre-Standard Working Group list of relevant SDO working groups and standard contributions from 5G-Crosshaul.
- Contribution by IDCC to European 5G Annual Journal.
- Contribution by IDCC to the 5G PPP Spectrum Working Group through a paper and presentation at EuCNC 2017 special session on 5G spectrum.

3.7 Work Plan for Year 3 (6 months)

For the next 6 months, the plan is to boost the numbers targeted for talks, articles, and demonstrations, such as:

- Submit/publish (or acceptance for publication) 10 peer-reviewed articles
- Deliver 5 talks/panels at key R&D events
- Showcase at least at 2 R&D demonstrations
- Organize 1 workshop/special session

4 Standardization Activities

This chapter provides an update on status of a few standardization bodies relating 5G-Crosshaul. It reports status of several relevant standard bodies and presents all standard activities in Year 2 by the consortium.

4.1 Update of Relevant Activities in SDOs

4.1.1 3GPP

Recently, 3GPP has completed several technical reports for study on New Radio (NR) access technologies for 5G specifications. In particular, several different options for fronthaul functional split have been identified in 3GPP TR 38.801 (March/2017), a report that mainly deals with radio access architectures and interfaces. The prospect options of functional split between a centralized unit (CU) a distributed units (DU) are illustrated in Figure 2:

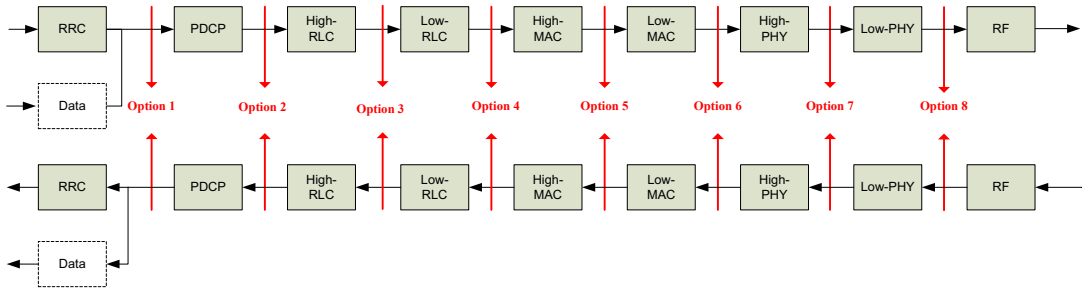

Figure 2 Functional split options considered by 3GPP

3GPP has concluded that only one higher-layer split and one lower-layer split will be supported. In particular, PDCP-RLC split (Option 2 shown in the figure above) has been adopted as the higher-layer split, while the final decision relating to lower-layer split is remained open with only a limited number of possibilities. In particular, an on-going study item in 3GPP is dedicated to determine whether Option 6 or one of the Option 7 variants should be opted for lower layer split. The three variants of Option 7 can be summarized as following:

- **Option 7-1**:
  - In the UL, FFT, CP removal and possibly PRACH filtering functions reside in the DU, the rest of PHY functions reside in the CU. The details of the meaning of PRACH filtering were not discussed in the study phase.
  - In the DL, iFFT and CP addition functions reside in the DU, the rest of PHY functions reside in the CU.
- **Option 7-2**:
  - In the UL, FFT, CP removal, resource de-mapping and possibly pre-filtering functions reside in the DU, the rest of PHY functions reside in

the CU. The details of the meaning of pre-filtering were not discussed in the study phase.
    - In the DL, iFFT, CP addition, resource mapping and precoding functions reside in the DU, the rest of PHY functions reside in the CU.
- **Option 7-3**:
    - Downlink only - the encoder resides in the CU, and the rest of PHY functions reside in the DU.

Furthermore, the scope of 3GPP will also cover the feasibility of carrying control-plane (e,g. RRC message) and data-plane traffics with differentiated transport between CU and DU.

4.1.2 eCPRI

As confirmed by industry leaders, including a few key members of 5G-Crosshaul partners such as EAB, NOK-N and NEC, the eCPRI standard will be released in August 2017. This is known that eCPRI is an enhanced version of CPRI aiming to offer higher efficiency and bandwidth of fronthaul interfaces, in a bid to cater for 5G requirements. In particular, according to the press release of eCPRI, this new specification will provide several advantages for base station design:

- The new split point enables ten-fold reduction of the required bandwidth.
- Required bandwidth can scale flexibly according to the user plane traffic.
- Use of main stream transport technologies like Ethernet will be enabled, Ethernet opens the possibility to carry eCPRI traffic and other traffic simultaneously in the same switched network.
- The new interface is a real time traffic interface enabling use of sophisticated coordination algorithms guaranteeing best possible radio performance.
- The interface is future proof allowing new feature introductions by SW updates in the radio network. 5G-Crosshaul partners are key members of the eCPRI consortium.

4.1.3 IETF

IETF DetNet (Deterministic Networking) has recently formed a Data Plane Solutions Design Team (DT). The DT is tasked with selecting the existing IP and/or MPLS data plane technologies that should be considered as the foundation for the DetNet data plane definition. The full scope of the DetNet data plane shall be considered and, as appropriate, shall include QoS, OAM, and time synchronization. This effort will leverage the Data Plane Alternatives WG draft. The initial deliverable of the Design Team is a Data Plane Solutions individual draft, and is expected prior to IETF 98 (March 2017). This is therefore a good opportunity for potential 5G-Crosshaul contributions on the data plane. UC3M is part of the team working on this document.

Moreover, another working group dubbed as *NetSlices* is underway to address network slicing. Apparently, transport networks need to provide the functionality and capability required to support end-to-end network slicing. Various use cases of network slicing in

5G such as eMBB, URLLC, and mMTC have been examined by the working group, and this is concluded that the current transport network architecture is not flexible and scalable enough to support the various services scenarios and fulfill specific set of performance requirements of each use case at the same time. Hence, 5G-Crosshaul is well-positioned in terms of offering scalable integrated backhaul/fronthaul solutions catering for network slicing applications.

4.1.4 IEEE

IEEE 1914.1 (NGFI, Next Generation Fronthaul Interface) group has been recently created targeting a new specification for architectural requirements for fronthaul beyond the conventional CPRI. Functional splits are being studied. Liaisons have recently been exchanged between IEEE 1914.1 and the 3GPP to inform each other on the ongoing discussions. IEEE P1914.3 Radio over Ethernet (RoE) Task Force (TF), on the other hand, is an ongoing standardization effort to define packetization of radio traffic over Ethernet. IEEE P1914.3 RoE TF standardizes a common "native RoE" header format for both data and control packets along with RoE level sequencing, synchronization and multiplexing primitives. Future amendments to a 1914.3 specification can add support for different functional splits, for example, based on the guidance from IEEE P1914.1 NGFI TF.

IEEE 802.1 CM (TSN – Time Sensitive Networking) is still pursuing the profiling of data plane protocols for time-sensitive CPRI fronthaul. It is anticipated that this group will extend its scope to include eCPRI and perhaps higher layer splits, subject on receiving the corresponding requirements for additional specification work.

4.1.5 ONF

The Wireless Transport group is progressing on the definition of the final information and data models for the control and management of MW and mmWave systems. This working group is now integrated in the Open Transport group, which is defining the Transport API (TAPI). A preliminary proposal for integration of wireless transport capabilities into the TAPI was drafted at the ONF interim meeting in Heidelberg, February 2017. Next steps consider the elaboration, specification and demonstration of such integration. By the way, the 4th PoC on the ONF information and data model for MW and mmWave transport networks takes place in the last week of June 2017.

In parallel, the Cross-Stratum Orchestration project is defining a number of Use Cases for coordination of network and computing resources in an optimal manner. One of the use cases included in the draft document describes a 5G slicing scenario with Crosshaul segments on it. Worthy to note, TID and UC3M are editors of such document. The release of this document is expected for Q3 2017.

4.2 Standardization Dissemination and Contribution

The 5G-Crosshaul partners have undertaken activities to disseminate the project concept and initial results at various standardization forums. Table 10 reports 9 standardization dissemination activities in various SDOs, in addition to 19 input contributions submitted to various standardization working groups reported in Table 11.

Table 10: Standardization dissemination in Year 2.

#	Month	SDO	Description	Leading Partner
1	Jul'16	IETF	Presentation on "Microwave radio link - Problem Statement" in IETF meeting in Berlin	NEC, TEI, TID
2	Aug'16	IEEE	Presentation on "Towards a Unified BH/FH Data-Plane: 5G-Crosshaul", IEEE 1914.1 meeting	NEC, IDCC, NOK-N
3	Aug'16	NGMN	Impacts on network and service management and orchestration for 5G.	TID
4	Sep'16	ONF	Cross Stratum Optimization (CSO) on-line presentation during ONF Member Workdays on CSO Gap Analysis.	CTTC
5	Oct'16	ITU-T 2020FG	Key Challenges of the 5G-Crosshaul project	IDCC, TEI
6	Nov'16	ITU-T 2020FG	Application of network softwarization to IMT-2020 (IMT-O-036-updated)	CTTC
7	Dec'16	ETSI	White Paper: The convergence of fronthaul and backhaul through softwarization and virtualization	UC3M, IDCC
8	Dec'16	ONF	Third Wireless Transport SDN Proof of Concept White Paper	TID
9	Jan'17	ONF	Position Paper of Mobile Networks Working Group	UC3M

Table 11: Standardization contributions in Year 2.

#	Month	SDO	Description	Leading Partner
1	Aug'16	IEEE	"Proposed options for functional splits for CRAN and fronthaul" submitted to IEEE P1914.1 TF August 2016 Meeting	NEC, IDCC, NOK-N
2	Oct'16	IRTF NFV	"VNF Pool Orchestration for Automated Resiliency in Service Chains"	NXW, TID
3	Nov'16	IETF DETNET	DETNET crosshauling requirements, IETF 97 meeting in Seoul, South Korea in November 2016.	UC3M, IDCC, TID
4	Nov'16	IETF SFC	Service Function Chaining Use Cases in Fog RAN, IETF 97 meeting in Seoul, South Korea in November 2016.	UC3M, IDCC
5	Nov'16	IEEE	Contribution to SDN Chapter of IEEE 802.1CF	UC3M
6	Nov'16	IETF CCAMP	"A framework for Management and Control of microwave and millimeter wave interface parameters", IETF 96 meeting in Berlin, Germany in July as well as in the IETF 97 meeting in Seoul, South Korea in November 2016.	NEC, EAB, TID
7	Nov'16	IEEE	"SDN Functional Decomposition" (omniran-16-0089-00-CF00), IEEE 802.1 OmniRAN TG Conference call	UC3M

8	Dec'16	ONF	Microwave Information Model	TID
9	Dec'16	ONF	Contribution (onf2016.179) to draft "Gap Analysis for Application-Driven Cross Stratum Orchestration"	CTTC
10	Dec'16	IETF CCAMP	"A YANG Data Model for Microwave Radio Link", presented in IETF 97 meeting in Seoul, South Korea in November 2016b (to be updated in Dec. 2016).	NEC, EAB, UC3M
11	Feb'17	ONF	Use cases for T-API PoC (document onf2017.048)	TID
12	Feb'17	ONF	Requirements for compliance of TR-532 model (document onf2017.047)	TID
13	Feb'17	eCPRI	"Alignment to IETF RFC 2360" (Tdoc 1430)	NOK-N
14	Mar'17	IETF	"Service Function Chaining Use Cases in Fog RAN", IETF Meeting 98, Chicago, USA	UC3M, IDCC
15	Mar'17	IETF	"DetNet Data Plane", IETF Meeting 98, Chicago, USA	UC3M, IDCC
16	Mar'17	eCPRI	"eCPRI over Ethernet and eCPRI over IP sections text proposal" (Tdoc 1457)	NOK-N
17	Apr'17	eCPRI	"eCPRI requirements to the Transport network layer: work document" (Tdoc 1508)	NOK-N
18	Apr'17	eCPRI	"eCPRI network QoS definition" (Tdoc 1509)	NOK-N
19	Jun'17	eCPRI	"eCommon Public Radio Interface (eCPRI); Transport Network Services Specification" (Tdoc 1541)	NOK-N

4.3 Work Plan for Year 3

In the next 6 months, the project will continue to disseminate its work into various SDOs. However, we expect a drop in the number of contributions as some working groups come to an end, and the project partners are focusing most of their efforts on the final demonstrations and trials.

5 Exploitation Activities

This chapter presents the key innovations identified for the technology development carried out during Year 2. It also reports on proof-of-concepts, commercial products, services, and solutions relating to the concept of crosshaul pioneered by the project.

5.1 Key Innovations in Year 2

In the second year, significant progress has been made across all work packages and based on the first innovations seeded in the first year. The innovations identified for the work carried out in Year 2 as summarized below (Table 12: Key innovations in Year 2.).

Table 12: Key innovations in Year 2.

#	Building block	Innovation	Leading Partners
1	XFE	Novel optical ROADM based on integrated silicon photonics to reduce cost and size of 100 times with respect current nodes	TEI
2	XFE	A latency reduction solution for mmWave-based backhaul/fronthaul dubbed fast-forwarding was developed, in order to support wireless transport for scenarios with stringent latency requirements (e.g. lower-layer split).	IDCC
3	XFE	Novel optical access solution for crosshaul services (Packetized FH) based on WS-WDM-PON technology is evaluated in a PoC where C-RAN schemes with different functional split options and SDN support are demonstrated in terms of 5G network requirements.	Telnet
4	XFE	Extension and evaluation of a Radio Resource Management algorithm for a dense deployment of small cells with mmWave transport capabilities powered with renewable energies based on distributed Q-learning. The agents placed at each small cell running this distributed algorithm will be able to improve the energy efficiency of the system by learning from the local environment. Moreover, thanks to the activities in WP4, the agents can collaborate with EMMA application in order to include a system wide view which allows to guide the learning process towards a more energy efficient solution (e.g., by avoiding conflicts among the small cells agents in multi cells scenarios).	CTTC
5	XFE	Development of a SBI agent to provide a common abstraction of wireless data-plane resources. The proposed approach decouples control operations from management operations. Thanks to this decoupling, the	All WP2 partners

		solution offers the required flexibility to evolve with the evolution and the integration of multiple technologies in 5G-Crosshaul networks.	
6	XFE	Network solution to use multi-layer nodes (packet and optical) to support tight requirements of latency and bandwidth	All WP2 partners
7	XFE	Local OAM was added to the data plane to support its operation. Packets for connectivity checks or latency measurements cannot be injected into the network from the SDN controllers. Local OAM allows the XPFEs themselves to generate and receive the corresponding packets. The invention provides a corresponding state machine on the XPFEs, which is under control of the SDN controllers. This allows to get accurate information on the status of the network without placing a computational burden on the SDN controllers.	UC3M, IDCC
8	XFE	Several fronthaul splits (MAC/PHY, PDCP/RLC) have been implemented on virtual machines and dedicated processor boards. The traffic according to different fronthaul splits can be generated without changing the underlying hardware and without having to apply for spectrum at the air interface. This eases considerable test setups to evaluate network configurations	NOK-N
9	XCI	In the control plane the VIM and the SDN controllers have been integrated to connect virtual machines in a data centre with other nodes in the Crosshaul network. The corresponding application allows the VIM to establish the network among virtual machines in data centres according to its own rules, e.g. regarding the use of VLANs. Thereafter the SDN controllers establish the connections inside the Crosshaul network using the information, which is provided by the VIM via the application.	NOK-N, NXW
10	XCI	A NFVO was developed, which is compliant to the ETSI NFV specifications and which allows to use different resource orchestration mechanisms. This NFVO allows to experiment with different optimization strategies to deploy VNFs in a data centre.	NXW
11	XCI	The hierarchical SDN control component of the XCI of different technological domains was shown in a PoC, covering three different transport domains (one optical and two wireless domains of different partners). The hierarchical SDN model allows through network abstraction to control multiple transport network domains and at the same time to encapsulate per-domain specific technological details in the	CTTC, IDCC

		corresponding child controllers. The developed XCI hierarchical control model decreases the e2e service provision time while increasing the XCI scalability in terms of number of managed domains transporting both fronthaul and backhaul traffic, hence easing the integration of different technological transport domains.	

5.2 Proof-of-Concepts with Exploitation Value

This section reports on PoCs, products and services that the project has identified in Year 2 with potential for further exploitation during and beyond the project lifetime.

5.2.1 Energy Management of 5G-Crosshaul

A few demonstrations have been conducted (or are being planned) to showcase how energy efficiency of 5G-crosshaul-based transport network can be enhanced or optimized. Based on such proof-of-concepts, following components have been identified as potential commercial products.

- **XCI MANO platform for Energy management**:

  MANO platform based on OpenStack, extended to control the provisioning of vEPC instances in an energy efficient manner. The MANO component includes the following modules:

  - *NFVO*, in charge of orchestrating the provisioning of vEPC instances and related cloud resources. It includes features for energy-aware resource allocation algorithms and automated power state configuration.
  - *vEPC VNFM*, in charge of allocating vEPC VNFs based on the VM placement computed by the EMMA application and configuring the OpenAirInterface (OAI) EPC components.
  - *VIM*, in charge of managing the XPU virtual resources. It is based on OpenStack and it is extended with features for XPU power consumption monitoring and power states changes (depending on hardware capabilities).

- **SDN Controller for Energy Management**:

  SDN controller based on OpenDaylight (ODL) and extended to control XPFEs and support energy monitoring and management features. In particular, it includes the following software modules:

  - *Provisioning Manager*, in charge of provisioning end-to-end connections assigned to different tenants over an XPFE domain. It instantiates flows based on the paths computed by a dedicated Path Computation module, triggers the automated re-configuration of the XPFEs power states and configure the flow rules interacting with the OpenFlow plugin.
  - *Path Computation Manager,* in charge of computing end-to-end paths based on energy efficient routing algorithms and the current configuration of power states in active XPFEs.

- *Power State Manager,* responsible for the actual configuration of the XPFEs power states via SNMP protocol.
- *Analytics Manager*, responsible of collecting power consumption information via SNMP protocol and computing per-tenant and per-service power consumption values based on traffic statistics and existing connection services.

- **SDN Application for Energy management:**
  - SDN application providing a graphical interface and the logic to manage requests for energy efficient paths and visualize power consumption data per physical and virtual entities. In cooperation with the MANO orchestrator, the EMMA will also select the optimal placement of VNFs and trigger the automated change of XPUs power states.

5.2.2 Media Distribution Over 5G-Crosshaul

Applicability of 5G-Crosshaul to TV broadcasting and Video on Demand (VoD) services have been demonstrated, in which a few different top layer applications with commercial product potentials have been developed to fulfil such services, including the following:

- **TVBA:** TV Broadcasting application (TVBA) is responsible for defining and provisioning the live video service and asking for the network resources needed to establish it (i.e from RMA optimal paths that will allow the broadcasting of multimedia content over the network). It uses the SDN Controller and the data obtained from it to establish the necessary rules and create an initial broadcasting-tree. For this task is also essential the TVBA Quality Probe, a media's quality analysis in real time performed by the Virtual Network Function deployed in the XPUs.
- **CDNMA:** The Content Delivery Network Management application (CDNMA) is a Web application composed of two basic algorithms that allow the CDN service management and implementation over the 5G-Crosshaul network. The first algorithm is in charge of the vCDN infrastructure instantiation, and the second one is oriented towards the control and management of the service during its lifetime. The CDNMA application shows the service provider/CDN operator a graphical interface for management and operation actions. The CDNMA GUI shows a graph of the network topology, with the nodes, hosts and links and also monitoring and configuration information about the vCDN infrastructure. The application allows the service provider/CDN operator to control and manage the service.
- **RMA:** The Resource Management Application (RMA) through its own algorithms and the XCI, provisions and establishes the optimal paths followed by the mobile users' traffic to support the VoD and live streaming services provided by the CDNMA and TVBA applications. Initial and end nodes, service bandwidth, latency and priority among other in-parallel deployed services are provided to the application as input parameters.
- **MMA:** The Mobility Management Application (MMA) is Distributed Mobility Management (DMM) based and its main goal is to optimize traffic offloading for

media distribution like CDN and TV Broadcasting. The MMA application provides important information about the point of attachment of the user to the network that allows optimizing the path followed by mobile users' traffic.

5.2.3 Service Provisioning for Transport Network with Multiple Technologies

As 5G transport network is anticipated to be composed of heterogeneous technologies, demonstrations will be carried out to show how a complex multi-domain and multi-technology network can be controlled via SDN. In particular, commercial values can be identified in the following components.

- **ABNO Controller:** Application Based Network Operations (ABNO) controller covers the requirements of multi-domain network orchestration; that is, the ability to coordinate service provisioning (e.g., flow and connection provisioning) across multiple (technology) domains.
- **VNTM**: Virtual Network Topology Manager (VNTM) is the responsible for the multi-layer management. The VNTM is in charge of satisfying upper layer's connectivity demands by spawning lower layer connections (e.g., optical DWDM channels) represented into the TED as Virtual Links.
- **Provisioning Manager**: The Provisioning Manager (PM) is the module which translates the connectivity requests. The PM implements a provisioning plugin for each different network controller connected to it. In the proposed architecture, it implements the SDN controller provisioning REST API and the PCEP with Stateful and PCE-initiated LSP Setup extensions, for the communication with the AS-PCE.

5.2.4 Data Plane Solutions for 5G-Crosshaul

5G-Crosshaul has aimed to demonstrate the feasibility of integrating multiple different data plane solutions, including both optical and wireless-based interfaces. Here are some examples that will potentially be further developed for commercial products:

- **mmWave Transport with Fast Forwarding:** The mmWave-based forwarding element equipping with special transceiver mechanisms that allow latency reduction. Such latency reduction allows mmWave to support fronthaul interfaces with lower layer splits.
- **Compressed and Packetized Fronthaul (CPFH)**: Fronthaul interfaces with I/Q samples compression and packetization that lead to reduction of bandwidth requirement. PoC implementation of packetized and compressed FH over Ethernet, which includes a radio head PoC prototype with an Ethernet-based FH interface and a conversion unit PoC prototype on the BBU side performing the conversion between the packetized FH and CPRI. The developed software running in the prototypes perform the FH data compression (3.5 times or higher) and Ethernet frame packetization. It shows the feasibility for highly compressed FH and packetized FH over Ethernet.

- **Experimental demonstration of a Direct Detection-Orthogonal Frequency Division Multiplexing (DD-OFDM) system** employing Sliceable-Bandwidth Variable Transceivers (S-BVTs) for a transparent delivery of mobile front/backhaul traffic in a converged metro/access elastic network.
- **Novel access solution based on WS-WDM-PON technology with SDN support:** The proposed PoC validates different RAN split options for C-RAN architectures to face 5G-oriented network requirements. The system prototype has been developed to operate with XCF (Backhaul and Fronthaul integration). In addition, for the PtP WDM system a Ryu framework based controller is implemented in order to control and to manage forwarding and physical issues.

5.3 Commercial Products

In this section, we present a new commercial product launched at MWC 2017 by 5G-Crosshaul partner Nokia, relating to transport networks. The product name is **Anyhaul.** It is described briefly below.

Nokia enhanced its portfolio on transport solutions to address the critical requirements of 5G, especially for latency-sensitive Ethernet Fronthaul. All capabilities utilize SDN and virtualization to deliver the programmable connectivity to assure the heightened service requirements.

The enhancements cover microwave, IP, packet optical, and fixed access products:

- The Nokia Wavence Microwave Portfolio [25] introduces a new family of ultra-broadband transceivers. The ultra-broadband transceiver twin, a 'dual carrier in a box' radio, and the ultra-broadband transceiver 80, a compact E-band radio, support carrier aggregation and carrier SDN to deliver multi-gigabit, low latency and programmable microwave transport.
- The Nokia 7250 Interconnect Router R6 (IXR-R6) [26] is a new IP/MPLS router with terabit-scale, low latency, improved port densities and support for next-generation interfaces, such as Ethernet fronthaul, that expands and complements Nokia's IP/MPLS mobile transport solutions including the 7705 SAR, 7210 SAS and 7750 SR product families.
- The Nokia 1830 family introduces new functionality to further enhance its optical anyhaul mobile transport solutions. New Integrated Packet Transport cards for the Nokia 1830 Photonic Service Switch [27] address Ethernet anyhaul applications by combining the scalability of 100G packet aggregation and coherent DWDM with ultra-low latency and industry leading time synchronization. Additionally, the Nokia 1830 Versatile WDM Module (VWM) adds optical protection switching, assuring high availability of WDM fronthaul traffic.
- The Nokia 7360 ISAM FX [28] access node and 7368 ISAM ONT optical network termination devices extend the performance of Passive Optical Networks (PON) and are designed to cost effectively introduce more bandwidth

with 10Gbps for PON and Point-to-Point technologies. Including network synchronization support, the new capabilities enable operators to easily leverage existing fiber-to-the-home deployments for 'anyhaul' applications.

5.4 Industry Awards

5G-Crosshaul partner Telefonica was named winner of the LTE & 5G World Awards 2016 in the category of "Best NFV/SDN solution". Part of the Telefonica's awarded work was carried out in the context of activities in the 5G-Crosshaul project. Figure 3 shows the award given to Telefonica on end-to-end SDN Transport Solution. This demonstrates appreciation by the industry for solutions featuring work partly developed within the context of 5G-Crosshaul project.

Figure 3: Industry Award for work partly conducted in 5G-Crosshaul.

5.5 Work Plan for Year 3

In the next 6 months, the focus will be on completing and consolidating all key innovations developed during the project and outline their potential for exploitation beyond the project lifetime. Notably, a lot of activities in the next months will be dedicated to test beds and trials, which we anticipate to help in setting out the exploitation activities beyond the project lifetime.

6 Conclusions

This document reported the progress on communication, dissemination, collaboration, standardization and exploitation activities, for the second year of 5G-Crosshaul project, i.e. July 2016 to June 2017. According to the reported progress, it is clear that the project has maintained the momentum of Year 1, and achieved significantly more than the targets set originally in the work plan of Year 2.

For communication, a number of press releases accompanied the project milestones in Year 2, notably the 2016 Berlin Trials, and the MWC 2017 show. This is in addition to a number of interviews, videos, blogs, and a second leaflet.

For scientific dissemination, 46 peer-reviewed journals and conference proceedings have been published (compared to 20 scientific publications as planned), while 25 talks have been delivered by the consortium partners (compared to the planned target of 20 talks). In addition, 12 demonstrations have been showcased throughout Year 2, and 5 workshops organized.

In order to bring impacts of this project to the specifications of new standards, various standard activities have been carried out to serve such purposes. The report has updated the status of several standardization bodies relating to 5G-Crosshaul project, as well as the standardization dissemination and contribution activities that have been undertaken by the consortium partners during Year 2. Examples of these latest updates include the possible functional splits between CU and DU in 3GPP, as well as the goals of eCPRI and the latest developments in IETF. It is also appreciated the significant boost of the number of input contributions to standards with 19 input contributions in Year 2 alone across various SDOs, IETF, eCPRI, IEEE, ONF, ETSI.

Exploitation of the innovations is also a key pillar to the activities. In particular, key innovations are identified for the technology development carried out in Year 2. This report also highlighted pre-commercial proof-of-concepts with potential for further exploitation, together with a commercial product (AnyHaul) from 5G-Crosshaul partner Nokia that might have an impact from/to the project.

In addition to the reported achievements in Year 2, this deliverable presented an outline of the work plan for the next 6 months, where the project will be focused on executing the final integrated demonstrations. Various communication and dissemination activities are planned to accompany the completion of the project and promote the findings from the final demonstrations planned throughout the rest of 2017.

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