“Third Year Annual Report”

D1.7

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PROJECT PERIODIC REPORT

Grant Agreement number: **248654**

Project acronym: **ACCORDANCE**

Project title: **A Converged Copper-Optical-Radio OFDMA-based access Network with high Capacity and Flexibility**

Funding Scheme: **SEVENTH FRAMEWORK PROGRAMME**
ICT2009.1.1: The Network of the Future (STREP)

Date of latest version of Annex I against which the assessment will be made: **18 February 2013**

Periodic report: **1st** ☐ **2nd** ☐ **3rd** **X** **4th** ☐

Period covered**:** **from January 1st, 2012 to June 30th, 2013**

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Declaration by the scientific representative the project coordinator

I, as co-ordinator of this project and in line with my obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):

  ☐ has fully achieved its objectives and technical goals for the period;

  ✓ has achieved most of its objectives and technical goals for the period with relatively minor deviations;

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.

- The public Website, if applicable

  ✓ is up to date

  ☐ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement (section 7).
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Jean-Charles Point

Signature: 

Date: 30/09/2013

The **ACCORDANCE Project Consortium** groups the following Organizations:

JCP-Consult SAS	JCP	FR
Research and Education Laboratory in Information Technologies	AIT	GR
ALCATEL-Lucent Deutschland AG	ALUD	DE
Deutsche Telekom AG	DTAG	DE
TELEFONICA Investigación y Desarrollo SA	TID	SP
The University of Hertfordshire higher education corporation	UH	UK
Karlsruher Institut für Technologie	KIT-U	DE
Universitat Politècnica de Catalunya	UPC	SP
EUPROCOM Oü	EPC	EE

Abstract:
This document provides D1.7 - Third Year Annual Report for the ACCORDANCE project and consists of main achievements and reports on resource usage of ACCORDANCE project during third period of project duration (January 2012-June 2103).

Taking into account delays in the manufacturing of hardware needed for accomplishing work of WP3 and WP6, this reports presents results achieved in ACCORDANCE up to present moment. Implementation work in ACCORDANCE is being continued and present report shall be updated after performing of final tests in the course of WP3 and WP6.

*“**The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 248654”***

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1. PUBLISHABLE SUMMARY

http://www.ict-accordance.eu

ACCORDANCE

Duration: 01/2012 – 06/2013
Total Cost: *€ 5,501,768*
EC Contribution: *€ 3,499,148*
Grant agreement n° 248654

ACCORDANCE: A Converged Copper-Optical-Radio OFDMA-Based Access Network with High Capacity and Flexibility

Partners: JCP-Consult SAS (FR) / Research and Education Laboratory in Information Technologies (GR) / Alcatel-Lucent Deutschland AG (DE) / Deutsche Telekom AG Laboratories (DE) / Telefónica Investigación y Desarrollo (SP) / University of Hertfordshire (UK) / Karlsruhe Institute of Technology (KIT) / Universitat Politècnica de Catalunya (SP) / Euprocom OÜ (EE)

While emerging network-based services and applications point towards an enormous increase in bandwidth and Quality of Service demands, the access and metropolitan parts of the telecommunications network hierarchy remain relatively underdeveloped compared to the high-capacity backbone networks and thus create a significant bottleneck as far as the end user is concerned. Optical fibre networks provide a future-proof solution for meeting the growing demand with guaranteed expansion possibilities, since copper-based solutions are approaching their theoretical capacity. However, the considerable fibre cabling costs and low levels of equipment sharing make the deployment of fully end-to-end fibre optic networks currently impractical and lead to the solution of Passive Optical Networks (PONs). At the same time, wireless communication networks represent a rapidly growing market where new standards are emerging to enable higher capacity, reliability and an extended base of supported users. To this end, the convergence with fixed networks is likely to deliver all desired benefits of data-centric, quality-service, mobile networks.

In order to meet the aforementioned challenges, ACCORDANCE introduces a novel ultra-high capacity optical access network architecture based on OFDMA (Orthogonal Frequency Division Multiple Access) technology and protocols. The key innovation of ACCORDANCE is the introduction of OFDM/OFDMA technology in PONs assuming a holistic approach, i.e. addressing both the physical and the Medium Access Control (MAC) layers. The end result is improved performance compared to evolving TDMA-PON and WDM-PON solutions by providing a variety of desirable network characteristics, like increased aggregate bandwidth and scalability, enhanced resource allocation flexibility, extended reach, and network node consolidation. Moreover, special emphasis is given to the convergence of the optical infrastructure with standard wireless solutions, as well as the migration from existing access technologies like xDSL and xPON in order to enable a seamless OFDM/OFDMA-based access network where virtually all different Telco services can be consolidated.
ACCORDANCE is a 42-month project partially funded by the European Commission, starting in January 2010 and ending in June 2013.

Summary of 3rd Year Progress

Main Objectives

We summarize below the objectives of the ACCORDANCE project, emphasizing on the work conducted and the results obtained during the third year:

1. Definition of a novel Access Network architecture achieving convergence among heterogeneous technologies (optical, wireless, copper).

All architectural decisions were taken during Y1 and Y2.

2. Proposal of low-cost, low-complexity concepts to achieve ultra high data rates in the access network (up to 100Gbps aggregate and more than 10Gbps in each segment).

The ACCORDANCE technological solution in order to achieve the goals set by the consortium was selected and described during Y2. Its implementation on the ACCORDANCE testbed was performed during Y3 and the relevant details are provided below.

3. Introduction of flexible bandwidth allocation concepts using dynamic FDM and OFDM sub-carrier assignment.

During the third year, the main part of the work regarding bandwidth allocation concepts has been associated with determining how the ACCORDANCE MAC protocol guidelines described in detail in deliverable D4.2 can be adapted to be used for the final ACCORDANCE testbed. In that respect, deliverable D4.5 published during Y3 first of all verified the alignment of the ACCORDANCE FPGA system from the MAC layer point of view with the specifications of D4.2. Furthermore, specific potential solutions were identified for implementing the MAC control messaging, as well as the algorithms detailed in D4.3. The main goal was to choose for implementation a subset of the MAC functionalities that would still be able to fully demonstrate the unique characteristics of the OFDMA-PON. Since a control block has already been reserved in each ACCORDANCE frame, it was decided to use it for hosting the required control messages, as all message types specified in D6.2 can be hosted using the reserved control bytes. In the upstream direction, TDMA coordination between ONUs for sharing the upstream control block across consecutive frames is required. Since two ONUs are implemented in the ACCORDANCE testbed, a fixed TDMA (odd/even frames) of upstream control blocks was proposed. D4.5 also elaborated how each of the key messages defined in D4.2 could be hosted in the ACCORDANCE experimental system (the actual control messaging implementation, including the actions taken upon message reception, was performed in T6.2 and is summarized below). For the ONU registration, a handshake mechanism is defined, consisting of a series of messages, namely a *Register request*, a *Register acknowledgement* and a *Register* message which concludes the registration process. Regarding bandwidth assignment, *Report* messages are required to provide the ONU queue status, while *Tx Configuration* and *Rx Configuration* ones need to be sent from the OLT to an ONU for the creation of upstream/downstream transmission pipes. Due to the rectangular shape of the allocations, it is only required to include the low/high subcarrier indices and the start/stop time within the upcoming frames. It should be noted that the way the payload data block is implemented provides significant flexibility for bandwidth allocation among ONUs. In particular, it allows implementing in essence all the key types of subcarrier allocation defined in WP4 namely Fixed Subcarrier Assignment (FSCA), Dynamic Subcarrier Assignment (DSCA) and Rectangular Dynamic Subcarrier Assignment (RDSCA).

4. Provision of smooth migration from and coexistence with legacy access solutions.

The relevant studies, including the proposed migration path to ACCORDANCE allowing coexistence with legacy technologies and wireless support, along with a suitable wavelength plan, were concluded during Y2.

5. Multi-operator, multi-service support.

During the third year, deliverable D4.6 was published, part of which focused on the need to address a plethora of emerging services via the ACCORDANCE OFDMA-based next generation PON network. Such a need is further supported by regulatory requirements for open multi-operator access. During Y2, the ACCORDANCE consortium already provided its view on how to support network unbundling in a feasible and realistic way, via the use of a WDM overlay (i.e. OFDMA-over-WDM). Under this scheme, several ACCORDANCE-based "virtual PONs" (or network segments in the ACCORDANCE terminology) can coexist by using different wavelengths according to the wavelength plan defined in ACCORDANCE deliverable D2.4. Within each segment, bandwidth is distributed using any of the proposed intra-segment MAC algorithms from deliverable D4.3, as well as from those described elsewhere in the current document. The WDM-based unbundling approach was mainly chosen due to its practical feasibility. However, a more technologically challenging approach involves performing the unbundling in the OFDMA domain, allowing thus a more flexible and efficient multi-operator and multi-service support at sub-wavelength granularities issue (especially given that wavelength resources are becoming increasing scarce). In that respect, with different ACCORDANCE segments running customized intra-segment medium access control (MAC) protocols over a common wavelength channel, efficient yet fair bandwidth allocation among them becomes a vital. Therefore, a mechanism that makes optimal use of limited bandwidth resources and also bridges the heterogeneous MAC divide was proposed in D4.6. We refer to this mechanism for inter-segment bandwidth allocation as the ACCORDANCE "inter-segment MAC" protocol and was designed for enabling efficient and fair bandwidth arbitration in the ACCORDANCE network. The proposed OFDMA inter-segment MAC resides at the OLT side on top of the component MAC protocols of the individual ACCORDANCE segments and dynamically manages bandwidth within each optical wavelength channel. To do so, the inter-segment MAC exploits dynamic OFDMA subcarrier assignment at a sub-wavelength bandwidth granularity. Note that the inter-segment MAC is independent from the individual intra-segment MAC layers, which would remain unchanged. Moreover, all wavelength channels are optimized independently and transparently. For each ACCORDANCE wavelength, the inter-segment MAC, which works on top of the intra-segment MACs, has a total bandwidth resource multiple subcarriers at its disposal, which it partitions among several segments in the network, so as to generate a sufficiently broad PHY bandwidth pipe for each of them according to their specific bandwidth requirements.

6. Contribution to standardization activities on Next Generation Optical Access.

During the third year the consortium had been monitoring the activities at the standardization bodies, but any possible contributions from our side were minimal due to the decision to adopt TWDM with OOK modulation as the primary solution for NGPON2. The choice of the 4/8 wavelengths by the NGPON2 WG was noted and would be considered in the future activities about OFDM-PON or/and other more advanced solutions than the TWDM-PON. As a conclusion, the work conducted within ACCORDANCE has the potential to influence significantly the standardization bodies in their efforts of specifying beyond-10G-PON solutions

7. Demonstration of the ACCORDANCE concepts using experimental test beds.

During the third year, a set of tests were defined to validate ACCORDANCE objectives over the converged testbed specified during Y2 and the complete description of the tests was included in D6.1. These for example included OLT/ONU management tests (system start-up, configuration), PHY measurements (mean launched powers, working wavelengths, -20dB spectral widths, side-mode suppression ratio, optical receiver sensitivity with/without FEC etc.), long reach and maximum capacity transmission tests, service tests (video transmission, dynamic bandwidth allocation), as well as coexistence tests with GPON, RF overlay and wireless (CPRI) signals. In the framework of WP3, the FPGA board design was finished and sent for manufacturing. Proper operation of the most important board sections was thoroughly checked and they were prepared for production.Most of the functionality and algorithms were tested in a controlled environment that emulated completely the FPGA operation. . At the moment of writing of this report, FPGA boards were still at manufacturing, due to the high complexity of the boards' layout. Given the existing risk of delayed delivery of panels, the experimental platform was assembled to carry out the tests indicated in D6.1, whereas platform setup has incremental nature (from minimum (offline processing) to maximum (real-time processing end-to-end service delivery). In that respect, the general performance of ACCORDANCE network and the performance limits described above were first assessed with offline processing. Then with the FPGA boards operative, a check in the performance is being carried out to determine penalties and fine tune the systems. All the tests listed above were done for validating the ACCORDANCE concept for the wireline and wireless testbed. A converged experimental platform was also evaluated to determine the compatibility between the optical feeding network and the wireless/wired access system. Furthermore, an upstream low-cost solution based on IMDD was also tested with offline processing. A small video was successfully transmitted in this setup to corroborate the concept with real data. Moreover, the developed ACCORDANCE MAC protocol suite was loaded onto an FPGA board implementing the OFDMA MAC at the KIT premises. Several tests were performed which verified its correct operation, including ONU registration and bandwidth allocation. All the results were detailed in the respective deliverables submitted throughout Y3.

8. Dissemination of project results.

A total of 13 conference publications resulting from work within ACCORDANCE have been presented at several prestigious international conferences in 2012/13, in particular at ANIC 2012, ICTON 2012, ECOC 2012, ACP 2012, OFC/NFOEC 2013 and FuNEMS 2013. At ECOC 2012, a next generation converged access networks workshop has been organized by ACCORDANCE partner DT, while an ACCORDANCE-related presentation were given during that workshop by ACCORDANCE partner ALUD. During FuNEMS 2013, workshop "*Opportunities, Challenges and Interplay of Next Generation Optical and Wireless Access Networks*" were jointly organized by ACCORDANCE and FP7 COCONUT.

Also, ACCORDANCE results were presented in other workshops (e.g. at "*Can the spectrum be exploited more intensively in PON's*?" at OFC 2013 and "*A techno-economic comparison of XGPON, UDWDM-PON and OFDMA-PON architectures/technologies*" in the course of the 11th Conference of Telecommunication, Media and Internet Techno-Economics.

Three journal articles were published in IEEE/OSA JLT and IEEE Communications Magazine – whereby in particular the IEEE Communications Magazine article is a joint work of several ACCORDANCE partners. Journal publication also took place within internal issue of ALUD: "Bell Labs Technical Journal" with article "*Quantitative Analysis of Split Base Station Processing and Determination of Advantageous Architectures for LTE*".

Moreover, the ACCORDANCE consortium contributed to the CaON positioning paper regarding regarding OFDMA-PON architectures technologies.

Two patent applications have been filed during year 2012 by ACCORDANCE partner ALUD.

Exchange with other projects active in neighbouring fields with similar focus has been continued by having a workshop with the EU FP7 project OASE in a joint plenary meeting of the two projects in Tallinn (Estonia) in February 2012.

Expected Impact

The ACCORDANCE consortium brings together expertise at European level in the form of European research centers, universities, operators and vendors with a tradition and dedication to European ICT research. Technologically ACCORDANCE combines expertise found at all levels of network deployment. The industrial partners of the consortium have, with the help of ACCORDANCE, the opportunity to define market trends and requirements in terms of services, network architecture, network management and cost. Through their lengthy involvement in EU projects, the academic partners of ACCORDANCE have gained an invaluable understanding of European research which, combined with the practical expertise of the industrial partners, will effectively help ACCORDANCE successfully specify next-generation broadband infrastructures.

To begin with, the next generation of broadband services is expected to lead to unprecedented bandwidth requirements, taking also into account the real-time nature of the majority of them. Those requirements cannot be satisfied by employing existing access solutions. The ACCORDANCE infrastructure, by **achieving ultra-high data rates in the access network** will make the offering of such services a reality.

Moreover, ACCORDANCE retains the general PON concept of sharing the fibre infrastructure among a multitude of users which, along with the totally passive nature of the Optical Distribution Network and the reduced number of ports at the OLT (compared to fibre point-to-point solutions), lead to an **extremely cost-efficient network infrastructure.** Additionally, the long-reach and high-splitting operation targeted by ACCORDANCE results in significant node consolidation, since each Central Office can cover a larger user base, **reducing in this way the CAPEX and OPEX costs of the network**. This leads naturally to an infrastructure where the cost per bit will be significantly low, an effect which is further augmented by the multi-operator, multi-service concept of ACCORDANCE which is expected to **lead to a competitive business environment**.

The ACCORDANCE consortium includes as partners vendors and operators with commercial interest in the successful completion of the project and future exploitation of the developed technology base and also committed to be active in standardization. The ACCORDANE consortium thus aims at providing input and **significantly influencing the upcoming Next Generation Optical Access (NGOA) standards**, since OFDMA-PON is one of the contending technologies considered for upgrading existing PONs (solving also the issues of TDMA-PON burst-mode operation when scaling to several tens of Gbps).

Furthermore, ACCORDANCE has the ability of offering end users access to content and services through a variety of networks and platforms, both wireline and wireless. In that way its adoption is facilitated by the new breed of customers who are accustomed to enjoying services at any location and using a variety of end devices, as well as by subscribers in developing countries where the number of mobile subscribers is significantly higher and far more diffused than the number of personal computer users. The converged wireline-wireless nature of ACCORDANCE, along with the longer network reach achieved, will also enable the provision of high-capacity connectivity to users in rural and sparsely populated areas. This will eventually help in bridging the gap of broadband adoption among geographic areas and consequently **accelerate the uptake of next generation networks across Europe**.

Finally, a widespread adoption of the ACCORDANCE vision could contribute to the **emergence of a large number of European Small & Medium Enterprises (SMEs)** manufacturing relevant components and equipment, thus stimulating the European telecommunications market.

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2. PROJECT OBJECTIVES FOR THE PERIOD

Objective 1: *Definition of a novel access/metro network architecture achieving convergence among heterogeneous technologies (optical, wireless fibre).*

All issues related with this objective have been addressed by the work performed during Y1 and Y2.

Objective 2: *Proposal of low-cost, low-complexity concepts to achieve ultra high data rates in the access network (up to 100Gbps aggregate and more than 10Gbps in each segment).*

Splitting the signal in several (ranging from tens to thousands) low bitrate (possibly of few Mbps each) sub-carriers provides the opportunity to use already available low-cost optical devices and electronics. This is a very crucial issue, since the cost for upgrading ONUs to support the envisaged ≥10 Gbps rates with existing solutions may prove prohibitive. In addition to the cost, the complexity of PON devices supporting ≥10 Gbps under TDMA operation becomes extremely challenging due to the requirement for very fast burst-mode operation. By adopting OFDM techniques, it will be possible to achieve long-reach operation using already available low-bandwidth optical components. With the consumer demands, as well as the standardization activities already pointing towards data rates in the access of more than one order of magnitude higher than existing solutions, we believe that the ACCORDANCE concept will play a key role towards the realization of this goal.

Measurable results for this objective can be summarized as follows:

- Design of the OLT/ONU transceivers using available components and FPGAs resulting in lower cost and lower implementation complexity with respect to the offered capacity and connectivity (i.e. number of supported users).
- Achieve more than 10Gb/s rates per segment and up to 100Gb/s aggregated rate for the whole access network
- The extended design in terms of data rate will cover the reach defined by current standards offering connectivity to a larger number of users equal to multiples of the number supportes by current GPON or EPON solutions; (the multiplication factor depends on the defined number of segments)
- Alternative designs will be provided for extended reach beyond 40km and up to 100km, by examining different modulation formats at the expense of lower aggregated data rates.
- Clearly demonstrate the advantage of OFDM technology over TDM solutions for scaling up to 100 Gbps in the access

This objective during Y3 was implemented by: WP3 (Task 3.3, Task 3.4)

Objective 3: *Introduction of flexible bandwidth allocation concepts using dynamic FDM and OFDM sub-carrier assignment.*

One key aspect of the ACCORDANCE concept is that the spectrum can be allocated in a significantly flexible manner and in multiple levels of granularity. At a first level, FDM windows are assigned to each network segment/service while the widths of the windows could be dynamically adjusted to fit the bandwidth needs in each case. In addition, the group of sub-carriers within the window of each of the OFDMA/DSCA PONs is shared among ONUs by allowing each ONU to dynamically get sub-carriers allocated according to their temporal bandwidth demands, leading to "OFDMA/DSCA PON"-specific MAC protocols. These protocols determine the number of sub-carriers assigned to each user, while allocation among ONUs comes at a granularity almost as fine as in classic TDMA-based PONs (since each sub-carrier will operate at relatively low data rates) and with almost as equal flexibility. Of course, as mentioned above, it will still be possible (and to some extent desirable) to support TDMA operation in OFDMA/DSCA PONs as well, particularly in the upstream direction. Moreover, the adoption of the OFDM-QAM modulation scheme endows the system with one more degree of flexibility since it can be manipulated to provide dynamic bandwidth adjustment in addition to power balancing.

Measurable results for this objective can be summarized as follows:

- Detailed definition of novel MAC protocols for ACCORDANCE
- Proposal and evaluation via simulations of algorithms taking advantage of the ACCORDANCE MAC
- Evaluation of the ACCORDANCE MAC on the experimental test-bed

This objective during Y3 was implemented by: WP4 (T4.2), WP5 (Task 5.4), WP6 (Task 6.2)

Objective 4: *Provision of smooth migration from and coexistence with legacy access solutions.*

All issues related with this objective have been addressed by the work performed during Y1 and Y2.

Objective 5: *Multi-operator, multi-service support.*

It has become clear that the ACCORDANCE network architecture allows one central office to manage at the same time several sub-networks or network segments. Although these co-exist within the same ODN, they are assigned to different sets of sub-carriers (producing in this way an overlay of FDM channels as mentioned before) and they correspond to separate processes at the OLT hardware or software. In other words, the proposed architecture can be used as the basis for supporting several segregated virtual access networks, possibly belonging to different providers and adopting diverse technologies. Virtualization of resources is guaranteed for each of them via the centralized control performed at the CO.

Measurable results for this objective can be summarized as follows:

- The use of subcarriers allows the overlay of FDM bands that support multiple providers. This architectural requirements will be studied both at the network design level and the MAC layer level.
- The project will define clearly the concept of virtual access networks using the same infrastructure but shared by different operators.
- The centralized control mechanism will provide the appropriate functions for the definition of the virtual multi-operator access networks and their adaptation to the traffic handled by each provider.

This objective during Y3 was implemented by: WP5 (Task 5.4)

Objective 6: *Contribution to standardization activities on Next Generation Optical Access.*

The next generation of PON standards by the major standardization bodies (ITU-T, IEEE) is ongoing, and it is evident that they will target towards increased data rates (10 Gbps) and increased reach. The ACCORDANCE concept moves towards both of those directions as was shown by the definition of Objectives 1 and 2 and even beyond, as the aggregate rate in the converged access/metro ACCORDANCE architecture can reach up to 100 Gbps. Moreover, the TDMA principle of operation which is currently expected to remain largely unchanged in the upcoming standards, compared to the existing GPON and EPON ones, will impose serious challenges to the burst-mode operation of receivers when addressing even higher capacities. In ACCORDANCE this can be easily addressed by providing the same multiplexing granularity in the sub-carrier domain. As a conclusion, the work conducted within ACCORDANCE has the potential to influence significantly the standardization bodies in their efforts of specifying beyond-10G-PON solutions.

Measurable results for this objective can be summarized as follows:

- Participation in the standardization bodies on next generation access networks in order to collect updated data and future standardization plans and also influence the relative standardization activities where possible.
- Follow the IEEE standards on EPON and next generation extensions.
- Follow the ITU-T standards on GPON and next generation extensions
- According to the project’s outcomes and studies, all or any of the following activities in the aforementioned standardization bodies will be influenced (if applicable):
- Extended reach and coverage limits in PONs,
- Wireless-wireline infrastructure for integration
- Requirements for multi-operator support
- Control and management issues and MAC design

This objective was implemented by: WP7 (Task 7.2)

Objective 7: *Evaluation of the ACCORDANCE concepts using experimental test beds.*

The necessary proof-of-concept will be provided at the end of the project, with a demonstration of the network concepts and physical layer performance measures on a test-bed located at the facilities of one of the partners. In addition, a number of experiments will be conducted during the project in a distributed fashion, either by individual partners or by groups of them collaborating together, in order to validate separate aspects of the ACCORDANCE concepts. The challenges are not few, taking into account that the experimental scenarios will involve radically novel concepts residing in multiple layers. It should be made clear again though that the target of ACCORDANCE is not to develop novel device prototypes but rather demonstrate the feasibility of the concept using mostly available, off-the-shelf network elements.

Measurable results for this objective can be summarized as follows:

- Implementation and testing of the ACCORDANCE nodes (OLT, ONUs)
- Assembly of a functional test-beds using off-the-self components, where advance processing functions will be implemented in FPGAs

The final experimental test-bed will test:

- physical layer issues,
- design tolerances and system limitations and
- control mechanisms through service delivery operations

This objective during Y3 was implemented by: WP6 (Task 6.2, Task 6.3)

Objective 8: *Dissemination of project results*.

This objective deals with the necessity of performing dissemination activities of the project visions and results. This has significant importance for ACCORDANCE since we realize that in order to make the proposed vision become a reality in the future, the details of ACCORDANCE, including its key benefits and proofs of feasibility, must be brought out to the research community and the decision-making actors in the market.
Measurable results for this objective can be summarized as follows:

- Definition of a clear and effective dissemination plan
- Publications in high quality journals/magazines
- Presentations in high quality conferences/workshops
- Web-site establishment

This objective was implemented by: WP1 (Task 1.3), WP7 (Task 7.1)

3. WORK PROGRESS AND ACHIEVEMENTS

3.1 WP2 – NETWORK ARCHITECTURE, DESIGN REQUIREMENTS AND SPECIFICATIONS

Workpackage number	**2**	**Start date:** M1- **End date:** M24
Activity type	RTD	
WPL	AIT	
Sub-tasks	Task 2.1: Network architecture and elements [AIT]	
	Task 2.2: Benefits and feasibility [DT]	
	Task 2.3: Migration and convergence scenarios [ALUD]	
Deliverables / Y3	None	
Milestones / Y3	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 3 (CE)													
JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	16.0	-	12.0	-	13.5	-	-	-	17.0	-	10.0	-

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
4.0	-	7.0	-	-	-	***79.5***	***-***

According to the Annex I, the objectives of WP2 "Network architecture, design requirements and specifications" are as follows:

- Define the complete ACCORDANCE architecture, including the basic network elements, their general design and functionality.
- Identify the exact requirements for ACCORDANCE in order to achieve the set goals.
- Investigate the feasibility of the aforementioned studies and define the ways in which the ACCORDANCE concepts can be brought to real-world deployment.

All WP2 activities were finalized during first and second year of ACCORDANCE, thus no activities were performed during the third year.

3.2 WP3 – NODE DESIGN/IMPLEMENTATION AND MODULATION/TRANSMISSION STUDIES

Workpackage number	**3**	**Start date:** M1- **End date:** M40
Activity type	RTD	
WPL	KIT-U	
Sub-tasks	Task 3.1: Access Requirements and Modulation Format Studies [UPC]	
	Task 3.2: Transmitter and receiver design and implementation [KIT-U]	
	Task 3.3: Design and implementation of FPGA modules for the OLT and the ONUs [KIT-U]	
	Task 3.4: Implementation of the OLT and the ONUs [ALUD]	
Deliverables / Y3	D3.6 - Implementation of the OLT and ONUs (M40)	
Milestones / Y3	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 3 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	12.0	-	28.0	3	2.0	-	8.5	-	1.0	0.5	-	-

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
59.0	30.7	24.0	4.9	-	-	***134.5***	***39.1***

According to the Annex I, the objectives of WP3 "Node design/implementation and modulation/ transmission studies "are as follows:

The work package aims at:

- Finding of the best physical implementation for the network concept from WP2.
- Design and implementation of the real-time processing capable OLT and ONUs.

In detail, objectives of this work package are:

- Identification of the optimum modulation format
- Implementation of the Transceivers for OLT and ONUs.
- Real-Time processing capable FPGA implementation
- Implementation and demonstration of the OLT and the ONUs

During third year the work in WP3 continued efforts made in Y2 with the focus mainly on objective 2 and in particular on the design and implementation of the OLT and ONU transceivers. This included first of all implementation and verification of the signal processing components required for the OFDMA system and completion of FPGA board layout.

Unfortunately the design of this board was delayed due to problems with the subcontractor assigned with the layout. Meanwhile the layout is ready and the first boards are in production. However, initial functional tests of the hardware are still pending. However, at the moment of writing of this rows, we expect the arrival of the first completely populated board in few days.

Task 3.1: Access Requirements and Modulation Format Studies

This task mainly fulfils Objective 1 of identifying the optimum modulation format for both DS and US. It is connected to the other objectives (2, 3 and 4) in giving insight on the devices that will be needed for implementation. Several modulation formats exist in literature for optical OFDM networks. In this task, the performance of these methods was compared by carrying out simulations of a point-to-point scenario. The downstream modulation format has been selected while several upstream solutions are still under study, mainly considering the cost and the inherent problem of optical beat interference (OBI) in OFDM networks.

There was not any activity in Task 3.1 during 3rd year since task has ended during Year 2.

3.2.1 Task 3.2: Transmitter and receiver design and implementation

The underlying objective that is to be satisfied by T3.2 is the development and design of cost-effective, high performance, and low complexity transmitter and receiver devices for both central office (OLT) and subscribers (ONU) (Objective 2). Inherently there is a tradeoff between high performance and cost. Therefore transceiver designs are chosen such that the highest possible performance is expected and the scalability to lower data rates guarantees cost effectiveness. A potential network scheme including the transceiver designs has been proposed with the focus on especially low complex and low cost ONU and a higher cost and high performance OLT. The higher cost OLT at the central office can be justified since these costs are shared among all subscribers that belong to the same network segment.

Significant results:

The optical and analog electrical hardware for ONU and OLT have been implemented and their functionality has been demonstrated using offline processing. The network including one OLT, two ONU and an emulated PON was implemented using arbitrary waveform generators as data sources and real-time sampling oscilloscopes for later off-line processing. The downlink (see **Figure 1**) and uplink (see **Figure 2**) have been demonstrated in two independent experiments using OFDM and the results were published.

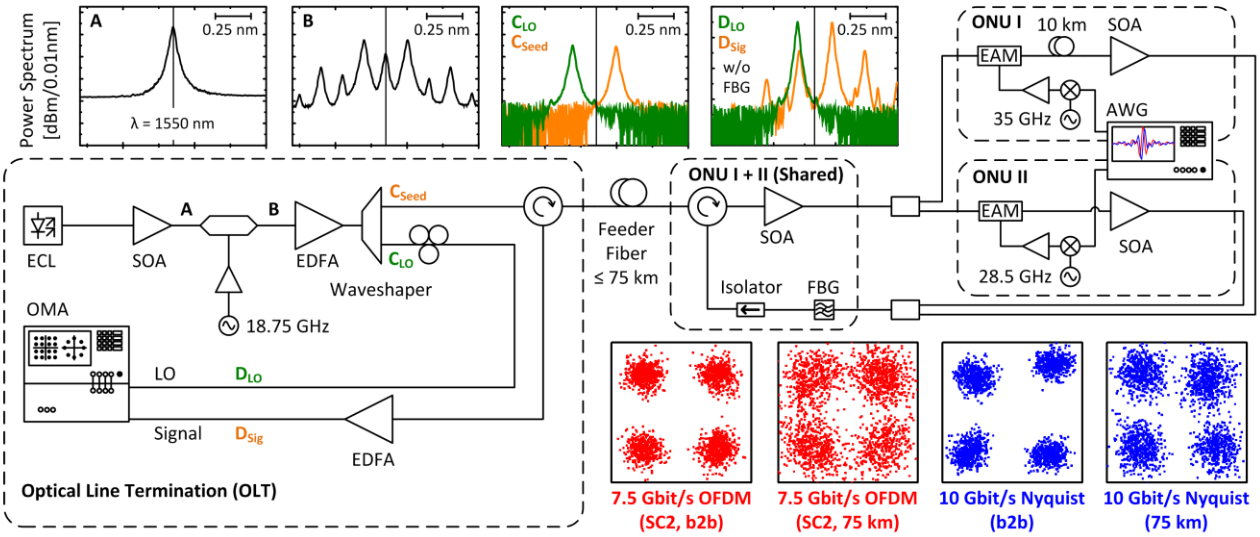

Figure 1 - Implementation of the uplink scenario and experimental results of OFDM signals and NFDM.

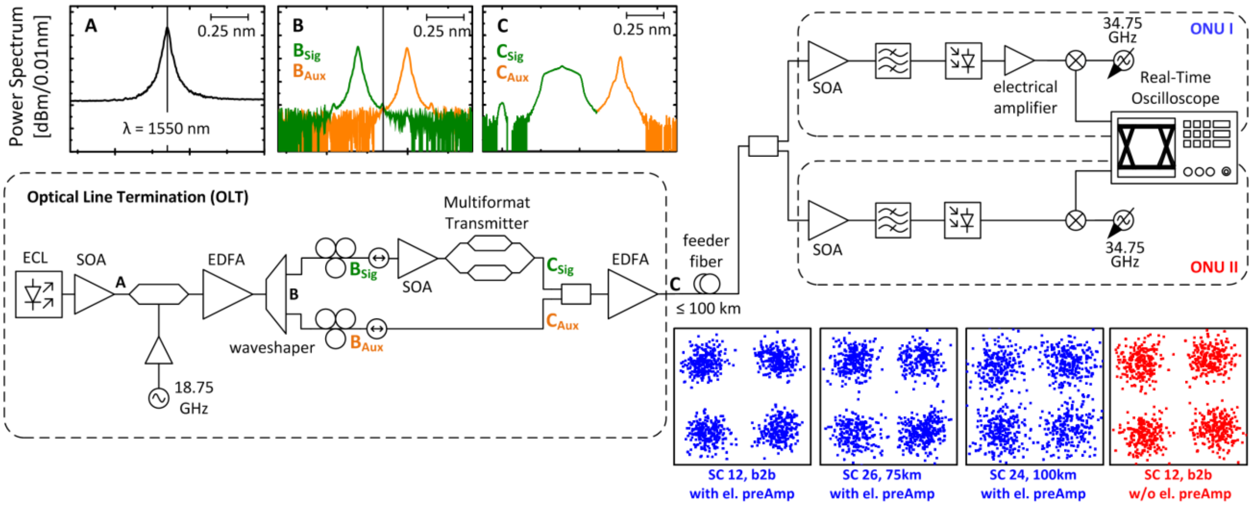

Figure 2 - Implementation of the downlink scenario and experimental results of OFDM signals

3.2.2 Task 3.3: Design and implementation of FPGA modules for the OLT and the ONUs

Based on the requirements arising from Objective 2, high performance FPGAs have been selected that are capable of processing the OFDM signal on a single chip. Avoiding a multi-chip architecture simplifies the digital signal processing since complex data transfers are obsolete.

Significant results:

All signal processing components required for the OFDMA system (e.g. FFT, CORDIC, SYNC, subcarrier mapping, etc.) were implemented and successfully verified with the help of Modelsim. Furthermore, a joint system simulation containing OLT and ONU transmitters and receivers, the MAC layer as well as proper data sources and sinks was successfully performed using Modelsim. This ensures a smoothly integration of the OFDM processing parts into the rest of the system.

3.2.3 Task 3.4: Implementation of the OLT and the ONUs

Fulfils Objective 7: Evaluation of the ACCORDANCE concepts using experimental test beds.

Significant results:

Due to lack of the FPGA signal processing boards a joint experiment of optical and digital components performing real time signal processing and transmission via the optical system could not be performed so far. However, with the help of a smaller FPGA development board it was possible to connect at least a part of the ONU digital system to the optical network. The test results showed that the ONU receiver could synchronize to the downstream signal generated by an AWG at the OLT.

On the optical layer, the bi-directional network has been tested with offline processing and NFDM-signals, since a defect synthesizer rendered the OFDM-experiments impossible. The experimental results with NFDM signals meet the standards for PON class A, B and C. Efforts still continue to achieve complete bi-directional operation with real-time processing towards the review of the project.

Figure 3 (a) shows the bit error ratio (BER) in the downstream dependent on the carrier frequency of the spectral group received. The receiver does only corporate pilot phase tracking and timing recovery. Setup inherent losses of 4.3 dB for a power-tap at each ONU and the 3dB-coupler to provide two ONU with the ODN are not taken into account in this plot. The best performing spectral group thus has a maximum attenuation of 30.5 dB (cyan) and the worst performing 25.2 dB. The black curve shows bad performance over the whole attenuation range, indicating issues with reception. We assume frequency deviations in this operation range for the electrical oscillator.

The frequency dependency of the signal – outer spectral groups have less SNR, thus perform worse – as well as of the down-converters – the highest frequency (magenta) performs worse than the second highest (cyan).

With real-time processing we expect the performance to increase thanks to more sophisticated digital signal processing and real-time adjusted local oscillators.

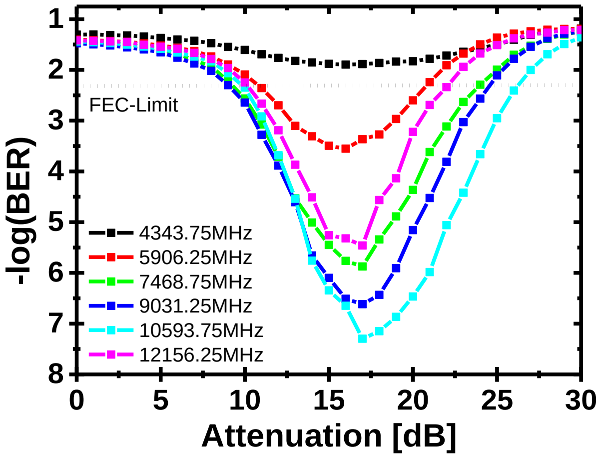

Figure 3 (a) – Bit error ratio dependent on the attenuation in the ODN without a fiber in the ODN (back-to-back case). The frequencies denote the second electrical local oscillator and identify the respective spectral group. The lowest frequency corresponds to the outer most spectral group investigated.

Unfortunately we were not able to detect the upstream transmission with the offline processing at hand. The receiver was not fully implemented as mentioned before, thus we were not able to correct the phase error completely.

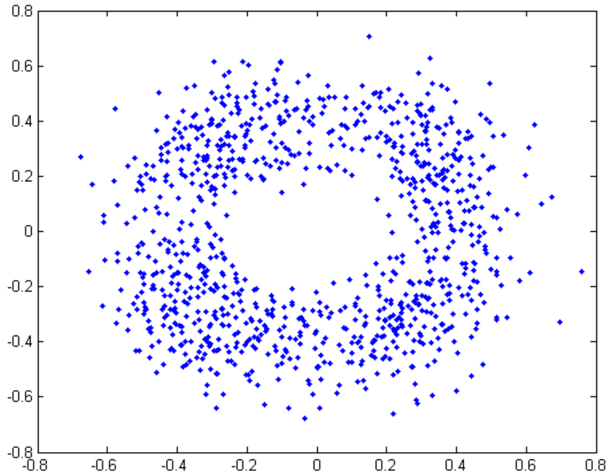

Figure 3 (b) – Exemplary constellation diagram for a subcarrier in the upstream direction with 16 dB attenuation in the network. Residual phase error renders demodulation impossible at this point.

3.3 WP4 – MAC LAYER ISSUES FOR THE SUPPORT OF FLEXIBLE BANDWIDTH ALLOCATION

Workpackage number	**4**	**Start date:** M1- **End date:** M26
Activity type	RTD	
WPL	UH	
Sub-tasks	Task 4.1: MAC layer requirements for the ACCORDANCE network [UH]	
	Task 4.2: Definition of MAC protocols supporting FDM/OFDM operation [AIT]	
	Task 4.3: Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE [UH]	
Deliverables / Y3	D4.5 - Definition of MAC protocols supporting FDM/OFDM operation (M25) - Update of D4.2 D4.6 - Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE (M30) - Update of D4.3	
Milestones / Y3	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 3 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	30.7	10.0	-	-	-	-	5.3	-	-	-	33.0	7.4

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
-	-	5.0	0.2	-	-	***74.0***	***17.6***

According to the Annex I, the objectives of WP4 "MAC layer issues for the support of flexible bandwidth allocation"are as follows:

The work package aims at:

- Establishing the MAC layer requirements for the ACCORDANCE network.
- Proposing novel protocols tailored for ACCORDANCE.
- Concentrating on the MAC algorithm development for dynamic FDM and OFDMA sub-carrier allocation.

In detail, objectives of this work package aims are:

- The enhancement of existing protocols/frames to support FDM and OFDMA operation.
- The study of the advantages and drawbacks regarding hybrid OFDMA/TDMA dynamic bandwidth assignment.
- Modeling and simulations of algorithms that exploit OFDMA/TDMA operation and comply with specific service level agreements.
- Identify protocol extensions to include wireless functionality.

Progress in WP4 in Y3 has been disseminated through the timely submission of deliverable D4.5 describing the alignment of the ACCORDANCE FPGA system developed in WP3 with the ACCORDANCE MAC protocol specifications provided in D4.2 and deliverable D4.6 serving as an update to D4.3 that set the grounds of the ACCORDANCE MAC intra-segment bandwidth allocation algorithms and in particular the assignment of subcarriers and timeslots to individual ONUs. Both remaining tasks of WP4, T4.2 and T4.3 were completed in Y3 in line with the submission of these deliverables.

D4.5 was originally intended as an update of D4.2. At the same time, work in ACCORDANCE WP3 progressed resulting in the design of a complete FPGA system able to demonstrate OFDMA-PON operation. For this reason it was decided to use D4.5 as the bridge between the theoretical definition of the ACCORDANCE MAC in D4.2 and the actual FPGA implementation that will be employed for its realization.. D4.6 included a revision of the originally defined intra-segment algorithms, the introduction of the framework and algorithms to also perform inter-segment bandwidth allocation, a summary of the required functions and algorithms to allow for the convergence at the MAC layer between the optical network and LTE standards and the uploading of specialised MAC algorithms and control messages over the FPGA designs of the ACCORDANCE OLT and ONUs to be used in WP6.

3.3.1 Task 4.1: MAC layer requirements for the ACCORDANCE network

Although T4.1 is designed to address the ACCORDANCE Objective 3 in relevance to the introduction of flexible bandwidth allocation concepts using dynamic FDM and OFDM sub-carrier assignment, it also widely associates with the activities of Objective 1 being the definition of a novel Access Network architecture achieving convergence among heterogeneous technologies (optical, wireless, copper). The latter is attended in particular by providing the definitions in T4.1 of achieving dynamic bandwidth allocation and end-to-end service delivery capability over the ACCORDANCE architecture in all three time, subcarrier and even wavelength domains. Deliverable D4.1 has been submitted in response to providing the above requirements.

There was not any activity in Task 4.1 during 3rd year since task has ended during Year 2.

3.3.2 Task 4.2: Definition of MAC protocols supporting FDM/OFDM operation

T4.2 is widely associated with the activities of Objective 3, namely to introduce flexible bandwidth allocation concepts using dynamic FDM and OFDM sub-carrier assignment but also addresses some concepts of Objectives 4 and 5 with respect to the provision of smooth migration from and coexistence with legacy access solutions as well as multi-operator, multi-service support respectively. These have been achieved by the introduction of new protocol designs for the implementation of OFDMA PONs.

Initially D4.2 provided a detailed list of all the control messages, their fields and the message exchanges that need to take place between the OLT and the ONUs to achieve all ACCORDANCE functionalities. The same document also suggested ways of migrating from existing TDMA-PON protocols to the ACCORDANCE MAC with minimal modifications. Therefore, D4.2 is a comprehensive document that contains all required ACCORDANCE MAC definitions. During Y3, the main part of the work for T4.2 has been associated with determining how the ACCORDANCE MAC protocol guidelines described in detail in deliverable D4.2 can be adapted to be used for the final ACCORDANCE testbed. In that respect, deliverable D4.5 published during Y3 first of all verified the alignment of the ACCORDANCE FPGA system (from the MAC layer point of view) with the specifications of D4.2. Furthermore, specific potential solutions were identified for implementing the MAC control messaging, as well as the algorithms detailed in D4.3. The main goal was to choose for implementation a subset of the MAC functionalities that would still be able to fully demonstrate the unique characteristics of the OFDMA-PON.

Significant results:

As described in D3.5, a basic building block of the ACCORDANCE FPGA system is the “MAC Layer & Subcarrier Management” module, which performs the routing between the external 10G Ethernet interfaces and the subcarriers of the OFDMA physical layer and is also responsible for creating the control and information flows. The whole system, along with the MAC module is controlled by an embedded Leon-3 processor. During the course of T6.2, the latter processor was augmented with specially developed code that makes it interact with the MAC module to enable all required functionalities. This code is in charge of preparing the necessary control messages and forwarding them (via specially defined functions) to the MAC module which implements them. Therefore, the complete ACCORDANCE MAC should be considered as a combination of the FPGA MAC modules along with the respective code on the embedded processor.

Both downstream and upstream transmission is organized in synchronized OFDM frames of fixed 105.6μs duration, as shown in **Figure 4**(a), with each frame containing both control and data. A total of 256 subcarriers are used, spread into 16 spectral groups of 16 subcarriers each. Note that the outer two spectral groups are not used. Moreover, in each of the rest groups, the central subcarrier is left unmodulated to avoid DC offsets while two subcarriers are used as pilots. As a result, 182 (=14x13) subcarriers are available and taken into account during the bandwidth allocation process performed via the MAC layer. In the time dimension, the frame is split into 8250 OFDM symbols of 12.8 ns each. As shown in **Figure 4**(a), each frame is broken down in four discrete blocks: The *synchronization block* consists of 10 training symbols for the ONU Rx to perform time/frequency synchronization, while the *phase reference* block (16 symbols) is used for phase estimation. The same *control block* (32 symbols) is sent in all spectral groups (and received by all ONUs), occupies 26 Bytes in each frame and its structure is shown in **Figure 4**(b). Finally, the *data block* takes up the rest of the frame (8192 symbols). Its subcarriers are shared among the ONUs and can be modulated using any *m*-QAM format. In each frame, each ONU can be allocated up to 13 adjacent subcarriers (being limited to a single group) and up to 8192 symbols. In that way, a series of *rectangles* (2-dimensional bandwidth structures) are assigned to each ONU in consecutive ACCORDANCE frames, called a Virtual Channel (VC).

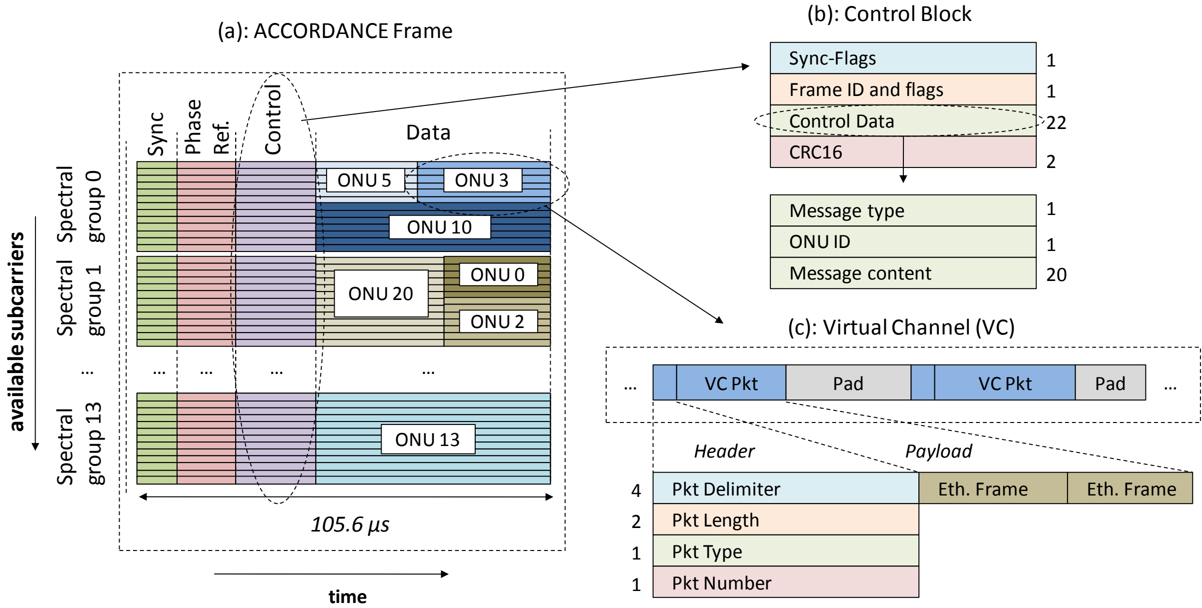

Figure 4 - (a) The implemented ACCORDANCE framing, enabling (b) control messaging in the control block and (c) data transmission via OFDMA/TDMA Virtual Channels (VC) formed in the data block.

Two different options were identified in D4.5 for implementing the necessary MAC protocol functionalities, In the first one, modified EPON MPCP control messages (as described in D4.2) could be sent using the *data block* of ACCORDANCE frames. This option provides the maximum possible flexibility, since it in essence allows implementing a full MAC protocol suite if needed. However, since the control information should be available to all ONUs, *at least one* of the 13 available subcarriers *per spectral segment* in all downstream ACCORDANCE frames should be reserved for this purpose, leading to a significant waste of bandwidth.

Since a control block has already been reserved in each ACCORDANCE frame (the same control information is sent in all spectral groups), it makes sense to use for hosting the required control messages. The only drawback is that the maximum possible control message size in each frame is 24 Bytes. However, all message types specified in D6.2 can be hosted using the aforementioned number of bytes. In the upstream direction frames are formed by adding the signals sent by the various ONUs, hence TDMA coordination between ONUs for sharing the upstream control block across consecutive frames is required.

Based on the aforementioned descriptions, the consortium decided to follow the second approach for the final ACCORDANCE testbed, since it was considered as the most feasible and adequate enough for demonstrating all MAC functionality. Since two ONUs are implemented, a fixed TDMA (odd/even frames) of upstream control blocks was proposed.

Next, D4.5 elaborated how each of the key messages defined in D4.2 could be hosted in the ACCORDANCE experimental system (the actual control messaging implementation, including the actions taken upon message reception, was performed in T6.2). Note that additional messages were needed to be implemented in the course of T6.2 – for example ones related to frame synchronization as well as an acknowledgement mechanism.

For the ONU registration, a handshake mechanism is needed, consisting of the following messages:

- ***Register request:*** This message contains no actual contents and is transmitted by an ONU to the OLT upon its connection.
- ***Register acknowledgement:*** This message also contains no actual contents and is transmitted by an ONU to the OLT upon to acknowledge receipt of the corresponding downstream REGISTER message (see below).
- ***Register:*** This message is sent from the OLT to an ONU after a *REGISTER_REQ* message has been received. In the context of the ACCORDANCE experiments, the additional information that needs to be sent within such a message is the modulation format to be used by the ONU. According to D4.2, 1 Byte is enough for this purpose.

<u>Regarding bandwidth assignment, the following messages are required:</u>

- ***Report:*** In case a queue status reporting approach is followed, an upstream message containing the amount of bytes stored in the ONU buffer is required.
- ***Grant (renamed to "Tx Configuration" in D6.2):*** This message is sent from the OLT to an ONU for the creation of an upstream transmission pipe. Due to the rectangular shape of the allocations, it is only required to include the low/high subcarrier indices (1 Byte is enough for each of the two aforementioned fields) and the start/stop time within the upcoming frames. The latter are specified in symbols and 2 Bytes are enough for each of the start/stop time fields.
- ***Rx Configuration:*** This message is sent in advance by the OLT to an ONU to inform it about the subcarrier range and timeslots they should receive in the downstream frames. The field lengths are identical to what was described above for the Gate messages.

As described above, the way the payload data block is implemented provides significant flexibility for bandwidth allocation among ONUs. In particular, it allows implementing in essence all the key types of subcarrier allocation described in D4.2, namely:

- ***Fixed Subcarrier Assignment (FSCA)**:* Each ONU is allocated, upon their registration, a fixed number of 1 to 13 subcarriers for the whole duration of each frame. This is the least flexible approach; however it serves well as an initial test case to verify the experimental setup.
- ***Dynamic Subcarrier Assignment (DSCA*)**: The ONU is allocated a fixed number of subcarriers (again, from 1 up to 13), but only for the next scheduling window. The duration of the scheduling window could range from 1 to several tens of frames. However, a very small time window will be very challenging from a processing point of view (given also the inevitable latency in the communication between the embedded processor, the MAC module and the PHY

layer). On the other hand, a very large window will cause an unwanted increase in packet delay. In D4.2, an indicative window of few ms is suggested.

- ***Rectangular Dynamic Subcarrier Assignment (RDSCA)***: According to D4.2, the RDSCA mode implies that the ONU is allocated a fixed number of subcarriers for a limited number of timeslots within the next scheduling window. Given the MAC implementation as described above, it is obvious that, unless the scheduling window duration equals 1 ACCORDANCE frame, RDSA can only be realized via the transmission of multiple control messages per scheduling window.

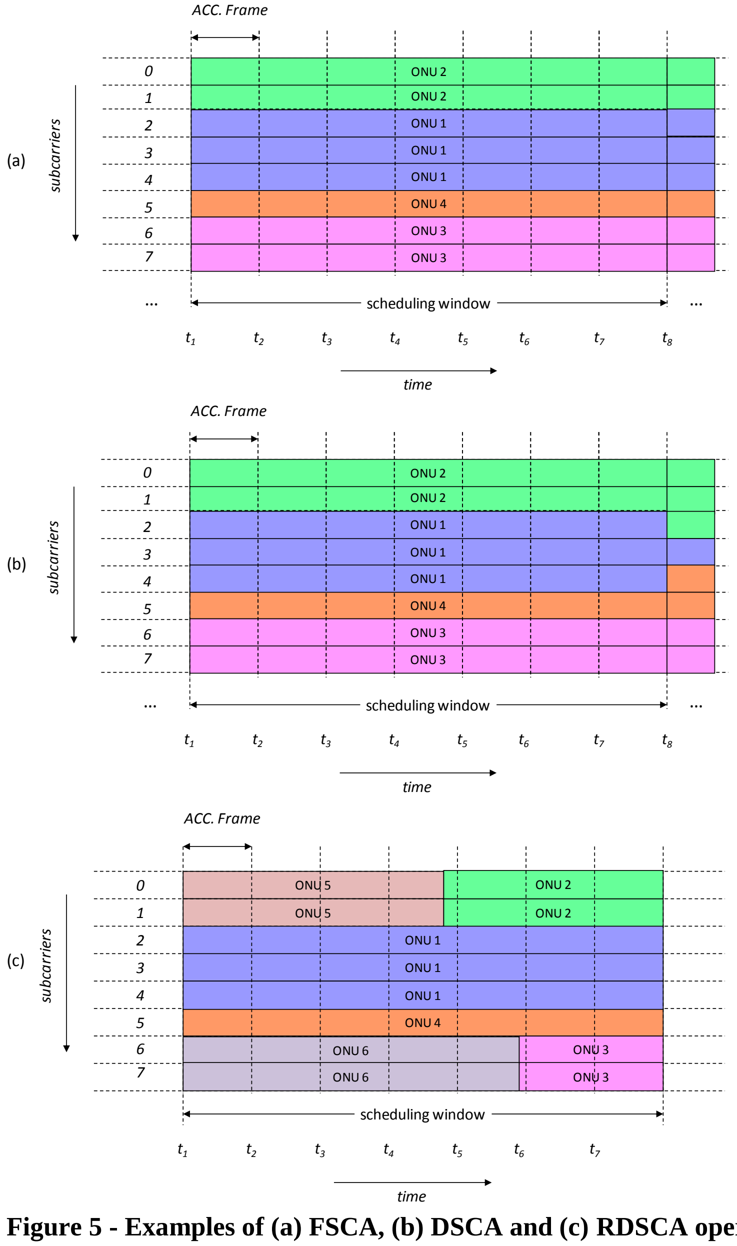

Figure 5 - Examples of (a) FSCA, (b) DSCA and (c) RDSCA operation.

Figure 5 shows an example of upstream bandwidth assignment using the FSCA, DSCA and RDSCA modes. In this example, the scheduling window equals 7 ACCORDANCE frames. For simplicity we show only the payload data block of each frame and only 8 subcarriers. It is obvious that in the FSCA case, control messages for bandwidth allocation only need to be sent once per ONU, while in DSCA they may be needed at maximum once per scheduling window. On the contrary, RDSCA implies a significantly larger amount of messages (in the ACCORDANCE frame timescale), in order to achieve the required sub-frame granularity.

3.3.3 Task 4.3: Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE

The scope of this task is to design, model and simulate algorithms, leading to the implementation of new MAC designs for OFDMA-PONs and perform network evaluations, with ACCORDANCE being the underlying infrastructure. The overlay of FDM bands for the support of multiple providers, specified in Objective 5, has been achieved by providing algorithms for both the intra-segment allocation of subcarriers and timeslots to individual ONUs and the inter-segment allocation of subcarrier bands to individual network segments supporting operators in an unbundled network configuration. During Y3 in particular, the design principles and trade-offs, including frequency of execution, fairness and security issues of a novel OFDMA inter-segment MAC are delivered, followed by the simulation verification of a detailed OFDMA inter-segment MAC dynamic bandwidth provisioning scheme. Updates of previous OFDMA/ TDMA intra-segment hybrids are evaluated with reference to both Service Level Agreement (SLA) and Class of Service (CoS) differentiation for various scenarios and network specifications to exhibit increased granularity in bandwidth allocation. Equally important the MAC functionalities and algorithms to exhibit the requirement for backhauling of LTE ONUs have also been explored. Algorithmic functions, scheduled for WP6 to deliver a specialised algorithm best suiting the ACCORDANCE OLT and ONU FPGA transceivers, are also specified.

Significant results:

Research outcomes have been drawn for the performance evaluation of new and revised algorithm designs, exhibiting SLA and CoS differentiation for up to 100 km reach, 256-split OFDMA-PONs.

Regarding the inter-segment MAC, a well-defined framework has been proposed. This consists of a novel module lying above the individual (intra-segment) MAC modules which controls each segment coexisting in the same ACCORDANCE wavelength. This is shown in the figure below.

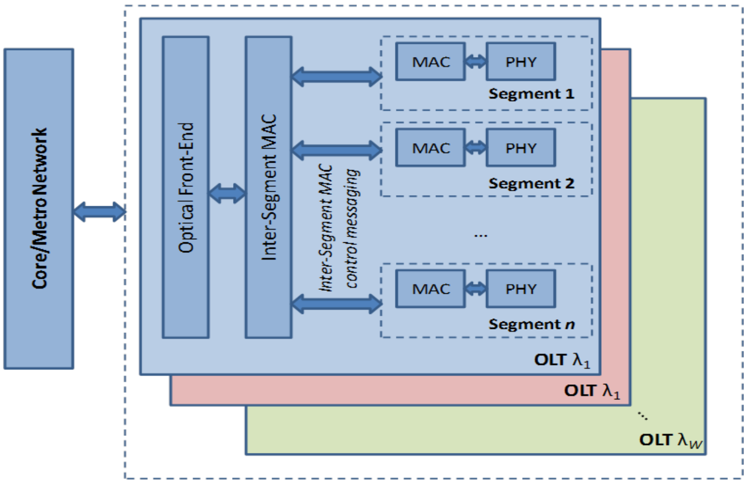

Figure 6 - Schematic diagram of the proposed inter-segment MAC module and its interaction with the individual (intra-segment) OFDMA-PON MAC modules

The inter-segment MAC communicates with the intra-segment MAC via a simple control protocol which allows it to identify each segment needs. The inter-segment MAC periodically executes a provisioning process which consists of segment admission, bandwidth assignment and spectrum allocation. The end result (communicated back to the segments) is the admission of all or part of the participating segments and the allocation to them of a number of subcarriers in a specific spectral area. The provisioning process has been formulated mathematically and several options have been proposed for the aforementioned provisioning steps. Accordingly, a detailed custom simulation model implementing all the proposed framework and algorithms was developed and the performance of the inter-segment MAC was evaluated. In particular, it was shown that the use of the proposed load balancing method significantly increases the achieved spectral utilization (at increased algorithmic complexity), while the best method for spectrum allocation mainly depends on the nature of the segments involved.

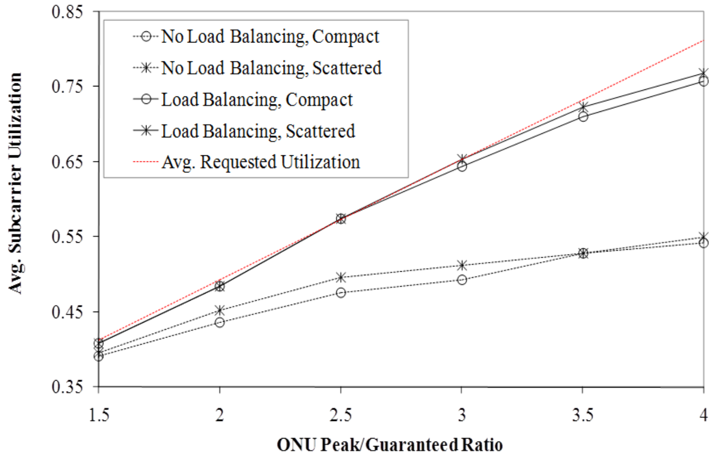

Figure 7 - Average subcarrier utilization of the proposed schemes for different ONU peak/guaranteed ratios and D $= 12.5\%$.

Subsequently, the update of the intra-segment algorithms has indicated that monitoring performs better at increased ONU numbers. In addition the distribution of bandwidth to ONUs based on the utilization of an increased percentage if not all available subcarriers, at SLA order and specified time intervals seems to also perform better at increased ONU numbers and for medium to high SLAs. Evaluation of the end-to-end packet delay for both the SDSCA and PDSCA algorithms for the 256 ONU scenarios based on the exchange of report messages to establish each ONU bandwidth requirement, suggests that the grant/reporting mechanism approaches bandwidth allocation more accurately compared to monitoring. Packet delay characteristics are significantly improved between monitoring and reporting for both the serial and parallel algorithms with PDSCA outperforming SDSCA. This is because the higher data rate transmitted at a given time with parallel allocation allows reducing the overall ONU queuing delays.

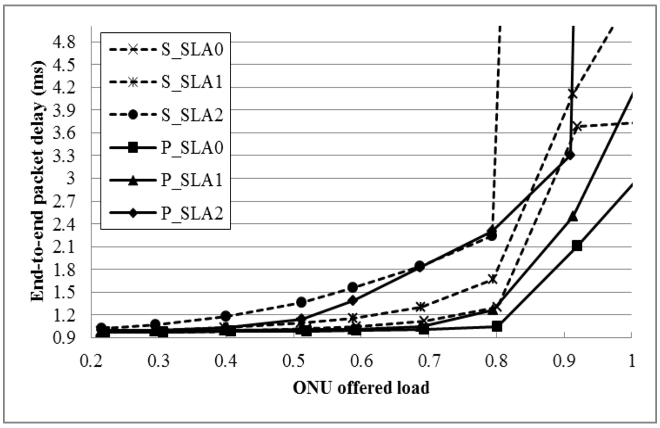

Figure 8 - Comparison of the end-to-end packet delay between SDSCA and PDSCA with 256 ONUs using grant/reporting mechanism in 100 km long reach.

D4.6 also provided a summary of MAC designs for optical/wireless convergence and their corresponding performance evaluation. It was established that IP backhauling and split-eNB variants require certain MAC modifications in order to meet the required QoS performance figures for wireless users. With respect to IP backhauling the performance evaluation was based on LTE system-level investigations over the ACCORDANCE PON simulating rural and femto-cell scenarios. The results obtained were based on QCI delay versus the aggregate wireless data rate US, following the application of the monitoring SDSCA MAC algorithm. In particular the mapping was evaluated by contrasting 1:1 mapping (3 bearers to 3 CoS) to group mapping (7 bearers to 3 CoS). Both mapping mechanisms were also assessed against non-mapping implemented by 3 bearers and 7 bearers respectively forwarded to a single optical queue.

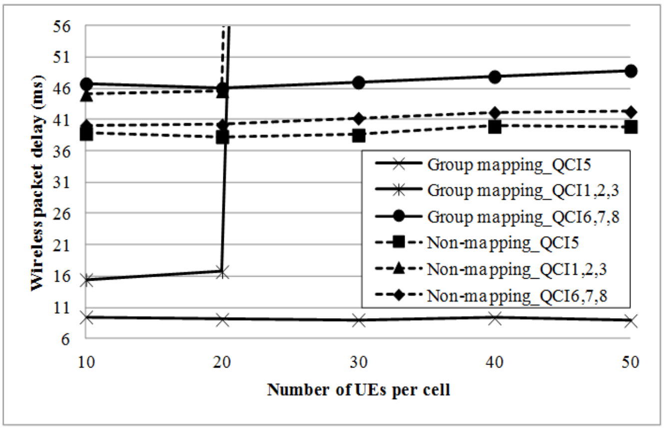

Figure 9 - Packet delay for group mapping versus non-mapping (7 bearers forwarded to the low priority ONU queue) in the urban scenario

Based on these scenarios it can be concluded that in the rural scenario, QoS mapping between the eNB and ONU might not be necessary. This can be directly justified by the absence of residential data, not imposing any buffering requirements at the eNB/ONU. In consideration of the femto-cell scenario, when the eNB/ONU employs 1:1 QoS mapping, the high priority bearer (carrier of QCI 5) and middle priority bearer (QCI 6) display notably decreased packet delay compared to non-mapping. If group mapping is employed instead (considering 7 bearers) the performance of the middle priority group (QCI1, 2 and 3) saturates early, at 20 UEs. This can be pinned down to the use of GBR services, comprising, in the 7 bearers mapping, the middle priority group.

Finally a MAC design with particular emphasis on the dynamic allocation of subcarriers to the two specified ONUs of the ACCORDANCE validation set-up has been presented. D4.6 has served the purpose of presenting an algorithmic pseudo code that could perform DBA over the FPGA hardware. An Ethernet Routing block has been implemented for that purpose at the OLT and each of the ONU FPGAs.

With respect to establishing communication between the OLT and ONUs, the traditional Report message informing the status of ONU queues is not necessary, aiming at reducing complexity. Instead the bandwidth allocation process is based on the statistics estimated by the OLT within a monitoring window of how many bytes were transmitted by each ONU in the previous transmission cycle. This corresponds to the monitoring mechanism developed in D4.3 for bandwidth allocation in ACCORDANCE

Set variables, *i* is the index of ONU
B_i^{Used} is the amount of the transmitted data per ONU during monitoring window.
B_i^{SLA} is the guaranteed bandwidth according to SLA levels.
B_i^{Pre} is the bandwidth assigned at the previous window.
B_i^{Assign} is the bandwidth for the next window.
$B^{remaining}$ is the remaining bandwidth.
$B_s^{increase}$ is the increment bandwidth according to SLA, s is the index of SLA

Calculate B_i^{Used} during the monitoring window time
For (Number of ONUs) **do**
  If $B_i^{Pre} > B_i^{Used}$ **then** //*underperforming group*
    If $B_i^{Used} > B_i^{SLA}$ **then**
      $B_i^{Assign} = B_i^{SLA}$
    Else
      $B_i^{Assign} = B_i^{Used}$
      $B^{remaining} = B^{remaining} + (B_i^{SLA} - B_i^{Used})$
    End If
  Else //*overperforming group*
    If $B_i^{Pre} > B_i^{SLA}$ **then**
      $B_i^{Assign} = B_i^{Used}$
    Else
      $B_i^{Assign} = B_i^{Pre} + B^{remaining}$
      $B^{remaining} = B^{remaining} + (B_i^{SLA} - B_i^{Assign})$
    End If
  End If
End do

For (Number of ONUs) **do**
  If $i \in$ {*overperforming* group} **then**
    $B_i^{Assign} = B_i^{Assign} + B_s^{increase}$
    $B^{remaining} = B^{remaining} - B_s^{increase}$
  End If
End For

Figure 10 - Pseudo code for bandwidth allocation over the FPGA OLT and ONUs

3.4 WP5 – WIRELINE/WIRELESS NETWORK CONVERGENCE AND CONTROL ISSUES

Workpackage number	**5**	**Start date:** M1- **End date:** M28
Activity type	RTD	
WPL	ALUD	
Sub-tasks	Task 5.1: First concepts for combined optical and wireless access [UH]	
	Task 5.2: Requirements of wireless/wireline systems and their impact on the optical network [ALUD]	
	Task 5.3: Mapping of radio signals to optical resources and distribution of mapping within the network [UH]	
	Task 5.4: Centralized wireless MAC: Definition of architectures making use of the centralized processing. Assessment of performance and complexity [ALUD]	
Deliverables / Y3	D5.5 - Centralized wireless MAC: Definition of architectures making use of the centralized processing. Assessment of performance and complexity (M28)	
Milestones / Y3	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 3 (CE)													
JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	3.0	-	40.0	7.8	1.1	-	-	-	8.9	-	24.0	2.9

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
-	-	-	-	-	-	***77.0***	***10.7***

According to the Annex I, the objectives of WP5 "Wireline/Wireless network convergence and control issues" are as follows:

The work package aims at:

- Provision of concepts for combining optical and wireless access networks for the realisation of enhanced deployment scenarios supporting advanced resource allocation schemes for the radio network.Wireless network performance can be improved by coordination of the resource allocation of different base stations. This workpackage will provide concepts to realize such advanced coordination schemes without the need for fast direct data exchange between base stations, as it would be the case in pure wireless systems.
- Making use of the possibilities offered by the centralised processing to improve wireless network performance through higher flexibility and lower processing delay in resource allocation without the need of capacity and power consuming direct data exchange between base stations.

In detail, objectives if this work package aims are:

- To define the PHY layer of the optical part of the network for efficient support of wireless networks.

- To define the architectural details and interfaces for embedding the wireless access networks into the overall network structure.
- To define MAC layer functionality and concepts and the split between centralized and segment individual functions to feed the different wireless network segments.
- To derive deployment schemes taking advantage of the centralised processing capability
- Provide inputs for the preparation of the final test-bed.

Tasks 5.1, 5.2. and 5.3 have ended during year 2. So, during year 3 only a single task was active – task 5.4 'Centralized wireless MAC: Definition of architectures making use of the centralized processing. Assessment of performance and complexity'.

The purpose of task 5.4 has been to build upon the concepts/architectures defined within the other tasks of work package 5. The proposed solutions have been rated with respect to various aspects of wireless communications. T5.4 provides rules and guidelines regarding the applicability of the architectures in the light of various key aspects both with respect to the wireless transport network and regarding the convergence with wireline systems.

Overall the progress of WP5 is in line with the plannings, no critical issues have been aroused.

The findings of WP5 have been disseminated externally and internally. Especially the concept of split processing has driven many continuative research activities both internally and externally.

3.4.1 Task 5.1: First concepts for combined optical and wireless access

Fulfils <u>Objective 1</u>: Definition of a novel access/metro network architecture achieving convergence among heterogeneous technologies (optical, wireless fibre).

There was not any activity in Task 5.1 during 3rd year since task has ended during Year 2.

3.4.2 Task 5.2: Requirements of wireless/wireline systems and their impact on the optical network

Fulfils <u>Objective 1</u>: Definition of a novel access/metro network architecture achieving convergence among heterogeneous technologies (optical, wireless fibre).

There was not any activity in Task 5.2 during 3rd year since task has ended during Year 2.

3.4.3 Task 5.3: Mapping of radio signals to optical resources and distribution of mapping within the network

Fulfils <u>Objective 1</u>: Definition of a novel access/metro network architecture achieving convergence among heterogeneous technologies (optical, wireless fibre).

There was not any activity in Task 5.3 during 3rd year since task has ended during Year 2.

3.4.4 Task 5.4: Centralized wireless MAC: Definition of architectures making use of the centralized processing. Assessment of performance and complexity

Fulfils Objective 1: Definition of a novel access/metro network architecture achieving convergence among heterogeneous technologies (optical, wireless fibre).

Significant results:

Relying on the outcomes of the other tasks and work packages, T5.4 has analyzed the available options under the relevant aspects of wireless networking being affected by the centralization:

- Channel ageing: While centralization provides many gains, the increased round trip time is not to be disregarded. With baseband processing being at least partly centralized, closed loop schemes relying on channel feedback (e.g. closed loop spatial multiplexing) suffer due to channel ageing (i.e. the measured channel deviates from the actual one the more time has passed).

- Schemes relying on multi-point cooperation are supported more natively as the processing elements are collocated and data exchange is less time-consuming. The proposed architectures have been analyzed with respect to the applicability of various cooperation schemes in a centralized manner.

- Means for saving costs have been analyzed.
  - The required transport capacity on the back/fronthauling network per split point has been determined. Additionally, the savings by exploiting statistical multiplexing per architecture option has been assessed.
  - Reach and coverage areas for the available architectures have been determined impacting the degree of node consolidation. This is important in the light of convergence with wireline services, e.g. for sharing of installations.
  - Wireless networking is continuously evolving. So, every once in a while the systems need to be updated. Updating (and maintaining) systems is easier and cheaper in case of centralized architectures, e.g. as less travel is required. Depending on the aspect to be renewed the available split options have been evaluated, if costly site visits are required.
  - The request of wireless services is strongly fluctuating during a day/week, e.g during working time in contrast to free time. By means of topology control the wireless network is able to react to this reducing the overall energy consumption. The available architectures have been rated with respect to the applicability of the proposed scheme.

Overall, there is no clear winner (as expected). Depending on the boundary conditions (e.g. greenfield vs. brownfield), on the targets of the provider (e.g. provider wants/does not want to install collaborative multi-point), areal impacts (e.g. digging costs) and so on and so forth different solutions are in favour.

3.5 WP6 – EXPERIMENTAL VALIDATION PLATFORM EXHIBITING SERVICE DELIVERY OVER A COMPOSITE NETWORK

Workpackage number	**6**	**Start date:** M18 **End date:** M42
Activity type	RTD	
WPL	UPC	
Sub-tasks	Task 6.1: Testbed definition and preparation of validation scenarios [ALUD]	
	Task 6.2: FPGA board preparation [KIT-U]	
	Task 6.3: Experimental platform integration and end-to-end service delivery [TID]	
Deliverables / Y3	D6.1 - Testbed definition and preparation of validation scenarios (M26) D6.2 - FPGA board preparation (M40) D6.3 - Experimental platform integration and end-to-end service delivery (M42)	
Milestones / Y3	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 3 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	8.0	10.1	9.0	6.8	-	-	-	-	11.0	7.3	8.0	6.3

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
16.0	19.5	9.0	7.8	-	-	***61.0***	***57.6***

According to the Annex I, the objectives of WP6 “Experimental validation platform exhibiting service delivery over a composite network” are as follows:

- Practical validation, in real-time, of the increased performance of the OFDM transmission over PON. Specifically, and as stated in the S&T Objectives, the overall solution has to experimentally demonstrate its scalability up to 100Gbps aggregate bandwidth and more than 10Gbps in each segment, transmitted over a PON with fibre reach higher than 100 Km delivering the final required quality, in terms of BER, EVM, etc. Logically, the present state-of-the-art of the A/D converters and ASICs limits the total throughput in the test experiment, but does allow to implement the most advanced prototype with latest digital technology available in order to fulfil the demonstration of the ACCORDANCE concept and targets. Above the digital real-time electronics limits, the operation of the electro-optical system will be also demonstrated using off-line post-processing, using equivalent algorithms as in the implemented DSPs. Once a better hardware becomes available, the test-bed will incorporate it.
- Another practical objective is to demonstrate that, unlike other technical approaches, low-cost, low-complexity key devices can be used to achieve the high data rates in the access network, thanks to the ACCORDANCE concepts. A benchmark analysis of the practical results, as compared to competing solutions will be performed, in terms of cost versus performance.
- Demonstration of dynamic multiple access with enhanced bandwidth allocation MAC with the advanced usage of the agile OFDMA operation is done only for the MAC functions of the optical feeding network.
- Compatibility between the optical feeding network and the wireless/wired access systems. The signal formats and parameters of the interfaces will be checked according to the proposed architectures. Validation of the heterogeneous interoperability between OFDM wireless system and FTTH access transported over the proposed PON.

Activities from previous years in all WPs gave a fruitful discussion and alternatives towards a unified testbed to verify the ACCORDANCE concept. In this year, firstly a set of tests were defined to validate ACCORDANCE objectives. The complete description was included in D6.1 and mainly separated the tests for the wireless, wireline and converged testbed. Related with WP3 work, FPGA boards design was finished and sent for manufacture. The proper function of most important sections of the boards were thoroughly checked and prepared for production. Besides, most of the algorithms were also tested with simulation tools. This activity required longer time than expected due to the high complexity of the boards' layout.

At the moment of writing of these lines, FPGA boards are at manufacturing, and due to existing risk of delayed delivery of panels. However, the experimental platform was assembled to carry out the tests indicated in D6.1, whereas the setup has incremental nature (from minimum with offline processing) to maximum (real-time processing end-to-end service delivery). Thus, the performance of the ACCORDANCE wireline network was first measured by means of offline processing to get a benchmark and the results are detailed in the corresponding deliverable. Then, when FPGA boards will be operative a check in the performance will be carried out to determine possible penalties and fine tune the systems. In addition, the upstream of a low-cost solution based on IM-DD was also tested and the results were reported. The remaining tests will be also performed for validating the concept and completing the first objective of WP6.

The interaction between WP2 and WP6 allowed to evaluate solutions in terms of cost and performance. As a result, ACCORDANCE concept will be compared with similar solutions as stated in the second objective of WP6. In relation to the third WP6 objective, from WP4, a MAC for ACCORDANCE was developed and will be loaded into the OLT. Several tests will be performed to verify OFDMA functions and assign bandwidth dynamically to the users.

The wireless architecture defined in WP5 for the converged testbed was first evaluated independently. A portable setup with off the shelf components was built and is about to be sent to KIT premises. Afterwards, it will be tested jointly with the wireline section to validate the operation of both and achieve the fourth objective of WP6.

Since there was a delay in the delivery of FPGA boards, the consortium has foreseen contingency plan for submitting deliverables D6.2 and D6.3, in which at least results derived from offline-processing tests will be presented. The estimated latest date for delivery of contingency D6.2 and D6.3 is 1st of October 2013.

3.5.1 Task 6.1: Testbed definition and preparation of validation scenarios [M18-M26]

Fulfils Objective 7: Evaluation of the ACCORDANCE concepts using experimental test beds.

This task is set to develop and describe a meaningful verification testbed configuration, respecting the constraints from the involved cutting-edge optical and DSP building blocks. Verification is split into two separate lab setups focusing mainly on the wireline situation (at TID) and wireless principles (ALUD). This task started in June 2011.

Significant results:

The principal setups of the testbeds (wireless and wireline) have been provided (for more details see section 3.5.3). These setups picture the overall topologies and the required network elements to assemble them. It has been decided to implement WDM overlay with CPRI fronthauling to include the wireless system into the overall network.

Lists of the required equipment and their availability have been assessed and assembled.

The tests/measurements to be performed are described in more detail. They cover a wide selection of aspects connected to the converged network ranging from basic system/component characteristics up to the capability of the overall setup to deliver services (wireless and wireline) with high quality.

The wireless testbed cases are divided in several groups as described in the following items:

- Wireless transmissions devices measurements (optical link budget, spectrum, pattern and eye diagram)
- Performance of the optical link without the radio equipment
- Performance of the GPON system with the radio equipment in the same fibre
- Attenuation and latency measurements for CPRI fronthauling
- Wireless signal quality measurements and service delivery

The wireline testbed cases are divided in several groups as described in the following items:

- The first tests are oriented to have a simple working environment, for this reason these tests are oriented to OLT and ONU administration and management issues which include system start-up, configuration process, device registration and initial connectivity tests.
- The second group of tests involves OLT and ONU physical layer tests, which consist of measurements of different optical values, such as the mean optical transmission power, operation wavelengths, spectral width, side-mode suppression ration, optical receiver sensitivity, and forward error correction (FEC) functionality.
- The third group of tests focuses in the system performance, including maximum binary transmission capacity, maximum reach distance, and maximum reach distance at maximum transmission capacity with and without amplification stage. These tests will define the maximum capacity of the experimental setup and the results obtained will be used in the following tests.
- The fourth group involves the service tests, which include video transmission tests with and without other data traffic at the same time to evaluate QoS issues, and demonstration of dynamic multiple access with enhanced dynamic bandwidth allocations (DBA) and validate the correct operation of the forward error correction (FEC) with other data traffic.
- The last group of tests is related to co-existence between ACCORDANCE and other technologies such as, GPON, RF video overlay and OTDR network monitoring.

Finally the options for combining the testbeds to a single converged one have been described. Due to delays related to the production of the FPGA boards the original plans to assemble the converged setup in Madrid (TID) had to be changed. KIT in Karlsruhe is the new host.

3.5.2 Task 6.2: FPGA board preparation [M24-M40]

The development of a custom design board holding both, FPGA and signal converters (DAC and ADC), is necessary in order to successfully demonstrate the ACCORDANCE concept as denoted in Objective 7. The board will be designed in a flexible way such that ONU and OLT transceivers can use the same platform with different DACs or ADCs mounted via hardware sockets.

Significant results:

Unfortunately the design of this board was delayed due to problems with the subcontractor assigned with the layout. Meanwhile the layout is ready and the first boards are in production. However, initial functional tests of the hardware are still pending.

Despite the above mentioned problems, some initial tests could be performed already with an FPGA evaluation platform (Xilinx Virtex 6 HXT 40G/100G Development Platform from HiTech-Global) featuring nearly the same FPGA as on the boards currently in production. Especially the interfaces to the 25GSa/s and 3.125 GSa/s DACs and ADCs as well as the 10G Ethernet interface have been extensively tested. Thus we don’t expect complex problems to occur when migrating the OLT and ONU designs to the final boards. Furthermore the complete ONU receiver, including all IO-interfaces, DSP and MAC components could be successfully verified on this evaluation platform.

At the moment of writing of these rows, we expect the arrival of the first completely populated board in few days.

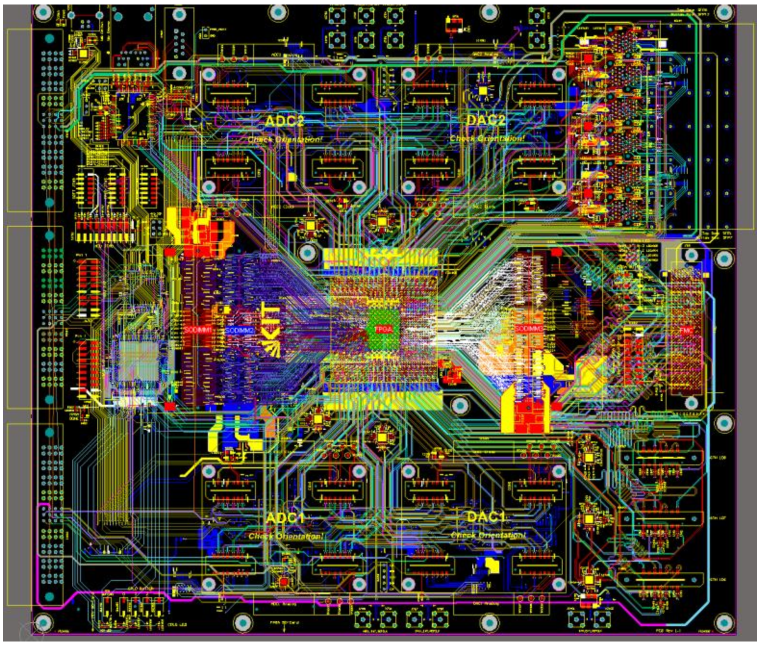

Figure 11 – FPGA board layout

3.5.3 Task 6.3: Experimental platform integration and end-to-end service delivery [M31-M36]

Fulfils Objective 7: Evaluation of the ACCORDANCE concepts using experimental test beds.

After all the technical work and the development of OFDM OLT and ONU prototypes it is necessary to assess their performance quantitatively and qualitatively through a set of end to end services. In order to do that, it was decided initially that ALU and TID will host respectively a wireless and a wireline lab setup where all the required equipment will be transported and services will be tested over the implemented OFDM solution on different scenarios. However, due to the delay in the prototype fabrication, some modifications in the scheduled lab setup locations have been made with regard to D6.1. It has been decided to complete the wireless tests in ALU's premises and to verify most of the prototype functionalities in KIT premises before the final demonstration in Karlsruhe (Germany).

After the independent wireless and wireline verification phase, both test-beds are going to be integrated to setup a single test-bed platform located also in KIT's premises. This integrated test-bed is going to be composed by components taken from the individual wireless and wireline test-beds (not all laboratory equipment and devices used during the validation tests will be useful for demonstrations purposes and not all equipment and infrastructures are able to be moved). The objective of the integrated test-bed is to validate and demonstrate end-to-end wireline and wireless convergent services. This task started nominally in July 2012.

Significant results:

All tests related to the wireleless test-bed have been completed using a setup assembled in ALUD's premises in Stuttgart (Germany). It has been verified the provision of wireless services over the ACCORDANCE's network using a CPRI fronthauling approach based on WDM. A system composed of two LTE eNodeBs, an Evolved Packet Core (EPC) and a GPON system have been used to verify the coexistence between wireless and fixed networks. **Figure 12** illustrates the wireless general setup with the main elements and the connections among them.

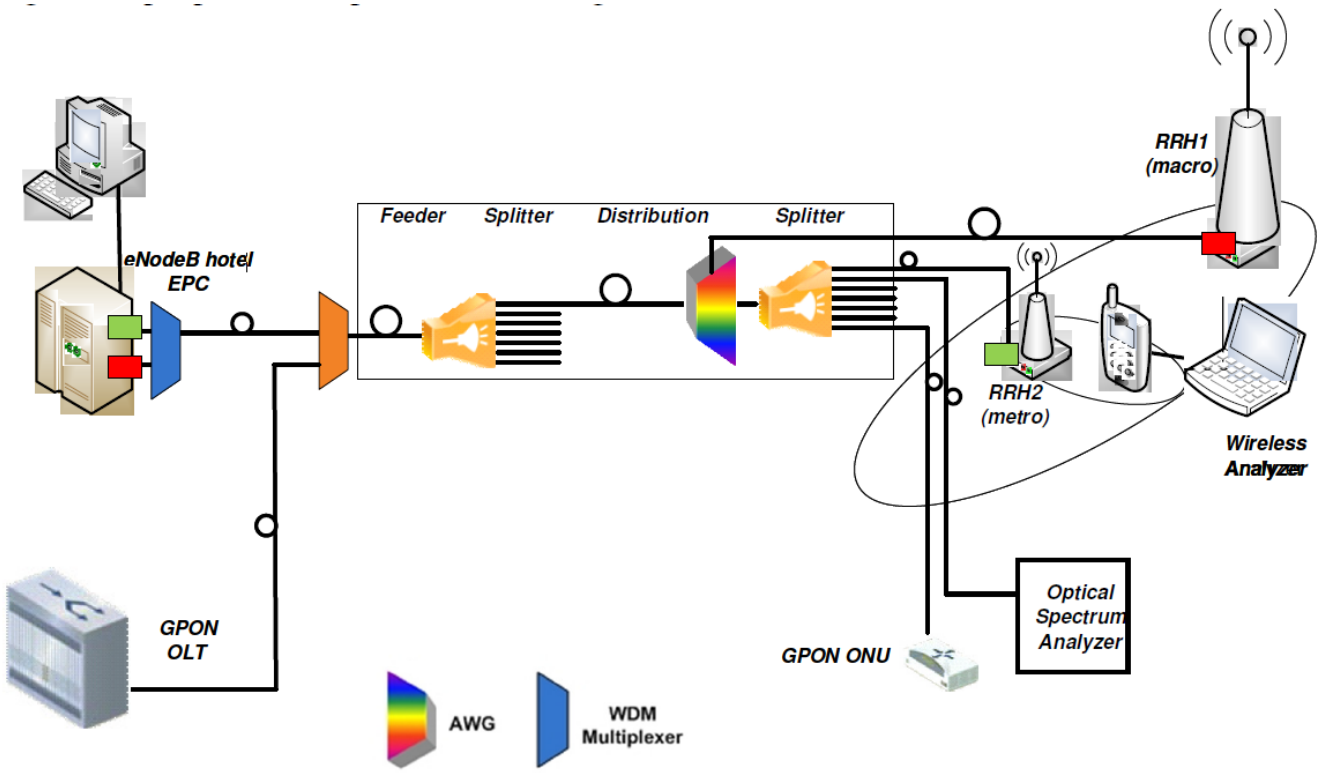

Figure 12: Wireless general setup

All tests have been passed successfully validating the CWDM and DWDM SFP used for the wireless signal transmission, verifying that it is possible to transport radio signals over a common fibre infrastructure of 20 km with a target BER of 10^{-11} and a maximum CPRI fronthauling distance of 18 km. Some of the most representative test were:

- Wireless transmissions devices measurements (optical link budget, spectrum, pattern and eye diagram)
- Performance of the optical link without the radio equipment
- Performance of the GPON system with the radio equipment in the same fibre
- Attenuation and latency measurements for CPRI fronthauling
- Wireless signal quality measurements and service delivery

Additionally, an alternative low cost upstream OFDM solution using non-preselected wavelength-emission distributed feedback (DFB) lasers has been tested. This solution is based on low-cost DFBs in which the wavelength used by the ONU to transmit is managed remotely by the OLT in order to avoid optical beat interference (OBI) among the different ONUs. **Figure 13** depicts the upstream schematics used for the experimental test-bed consisting of:

- An arbitrary wavelength generator (AWG) to generate the OFDM signals.
- Two ONUs transmitting initially at 1554.5 nm and 1554.7 nm.
- Two DFBs.
- Two variable optical attenuators (VOA) to adapt their transmission power.
- A 50/50 coupler to combine both OFDM signals.
- An attenuator to simulate a total PON splitting ratio of 1:16.
- A fibre spool of 25 km.
- A single 10GHz PIN photodiode to receive the transmitted signals.
- A 50 GHz real-time sampling oscilloscope that process the data and calculates the BER.

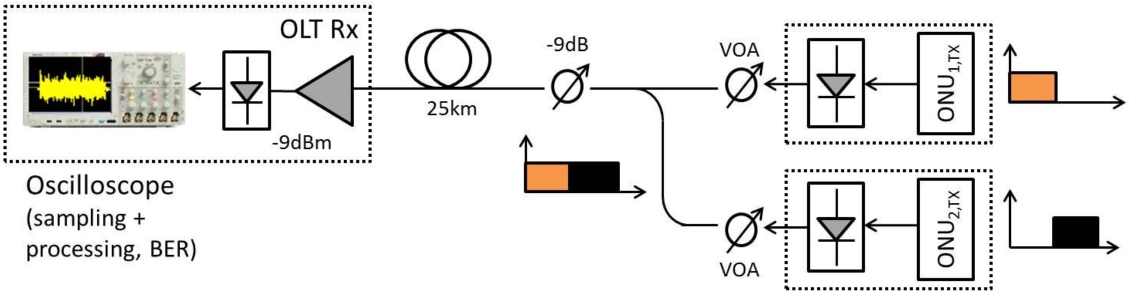

Figure 13: Low cost upstream general setup

The previous solution has been designed, implemented and evaluated successfully with a simultaneous detection of two ONUs using a different number of subcarriers and different modulations in each ONU. In addition, the upstream concept of ACCORDANCE consisting of two ONUs with RF upconversion stage has been tested. Signals with BPSK and QPSK modulation as well as several bandwidth allocations at the ONUs were evaluated, and both ONUs were properly detected with a single FFT.

The experimental setup for the ACCORDANCE setup based on the remodulation of remotely supplied oscillators has been assembled and first offline evaluations were done. However, complete digital signal processing is required for full demonstration of bi-directional operation. The preliminary results were shown in Task 3.4

The setup for the converged test-bed using the ACCORDANCE prototype has been developed among the partners (see **Figure 14**) and the test procedures to verify the setup have also been completed with additional details.

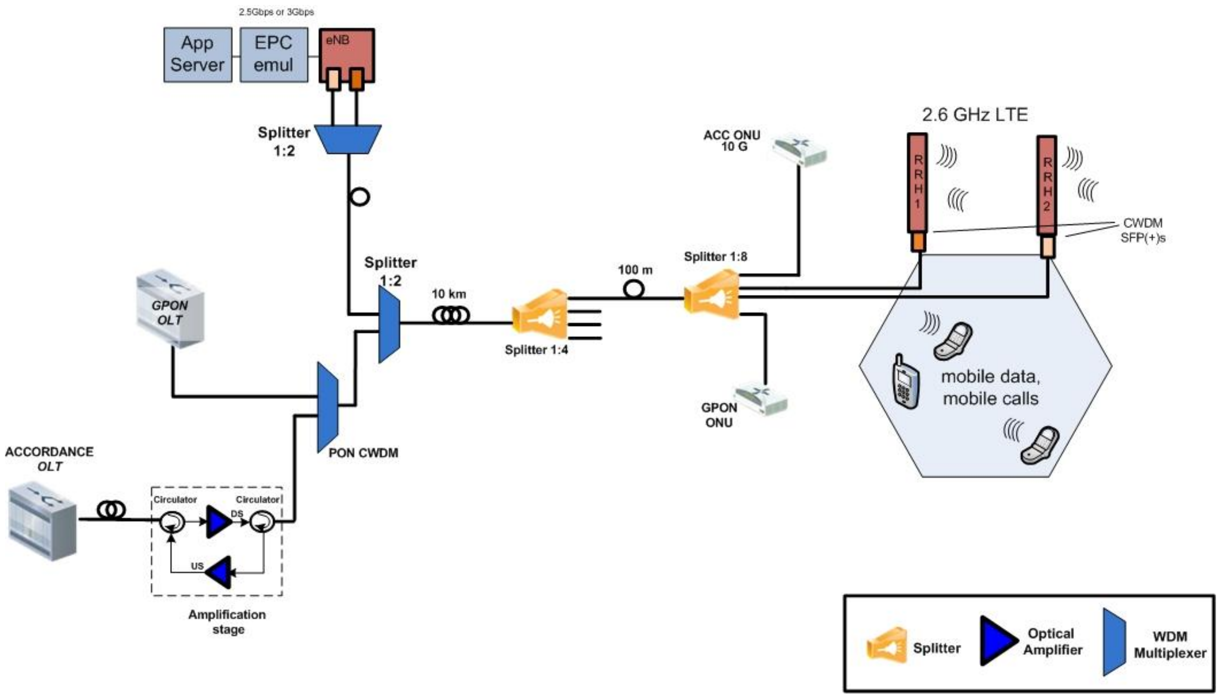

Figure 14: Converged test-bed general setup

Some tests defined in D6.1 related to end-to-end service delivery using the ACCORDANCE prototype have not been initiated currently; however it is expected to complete these validation tests when the prototype is ready to be tested at system level with real time processing.

3.6 WP7 – DISSEMINATION, STANDARDIZATION AND EXPLOITATION ACTIVITIES

Workpackage number	**7**	**Start date:** M1 **End date:** M42
Activity type	RTD	
WPL	DT	
Sub-tasks	Task 7.1: Dissemination activities [DT]	
	Task 7.2: Standardization activities [ALUD]	
	Task 7.3: Exploitation Plans [ALUD]	
Deliverables / Y1	D7.5 Dissemination activities (M42) D7.6 Standardization activities (M42) D7.7 Exploitation plans (M42)	
Milestones / Y1	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 3 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
3.0	2.1	6.2	4.3	4.0	4.0	5.8	2.1	1.0	-	5.0	2.5	1.0	0.2

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
2.0	-	1.0	0.7	3.0	1.5	***32.0***	

According to the Annex I, the objectives of WP7 "Dissemination, standardization and exploitation activities "are as follows:

- Promote the technical results of ACCORDANCE to the European and global research community (e. g. setting up a project web site, dissemination event)
- Coordination of dissemination activities (e. g. participation in conferences, contribution to scientific journals, organisation of workshops and events, etc)
- Coordination of activities relevant to standardisation carried out by the project, provide contributions to related standardisation bodies and fora
- Exchange with other projects active in neighbouring fields with similar focus (within and possibly outside FP7)

In WP7 a very good progress has been achieved in 2012/13 in continuing and maintaining awareness of the project in the research and industrial community as well as in promoting major project results. Project has beein active in multiple dissemination measures that included first of all publication of ACCORDANCE results via scientific papers at high-level conferences, articles in recognized IEEE/OSA journals, organization of a workshops and contribution to workshops organized by related projects/initiatives, participation in EU concertation meeting etc.

Details are given in the task-specific sections below as well as in the deliverable D7.5 on the year 3 project dissemination activities delivered in December 2012.

3.6.1 Task 7.1: Dissemination activities [M1-M36]

Fulfils Objective 8: Dissemination of project results. Fulfils the objectives of promoting the technical results of ACCORDANCE to the European and global research community as well as of coordinating the dissemination activities (e. g. participation in conferences, contribution to scientific journals, organization of workshops and events, etc).

Significant results:

A total of 13 conference publications resulting from work within ACCORDANCE have been presented at several prestigious international conferences in 2012/13, in particular at ANIC 2012, ICTON 2012, ECOC 2012, ACP 2012, OFC/NFOEC 2013 and FuNEMS 2013. At ECOC 2012, a next generation converged access networks workshop has been organized by ACCORDANCE partner DT, while an ACCORDANCE-related presentation were given during that workshop by ACCORDANCE partner ALUD. During FuNEMS 2013, workshop "*Opportunities, Challenges and Interplay of Next Generation Optical and Wireless Access Networks*" were jointly organized by ACCORDANCE and FP7 COCONUT.

Also, ACCORDANCE results were presented in other workshops (e.g. at "*Can the spectrum be exploited more intensively in PON's*?" at OFC 2013 and "*A techno-economic comparison of XGPON, UDWDM-PON and OFDMA-PON architectures/technologies*" in the course of the 11th Conference of Telecommunication, Media and Internet Techno-Economics.

Three journal articles were published in IEEE/OSA JLT and IEEE Communications Magazine – whereby in particular the IEEE Communications Magazine article is a joint work of several ACCORDANCE partners. Journal publication also took place within internal issue of ALUD: "Bell Labs Technical Journal" with article "*Quantitative Analysis of Split Base Station Processing and Determination of Advantageous Architectures for LTE*".

Moreover, the ACCORDANCE consortium contributed to the CaON positioning paper regarding regarding OFDMA-PON architectures technologies.

Two patent applications have been filed during year 2012 by ACCORDANCE partner ALUD.

Exchange with other projects active in neighbouring fields with similar focus has been continued by having a workshop with the EU FP7 project OASE in a joint plenary meeting of the two projects in Tallinn (Estonia) in February 2012.

3.6.2 Task 7.2: Standardization activities [M1-M36]

Fulfils Objective 6: Contribution to standardization activities on Next Generation Optical Access. Fulfils the general objective of coordinating the activities relevant to standardisation carried out by the project, provide contributions to related standardisation bodies and fora.

Significant results:

The partners have continued screening standardization. TWDM with OOK modulation has been chosen as the primary solution for NGPON2. So, for NGPON2 no further contributions to standardization for OFDM based access have been made. With the start of a new round of standardization beyond NGPON2, OFDM based access will be revisited.

With respect to wireless back/fronthauling the outcomes of ACCORDANCE related to split processing have provoked many activities. With the start of defining a new generation of wireless access beyond LTE (5G) in the years to come, the outcomes of ACCORDANCE will be used to actively contribute here.

3.6.3 Task 7.3: Exploitation Plans [M25-M36]

Significant results:

The decision of the FSAN on choosing TWDM with OOK modulation as the primary solution for NGPON2 have somewhat slowed down the exploitation of OFDM based access. Nevertheless, internal discussions have taken place to promote the solutions to the respective development groups within the units building equipment for optical access; however, the actual adoption naturally depends on further developments within the related standardization groups.

With respect to wireless back/fronthauling the outcomes of ACCORDANCE related to split processing have significantly influenced both partners being part of the consortium and others working in the field of wireless communications. Continuing research in this area is performed, potentially influencing the architecture of future wireless communication solutions (both based on LTE and its advancements and based on completely new wireless communication paradigms typically known under the umbrella of 5G).

Different alternatives to transport DSL signals over fibre have been also studied in ACCORDANCE to transmit DSL signals from the CO up to a demarcation point close to the customers where existing copper wires could be re-used to enter the customer's premises. Although such OFDM-based transmission over fibre solutions have not been finally included in the development of near-future FTTx solutions, research made in ACCORDANCE can be potentially re-used in the middle-/long-term FTTx solutions, such as in future Fibre to the Demarcation Point (FTTdp) alternatives, which actually proposes point-to-point Ethernet, GPON/EPON or bonded copper pairs to provide backhaul connectivity to the demarcation point units and could consider DSL transmission over fibre for some deployment scenarios.

The deep understandings of the technical and architectural challenges gained during ACCORDANCE will be exploited for the future network evolution strategy of wireless service providers. Decisions regarding network architecture and technology solutions will be influenced by the knowledge gained.

The knowledge gained during the course of the project strengthened the competence of the partners in academia and industry on a very broad range of fields. Significant recognition has been gained bringing new opportunities for future collaborations. Thanks to the work performed in ACCORDANCE academia could improve on its educational activities.

Beyond the progress and advancements achieved related to technology thanks to the work in ACCORDANCE, a deeper understanding related to the coordination and organization of EU projects in general helped and will help to increase participation of Estonia and neighboring countries in future research programs.

4. DELIVERABLES AND MILESTONES

TABLE 1. DELIVERABLES

Del. no.	Deliverable name	WP no.	Lead participant	Nature	Dissem. level	Due delivery date Annex I	Delivered Yes/No	Forecast delivery date	Comments
D4.5	Definition of MAC protocols supporting FDM/OFDM operation	WP4	UH	R	PU	M25	**Y**		
D6.1	Testbed definition and preparation of validation scenarios	WP6	ALUD	R	PP	M26	**Y**		
D5.5	Centralized wireless MAC: Definition of architectures making use of the centralized processing. Assessment of performance and complexity	WP5	ALUD	R	PU	M28	**Y**		
D4.6	Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE	WP4	UH	R	PU	M30	**Y**		
D3.6	Implementation of the OLT and ONUs	WP3	ALUD	R	CO	M40	**Y**		See footnote[1]
D6.2	FPGA board preparation	WP6	KIT-U	P	PP	M40	**Y**		See footnote[1]
D1.7	Third Year Annual Report	WP1	JCP	R	PU	M42	**Y**		
D1.8	Final Report	WP1	JCP	R	PU	M42	**Y**		
D6.3	Experimental platform integration and end-to-end service delivery	WP6	TID	P	PP	M42	**Y**		See footnote[1]
D7.5	Dissemination activities	WP7	DT	R	PU	M42	**Y**		
D7.6	Standardization activities	WP7	ALUD	R	PU	M42	**Y**		
D7.7	Exploitation plans	WP7	ALUD	R	PU	M42	**Y**		

[1] Those 3 deliverables are prepared based on the currently available FPGA board (Virtex-6 FPGA board from Hitech-Global) and Consortium is expecting update of given deliverables as the main ACCORDANCE FPGA boards, that are currently being manufactured, will be available

TABLE 2. MILESTONES

Milestone no.	Milestone name	Due date From Annex I	Achieved Yes/No	Actual / Forecast achievement date	Comments
M1.7	Quarterly Management Report (QMR)	M27	**Y**		
M1.8	Quarterly Management Report (QMR)	M30	**Y**		
M1.9	Quarterly Management Report (QMR)	M33	**Y**		
M1.10	Quarterly Management Report (QMR)	M36	**Y**		
M1.11	Quarterly Management Report (QMR)	M39	**Y**		
M6.2	FPGA board preparation and test passed	M39	**N**	7th of October 2013	At the moment of writing this report, FPGA board is being manufactured. After completion of manufacturing it will undergo functional testing that will indicate achievement of the milestone.

5. PROJECT MANAGEMENT

Workpackage number	**1**	**Start date:** M1- **End date:** M42
Activity type	MGT	
WPL	JCP	
Sub-tasks	Task 1.1: Project Organization and Management [JCP]	
	Task 1.2: Project Quality Management [EPC]	
	Task 1.3: Web Site and Maintenance [EPC]	
Deliverables / Y1	D1.7 Third Year Annual Report (M42) D1.8 Final Report (M42)	
Milestones / Y1	M1.7 Quarterly Management Report (QMR) (M27)	
	M1.8 Quarterly Management Report (QMR) (M30)	
	M1.9 Quarterly Management Report (QMR) (M33) M1.10 Quarterly Management Report (QMR) (M36) M1.11 Quarterly Management Report (QMR) (M39)	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 3 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
7.0	4.1	2.0	1.7	1.0	0.7	1.0	0.5	0.5	-	1.0	0.6	1.0	0.2

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
1.0	0.5	1.0	0.3	15.0	4.9	***30.5***	***18.9***

The WP1 aims at the administrative and financial management of the project. The project management structure has the main goal of controlling the overall progress of the work:

- To ensure that the project is conducted in accordance with EC rules.
- To reach the objectives of the project within the agreed budget and time scales.
- To identify the actions needed to be taken in case of deviation from project plan (Risk management).
- To coordinate the work of, and ensure effective communication between the partners.
- To assess the quality of the work and the deliverables.
- To maximize the potential for exploiting results.
- To manage all technical, commercial, financial and administrative issues.
- To inform and disseminate the project results through the Web Site.

Those tasks were successfully achieved within this first period.

5.1 Task 1.1 - Project Organization and Management

Third period had a number of challenges for ACCORDANCE not only from technical side, but also on organizational and managerial matters. Since number of changes happened during third period, below we report on all major issues that took place in 2012 and 2013.

The most challenging issue was undoubtedly organization and coordination of DoW changes that took place in April 2012 and February 2013. More specifically, in the beginning of 2012 ACCORDANCE Consortium started planning of implementation of the converged (wireline+wireless) testbed. Due to that, it was decided in addition to implementation of OLT/ONU to transfer also platform integration from Partner ALUD to Partner KIT. In parallel, additional work in Tasks 6.2 and 6.3 was planned by Partner UH and overall duration of the project was extended by two month (i.e. until M38/February 2013). All those changes required significant effort and coordination on the management side – both within Consortium and between Consortium and EC.

In the January 2013 it became clear, that implementation of OLT and ONU and completion of FPGD PCB boards electrical layout will be delayed and thus another round of significant organizational effort was needed. As a result, project duration was extended to a M42/June 2013.

Furthermore, constant organizational work was needed also after official completion of the project (June 2013). At the moment of writing this rows (end of August 2013) very active work in WP3, WP6 and consequently also WP1 is continuing, since project is actively working on solving problems with the manufacturing, testing and verification of FPGA PCB boards needed for testbed implementation.

Further to the activities needed for the organizational and management parts of the project, WP1 has organized 3 (three) plenary meetings during 2012/2013 and then assisted those Partners of Consortium who hosted project meetings in organizing them (practical aspects as accommodation, list of attendees & agenda) and organized completion of the minutes and follow-up of action items.

The production of the deliverables and deliveries at the agreed milestones by planned schedule was greatly facilitated by ensuring intensive communication within Consortium. Thus, further to the face-to-face meetings, WP1 helped in setting-up several conference calls on technical matters, and, when needed, on administrative matters (totally almost 30 phone conferences during 2012/2013).

Activities in WP1 also covered communications between the Project and the Commission (representation at the regular Concertation meetings, participation to events organized by other projects, participation as requested to Commission organized events, etc.) and to external organizations. Such activities were performed e.g. during organization of public and closed workshops between FP7 ALPHA, OASE and ACCORDANCE projects during plenary meeting in February 2012), participation in EC sconcertation meeting and CaON cluster workshops, etc.

Optimization of the project efficiency was constantly followed and during whole 2012. Thus, in order to leverage impact of changes made to ACCORDANCE DoW mentioned above, secure continuation of project and minimize possible negative impacts of changes WP1 organized smooth takeover of workload by respective partners, worked with administrative and financial issues, secured information flow between involved partners, as well as between EU and Consortium.

With regards to the reporting matters, WP1 organized quarterly reporting tools (templates and follow-up):

- 7th Quarterly Management report (QMR M25-M27) has been delivered on May 30th , 2012;
- 8th Quarterly Management report (QMR M28-M30) has been delivered on August 3rd, 2012;
- 9th Quarterly Management report (QMR M30-M33) has been delivered on December 1st, 2012;
- 10th Quarterly Management report (QMR M34-M36) has been delivered on March 1st, 2013;
- 11th Quarterly Management report (QMR M37-M39) has been delivered on June 4th, 2013.

Person-Month Status Table (actual vs. planned person-months per WP and per beneficiary) for Period 3 can be found below:

	1		2		3		4		5		6		7		8		9		10		Total	
	JCP		AIT		ALUD		DT		ICOM		TID		UH		KIT		UPC		EPC			
	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
PM Total	4.3	6.2	17.4	26.1	20.4	22.3	3.5	2.6		-	14.6	10.9	16.6	17.0	36.5	50.6	14.5	13.8	7.7	6.4	137.7	155.7
WP1	3.0	4.1	0.9	1.7	0.4	0.7	0.4	0.5	-	-	0.4	0.6	0.4	0.2	0.4	0.5	0.4	0.3	6.4	4.9	13.1	13.4
WP2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WP3	-	-	-	-	2.4	3.0	-	-	-	-	0.8	0.5	-	-	16.8	30.7	4.0	4.9	-	-	24.0	39.1
WP4	-	-	5.0	10.0	-	-	-	-	-	-	-	-	4.7	7.4	-	-	-	0.2	-	-	11.2	17.6
WP5	-	-	-	-	5.0	7.8	-	-	-	-	-	-	2.0	2.9	-	-	-	-	-	-	7.0	10.7
WP6	-	-	7.8	10.1	9.7	6.8	-	-	-	-	10.1	7.3	9.0	6.3	18.4	19.5	9.7	7.8	-	-	64.7	57.6
WP7	1.3	2.1	3.8	4.3	2.9	4.0	3.1	2.1	-	-	3.3	2.5	0.4	0.2	0.9	-	0.4	0.7	1.3	1.5	17.7	17.4

Total cumulated consumption of person-month during years 2010-2013 can be found from table below:

	1	2	3	4	5	6	7	8	9	10	**Total**
	JCP	AIT	ALUD	DT	ICOM	TID	UH	KIT	UPC	EPC	
PM Total	**9.5**	**84.3**	**99.1**	**23.2**	**15.3**	**44.1**	**74.9**	**85.6**	**49.4**	**20.1**	**505.6**
WP01: Project management	7.0	3.0	1.3	1.2	0.5	1.4	0.7	0.6	0.6	16.1	32.2
WP02: Network architecture, design requirements and specifications	-	16.0	12.7	13.5	-	17.7	10.0	3.6	8.0	-	81.5
WP03: Node design/implementation and modulation/transmission studies	-	12.0	29.1	2.0	8.5	1.0	-	60.0	24.9	-	137.5
WP04: MAC layer issues for the support of flexible bandwidth allocation	-	32.6	-	-	5.3	-	33.1	-	5.0	-	75.9
WP05: Wireless/wireline convergence and control issues	-	3.0	40.8	1.1	-	8.9	24.0	-	-	-	77.8
WP06: Experimental demonstration platform exhibiting service delivery over a composite network	-	11.6	9.4	-	-	10.4	6.4	20.5	9.7	-	67.9
WP07: Dissemination, standardization and exploitation activities	2.5	6.2	5.8	5.4	1.0	4.7	0.8	1.0	1.3	4.0	32.7

5.2 Task 1.2 - Project Quality Management

Task 1.2 is especially devoted to the quality assessment of the work and the deliverables produced in the project. With regard to first part, undoubtedly Consortium changes required significant work to ensure such a continuation work where quality woudn't suffer. With regard to the second part, Detailed Task Workplans (DTW) were produced for 3rd period tasks and Tables of Contents (ToC) were generated for the deliverables.

Each technical deliverable produced undergone peer review process, where 1-2 peer reviewers were assigned for each deliverables. Those reviewers were assigned from Partner organizations with the pre-condition, that they are not involved in the project, or not active in particular deliverable. The following table summarizes the reviewers' participation:

Del. no.	Deliverable name	WP	Reviewers
D4.5	Definition of MAC protocols supporting FDM/OFDM operation	WP4	Chistoforos Kachris
D6.1	Testbed definition and preparation of validation scenarios	WP6	Victor Polo (UPC) Frank Geilhardt (DT)
D5.5	Centralized wireless MAC: Definition of architectures making use of the centralized processing. Assessment of performance and complexity	WP5	Ignacio Berberana (TID)
D4.6	Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE	WP4	Josep Segarra (UPC)
D3.6	Implementation of the OLT and ONUs	WP3	Rene Bonk (ALUD) Josep Prat (UPC)
D6.2	FPGA board preparation	WP6	George Tzimpragos (AIT)
D1.7	Third Year Annual Report	WP1	All partners
D1.8	Final Report	WP1	All partners
D6.3	Experimental platform integration and end-to-end service delivery	WP6	Josep Segarra (UPC)
D7.5	Dissemination activities	WP7	All partners
D7.6	Standardization activities	WP7	All partners
D7.7	Exploitation plans	WP7	All partners

5.3 Task 1.3: Web Site and Maintenance

The main structure and public pages/subpages of the website remained unchanged during 3rd period of ACCORDANCE. Website was continuosly updated with latest finding of ACCORDANCE and related publications.

During 3rd period website was visited 4427 times by 2890 unique visitors from 112 countries, whereas 64% of visitors were new visitors:

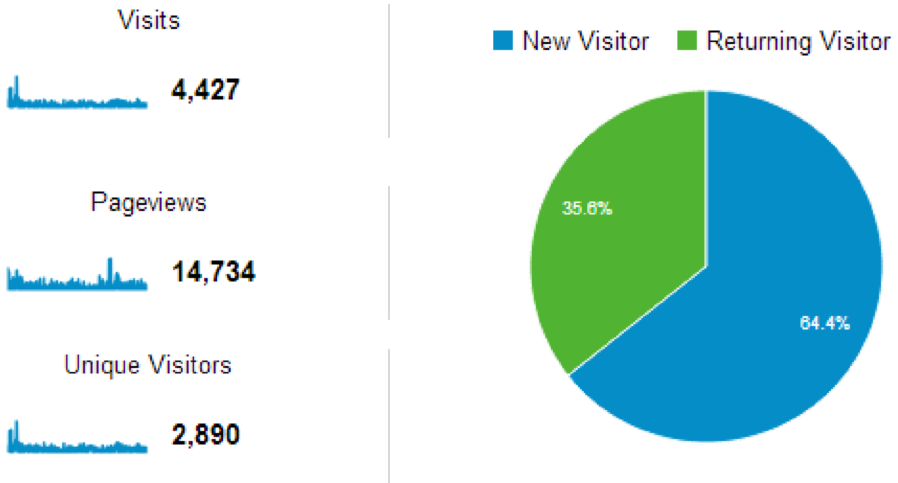

Figure 15 – website visitors overview

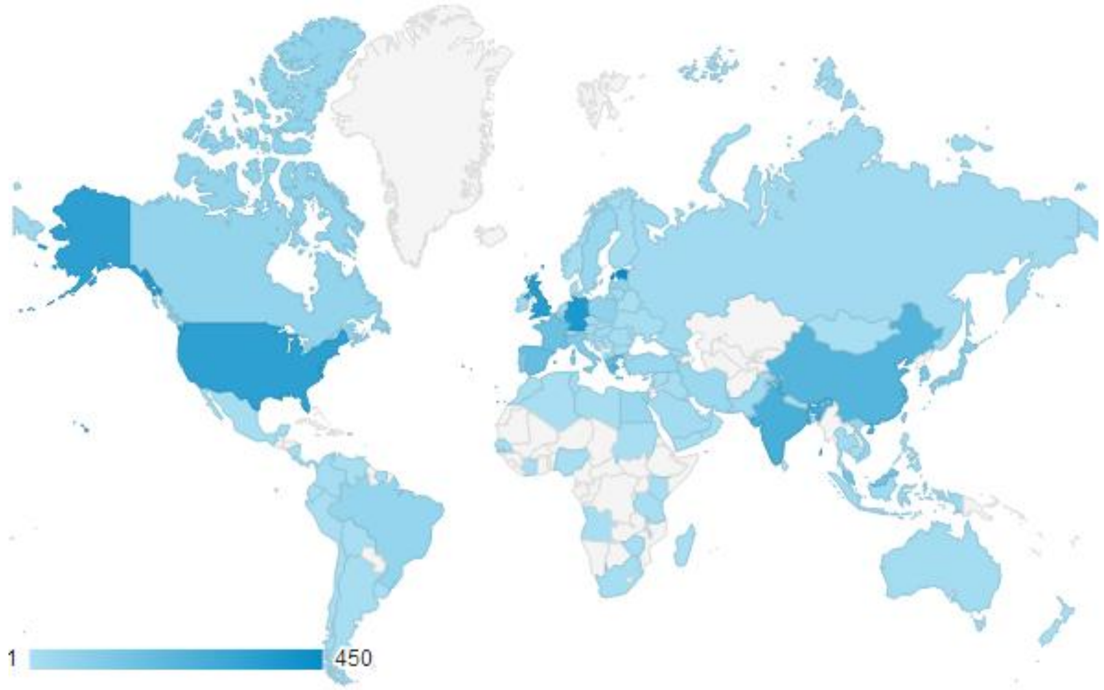

Figure 16 – website visitors geography overview

In addition to policy of keeping significant part of technical content on the website for the increase of website visibility, Consortium followed recommendation from 2nd periodic review and implemented secured section for the website, where registered users are able to download public deliverables after registration. Also files download tracking mechanism was implemented to ensure visibility of deliverables download:

Access log:

When	Username	ID	IP
2013-02-04 17:55:06	Madara	28	84.237.190.212
2013-02-07 12:22:53	Madara	28	46.109.24.224
2013-02-11 11:38:15	deli	29	129.69.173.132
2013-02-27 04:29:09	cwflying	31	10.142.150.222
2013-03-04 04:40:06	cwflying	31	10.142.150.222
2013-04-16 11:45:29	deli	29	129.69.173.132
2013-05-05 13:56:04	tismail	37	196.218.205.34
2013-05-07 09:03:36	deli	29	129.69.173.132
2013-05-08 19:32:45	nltl	38	171.214.212.243
2013-07-27 23:38:16	castudillo	45	143.106.201.13
2013-08-05 13:59:20	PauloMonteiro	47	193.137.168.16
2013-08-16 11:02:43	hafizulmd	52	175.138.67.38
2013-08-21 10:23:58	philye	53	10.135.94.51
2013-08-21 13:17:32	suyuxin	54	10.142.190.192
2013-08-21 15:58:45	philye	53	122.82.45.6
2013-08-25 11:39:18	philye	53	122.82.237.227

Figure 17 – deliverables download log file

5.4 PROBLEMS AND SOLUTIONS

The main difficulty during 3rd period was the fact of multiple delays in the manufacturing of FPGA PCB boards needed for testbed implementation. Due to the high complexity of this HW, timely production of them for the time of final review of ACCORDANCE project remains high and to leverage this risk, Consortium started implementation of contingency plan for covering minimum necessary functionality testbed (based on existing HW). At the moment of writing of these rows, contingency plan testbed is being implemented.

5.5 LIST OF PROJECT MEETINGS AND OTHER VENUES

Alltogether, project had 3 physical meetings during 3rd period:

- Tallinn, Estonia – February 2012
- Berlin, Germany – June 2012
- Madrid, Spain – November 2012

In addition, monthly telcos took place in the beginning of each month and WP-specific telcos were conducted when necessary. Alltogether, more than 20 phone conferences took place during 3rd period.

5.6 PROJECT PLANNING AND STATUS

As mentioned above, project implementation is delayed due to FPGA PCB boards manufacturing. There is a risk of full functionality system implementation delay for the time of final review (24th of October 2013), however Consortium took precaution measures in order to implement at least minimum functionality platform with offline processing.

5.7 IMPACT OF POSSIBLE DEVIATIONS FROM THE PLANNED MILESTONES AND DELIVERABLES

Certainly, most obvious impact of mentioned delay is potential inability of the Consortium (as a whole) to make wider community aware of latest technical achievements of ACCORDANCE and demonstration of end-to-end OFDM(A) based access network with real-time signal processing functionality. However, single Partners will be still able to perform academic and industrial dissemination (e.g. in the forms of conference articles) based on results achieved even after official end of the project.

5.8 BENEFICIARIES LEGAL STATUS

ACCORDANCE coordinator, JCP-Consult SAS performed its capital modification from 37.042,92€ up to 48.600€.

No other changes to beneficiaries' legal status happened during 3rd period of ACCORDANCE project.

5.9 USE OF FOREGROUND

2 patent applications were made during 3rd period, that makes alltogether, 4 patent applications outcoming of ACCORDANCE project. More information about Foreground can be found in final report (D1.8), chapter 6.2.1.

6. FINANCIAL STATEMENTS – FORM C AND SUMMARY FINANCIAL REPORT

A separate financial statement from each beneficiary together with a summary financial report which consolidates the claimed Community contribution of all the beneficiaries in an aggregate form will be provided through the NEF tool.

According to Article II.4.4 of the Grant Agreement, no certificate on financial statements shall be submitted by the any beneficiaries as the requested grant threshold of 375 000 € has not been reached.

7. CERTIFICATES

Beneficiary	**Organisation short name**	**Certificate on the financial statements provided? yes / no**	**Any useful comment, in particular if a certificate is not provided**
1	JCP	No	Contribution threshold not reached
2	AIT	Yes*	* Audit is being performed at the moment of writing of this rows and should be finalized before final review of ACCORDANCE. Cost reported in the NEF (4000€) is a provisional one and may change.
3	ALUD	No	Contribution threshold not reached
4	DTAG	No	Contribution threshold not reached
5	ICOM	No	Contribution threshold not reached
6	TID	No	Contribution threshold not reached
7	UH	Yes	
8	KIT-U	Yes	
9	UPC	No	Contribution threshold not reached
10	EPC	No	Contribution threshold not reached

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