“Second Year Annual Report”

D1.6

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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: **16 December 2011**

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

Period covered**:** **from January 1st, 2011 to December 31st, 2011**

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DECLARATION BY THE SCIENTIFIC REPRESENTATIVE OF 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 (sections 7 and 8).
- 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: 01/03/2012

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
INTRACOM SA Telecom Solutions[1]	ICOM	GR
TELEFONICA Investigation 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 D1.6 - Second Year Annual Report for the ACCORDANCE project and consists of main achievements of ACCORDANCE project during 2011, reports on resource usage and describes plans for year 2012

"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"

[1] Participation in ACCORDANCE Consortium up to 30th of May 2011

Table of Contents

1. PUBLISHABLE SUMMARY

http://www.ict-accordance.eu

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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 36-month project partially funded by the European Commission, starting in January 2010 and ending in December 2012.

Summary of 2nd Year Progress

Main Objectives

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

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

Having defined the overall network architecture of ACCORDANCE and studied the technological options for realizing the ACCORDANCE concepts already during Y1, in the course of Y2, the consortium assembled a narrow list of six technological options for the ACCORDANCE downstream/upstream operation and one of them was chosen as the most appropriate for being implemented and demonstrated. For this decision, performance of the solutions in terms of the exact deployment scenarios targeted by ACCORDANCE was taken into account, along with cost/complexity criteria. The selected solution consists of optical I/Q modulation at the OLT transmitter and direct detection at the ONU receiver for the downstream, together with seeded intensity modulation (IM) at the ONU Tx and coherent detection at the OLT Rx for the upstream. It has the main benefit of using a seeded approach: Since all ONUs share the same optical source, the US OFDM signals are perfectly aligned and no optical frequency drifts among ONUs need to be accounted for. Hence, the idea behind upstream OFDMA can be fully applied. Moreover, the principles of operation and the corresponding OLT/ONU system architectures for all the aforementioned solutions were presented, providing feedback to WP3 for further theoretical and experimental studies as well as for the actual implementation activities. Regarding the definition of the ACCORDANCE optical/wireless converged architecture, the targeted architectural parameters for the wireline part of the network were used to evaluate two different possible transport mechanisms for the backhauling of wireless signals. The first one involved digital backhauling, and the other analogue wireless signal transport. The use of the latter for spectral insertion and extraction of the wireless signals into/from the OFDM optical signal band was finally deemed very challenging and costly to implement. Moreover, there seem to be only minor flexibility gains from using a joint multiplexed signal, since fronthauling data streams have a constant bitrate. Hence, for networking reasons, it is advantageous to use separate wavelengths for the numerous wireline and wireless signals, which can be joined and separated with passive filter means, i.e. not requiring local electrical power at the flexibility points. This applies in the same way to digital as well as to analogue transport. However, the availability of a high attenuation budget from digital transmission is mandatory to preserve signal integrity of the transported wireless antenna signals in the preferred fronthauling case. Accordingly, a converged networking model was developed which recognizes the major types of antenna stations (macro, metro, femto).

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).

As mentioned above, during Y2 six OFDMA-PON technological solutions were chosen, offering different cost/complexity and performance trade-offs. The preferred solution though was chosen so that it can provide the best possible trade-off between cost/complexity and performance. The use of seeded ONUs allows them to be colourless, while each ONU has an RF downconversion stage, thus their electronics do not need operate at the aggregate speed. In addition, it was deemed acceptable to use coherent receivers at the OLT side, since the cost in that case is justified by it being shared among a multiplicity of users. The selected solution can provide aggregate bitrates of up to 40Gbps in a single wavelength, while higher bitrates are expected to impose severe challenges in the associated electronics (ASIC, DAC/ADC). Therefore, scalability up to 100Gbps aggregate is proposed to be achieved by using three wavelengths operating at 40Gbps each. Further scaling up of the capacity can be achieved by increasing the modulation levels, when allowed by passive attenuation budget constraints. Moreover, certain deployments may necessitate amplification due to passive attenuation budget limitations. In that case, the amplifier could be placed at the OLT (for shorter reach scenarios) or be collocated with the seeding site in longer reach cases. Furthermore, a much lower-cost solution based on IM-DD and temperature control of ONU independent lasers was found promising for certain short-reach applications and is also studied in parallel by ACCORDANCE partners. Moreover, a large set of techno-economic studies were conducted to evaluate the feasibility of the ACCORDANCE concepts. In that respect, significant ODN deployment cost benefits arising from the ACCORDANCE converged metro-access architecture with high splitting ratio were verified. Finally, an elaborate

CAPEX/OPEX analysis comparing OFDMA-PON with contending solutions like XG-PON and UDWDM showed cost advantages of the former.

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

During the second year the definition of a MAC protocol able to leverage on the innovative functionalities of ACCORDANCE was performed. The specific messages and control operations that require a novel approach compared to legacy TDMA-PONs, due to the underlying OFDMA technology, were outlined. In that respect, additional control protocol fields as well as new control messages and processes required in terms of ONU registration, upstream/downstream bandwidth allocation and adaptive subcarrier modulation (ASM) were detailed. A two-level MAC hierarchy (inter-segment, intra-segment) has been proposed. Different modes of intra-segment bandwidth allocation, taking advantage of both the subcarrier and time domains, have been defined. Additionally, in support of legacy protocols and their updates, the necessary modifications in order to upgrade the 10G-EPON and XG-PON standards for accommodating the ACCORDANCE OFDMA-PON MAC functionalities have also been analyzed. Moreover, based on the defined MAC framework and parameters, specific algorithms to provide efficient dynamic bandwidth assignment have been proposed. A multitude of algorithmic variants (reporting/non-reporting, GPON/EPON-based, cross-layer optimized etc.) have been proposed and modelled using custom simulation models. Their performance in terms of packet delay and subcarrier utilization has been evaluated and compared using realistic network parameters and traffic assumptions. Finally, work has been progressing towards the alignment of the proposed MAC concepts with the actual FPGA implementation as well as the adaptation of algorithms to be used for the final experimental tests.

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

The relevant studies comprised a large part of the consortium activities during Y2. Regarding legacy GPON networks' migration into next generation PONs, four basic general types, offering various levels of coexistence, have been considered. Subsequently, addressing possible migration processes from GPONs to ACCORDANCE-type NGPONs (i.e. in a brownfield situation) and the variety therein, a set of 12 basic migration scenarios have been defined and analyzed. The assessment metrics included criteria like ODN upgrade needs (AWG), impact on legacy system power budgets and service interruption time, among others. The benchmarking criteria and their weighting were based on operators' inputs. After the analysis performed, the scenario involving a WDM metro feeder with shared access feeder, distribution & drops was found to be the overall superior solution. All in all, the prevalence of WDM-metro scenarios providing and exploiting coexistence on an unmodified ODN over potentially higher capacity solutions with filtering in the ODN was proven. For this scenario, the migration steps were detailed for a typical power-splitting approach. Additionally, for the cases of an AWG-based solution and one involving a complete overbuild, the migration procedures were also detailed for the sake of comparison. Augmenting the aforementioned studies, a specific wavelength plan enabling coexistence of the ACCORDANCE US/DS signals with legacy PONs has been proposed.

5. Multi-operator, multi-service support.

This objective has in essence been covered by the relevant studies described above, concerning wireline-wireless convergence, migration and coexistence. The ACCORDANCE architecture as it has been elaborated can support a multiplicity of services (OFDMA-PON, legacy PON, wireless) which could belong to different operators. The preferred option for network unbundling makes use of WDM for practical reasons. However, note that further theoretical studies during Y3 will focus on MAC concepts and algorithms on how to exploit the subcarrier domain to arbitrate bandwidth among different operators/services in a dynamic and fair way.

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

During the second year, the ACCORDANCE consortium partners have followed closely the Optical Access Network Standardization activities of FSAN, while active contribution has been increased compared to Y1. In particular, ACCORDANCE partner ALUD has given a second presentation on the ACCORDANCE approach titled "OFDM for NGPON2 Network Convergence" at the May 2011 FSAN meeting. Moreover, the OFDM-PON access idea as developed in the ACCORDANCE project has been submitted as an input to the FSAN Vendor White Paper currently in preparation under the topic "Asymmetric coherent/envelope-type 40Gbps OFDM/-A PON". The ACCORDANCE concept is one out of three concepts submitted to the aforementioned White Paper and the only proposal originating from Europe.

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

During the second year important developments took place regarding the preparation of the ACCORDANCE experimental setups and the corresponding verification scenarios. Verification is split into two separate lab setups focusing mainly on the pure OFDMA-PON wireline case (at TID premises) and the ACCORDANCE wireless schemes (at ALUD premises). The general setups down to the single elements have been defined, their availability has been checked and additional equipment orders have been made where required. The wireline testbed heavily builds upon equipment designed and implemented within the project (the OLTs and ONUs), while the wireless testbed is based on off-the-shelf equipment and makes use of an optical/wireless convergence solution based on WDM and CPRI fronthauling. Additionally, the possibility for a converged testbed including both wireless and wireline components has been elaborated. This will be realized by setting up a portable version of the wireless testbed to be sent from ALUD to the TID labs in Madrid. Regarding the preparation of the required components for the experimental testbeds, significant work has been performed during Y2 towards the implementation of the key modules comprising the ACCORDANCE OLT and ONUs. High performance FPGAs have been selected that are capable of processing the OFDM signal on a single chip. The digital signal processing concept of the ACCORDANCE demonstrator was developed in detail and the FPGA modules for all OFDM processing related tasks were implemented (e.g. FFT/IFFT, PID controller, modulators/demodulators etc.). The whole system was extensively simulated and optimized with using a testbench reflecting the non ideal characteristics of channel and oscillators. Moreover, the OLT and ONU Tx/Rx design and implementation based on the seeded solution described above has also been completed. Relevant experiments have been performed, using OFDM signals similar to the ones generated by the real-time processing blocks. Successful transmission of 256-QPSK modulated subcarriers in a 25 GHz OFDM band and their reception by two ONUs over 100 km of feeder fibre was performed. For the upstream, successful experiments were conducted with two ONUs transmitting 5 GHz OFDM bands with QPSK modulated subcarriers over 75 km of fibre (seeded by the OLT, thus not requiring a laser source).

8. Dissemination of project results.

From the beginning of the project, an ACCORDANCE project web site has been created (http://www.ict-accordance.eu). A poster and a leaflet of the ACORDANCE project have been prepared and have been used at several conferences. A total of 26 conference publications resulting from work within ACCORDANCE have been performed and presented at several prestigious international conferences in 2011, in particular at OFC/NFOEC 2011, PIERS 2011, ICT 2011, ANIC 2011, Future Network & Mobile Summit 2011, ICTON 2011, IEEE ISCC 2011, NOC 2011, INDIN 2011, FITC and ECOC 2011. At the Future Network & Mobile Summit 2011, a next generation converged access networks workshop has been organized by ACCORDANCE partner DT, while ACCORDANCE-related presentations were given during that workshop by ACCORDANCE partners AIT, ALUD and DT.

Two patent applications have been filed during year 2011 by ACCORDANCE partner ALUD.

Exchange with other projects active in neighbouring fields with similar focus has been started by having a joint workshop with the EU FP7 project OASE in Athens (Greece) in 2010 and will be continued by having a joint meeting in Tallinn (Estonia) in February 2012.

Moreover, ACCORDANCE Consortium contributed to the joint Photonics21-Net!Works white paper: "Next Generation Optical Networks: Enabler for Future Wireless and Wireline Applications" and to the white paper issued by CaON cluster regarding regarding OFDMA-PON architectures technologies.

Based on work performed within the project, three scientific articles prepared by ACCORDANCE partners and submitted during Y2 have been accepted for publication in major journals in the field (IEEE/OSA JLT, IEEE PTL, OSA Optics Express). Finally, a scientific article on the ACCORDANCE concept has been submitted to the IEEE Communications Magazine as a joint work of several ACCORDANCE partners and is currently under review.

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).*

The first and most important goal of the ACCORDANCE project will be to define a completely novel converged type of network architecture, incorporating essentially all kinds of access technologies, namely optical-, wireless- and copper-based. As a result, the ACCORDANCE network can indeed support high data rate access using a variety of devices (fixed or mobile), while the unique transmission properties of the OFDM technology enable the extension of the ACCORDANCE scope to cover a metro area.

The need for energy efficiency is covered in more than one ways: First and foremost, the optical distribution network of ACCORDANCE is fully passive. In addition, the use of OFDM technology allows the reach of the network to increase help thus significantly to decrease the total number of power-consuming central offices. This effect is further augmented by the fact the ACCORDANCE central office addresses the wireless part of the network as well, eliminating the need for separate premises and equipment.

Finally, from an architectural point of view, ACCORDANCE can also be thought of as a novel, wide-area terrestrial network architecture carrying wireless traffic, as is described within the Call text[2].

Measurable results for this objective during Y2 can be summarized as follows:

- Clear definition the ACCORDANCE OFDMA-PON technological solutions and the respective node architectures, as well as a selection of the preferred ones, reported in deliverable D2.2
- Detailed study of how a migration from and coexistence with legacy optical access networks can be achieved, reported in deliverable D2.3.
- Detailed study of techno-economic aspects for ACCORDANCE and comparison with contending solutions, reported in deliverable D2.4.
- Detailed study of wireless schemes taking advantage of the ACCORDANCE converged and consolidated network architecture, reported in deliverables D5.1-D5.4.

This objective will be implemented by: WP2 (all tasks), WP5 (Task 5.1)

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 off-the-self components and custom FPGAs resulting in lower cost and lower implementation complexity with respect to the offered capacity and connectivity (i.e. number of supported users). The correpospoding work is reported in deliverables D3.4 and D3.5.

[2] Call 4 of ICT2009.1.1 objective of FP7 2009-2010 workprogramme

- Proposal evaluation and selection of technological solutions to achieve more than 10Gb/s rates per segment and up to 100Gb/s aggregated rate for the whole access network, reported in deliverables D2.2 and D3.1 respectively.
- 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.
- Detailed techno-economic studies to prove the benefits and feasibility of the ACCORDANCE concepts, reported in deliverable D2.3.

This objective will be implemented by: WP2 (Task 2.1, Task 2.2), WP3 (All Tasks)

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. 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, 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, reported in deliverable D4.2.
- Proposal and evaluation via simulations of algorithms taking advantage of the ACCORDANCE MAC, reported in deliverable D4.3.
- Adaptation of the ACCORDANCE MAC protocol and algorithms for evaluation on the actual experimental test-bed (work begun in Y2 and will be reported in D6.2 in Y3).

This objective will be implemented by: WP4 (all tasks), WP6 (Task 6.2, Task 6.3)

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

The proposed architecture offers on the one hand a highly forward-looking perspective for the access network (mainly through the introduction of OFDMA-PONs with dynamic sub-carrier allocation), but can also provide a smooth migration from and co-existence with existing access technologies by allowing the support of current PON protocols (e.g. GPON and EPON, without excluding their upcoming standard updates) as well as copper-based solutions (e.g. DSL) all within the same fibre infrastructure. The migration paths to the new ACCORDANCE concept both from a technical as well as from a techno-economical point of view will be studied in detail in relevant tasks within the project.

Measurable results for this objective can be summarized as follows:

- Definition of migration paths from existing access networks to the ACCORDANCE vision, reported in deliverable D2.4.
- The proposed design causes no interference with the existing PON infrastructure but rather targets the upgrade on the OLT and ONU sites of the network. Any upgrade on the infrastructure level will consider only the passive joint between them.
- The utilized bands of operation will be proposed in order to co-exist with those used by other standards without overlapping to them, while a gradual replacement procedure will be defined.

This objective will be implemented by: WP2 (Task 2.3)

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 wavelengths or 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 requirement 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 will be implemented by: WP2 (all tasks), WP4 (Task 4.3)

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.
- In particular, ITU-T FSAN activities are to be actively followed, with the goal of promoting OFDMA-PON (and the ACCORDANCE concepts) as a candidate solution for next generation PONs

This objective will be 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 test-beds located at the facilities of two of the partners. The latter will be addressing the purely optical and the wireless schemes of ACCORDANCE respectively. Moreover, a converged wireline-wireless demo will demonstrate the converged nature of the ACCORDANCE architecture. 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:

- Definition of the ACCORDANCE wireline, wireless and converged testbeds and the associated validations scenarios (initial results reported in milestone M6.1)
- Implementation and testing of the ACCORDANCE nodes (OLT, ONUs). FPGA modules and OLT/ONU transceiver design/implementation reported in deliverables D3.4 and D3.5 respectively.
- Assembly of functional test-beds using off-the-shelf components, where advanced processing functions will be implemented in FPGAs

The final experimental test-beds will test:

- Physical layer issues,
- Design tolerances and system limitations and
- Control mechanisms through service delivery operations

This objective will be implemented by: WP6 (all tasks)

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 will be 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 / Y2	D2.2 - Final report on network architecture and elements' requirements (M15) D2.3 - Benefits and feasibility (M16) D2.4 - Migration and convergence scenarios (M23)	
Milestones / Y2	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 2 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	16.0	16.0	12.0	12.7	13.5	13.5	-	-	17.0	17.7	10.0	10.0

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
4.0	3.6	7.0	8.0	-	-	***79.5***	***81.5***

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.

During the second year, significant work was performed in all three tasks of this work package. In particular, in Task 2.1 a short list of the possible OFDMA-PON technological options was defined and a specific solution was chosen as the best compromise in terms of performance and cost/complexity. With this solution in mind, an extended techno-economic study comparing ACCORDANCE with current and future contending solutions (XG-PON, UDWDM-PON) in terms of CAPEX/OPEX costs was performed in Task 2.2. Furthermore, studies concerning infrastructure deployment cost benefits for the case of high-splitting, converged access-metro architectures (like ACCORDANCE) were also conducted in the framework of Task 2.2. Finally, the main quantitative benefits of the ACCORDANCE concept as a potential next generation PON solution were singled out. In Task 2.3 the wireline/wireless network convergence model of ACCORDANCE was defined (not all-in-OFDM as originally expected, due to the particular needs of the radio network part), adapted to the solution chosen in Task 2.1. Finally, in the same task, a preferable migration process with a suitable wavelength plan and coexistence with legacy access was developed, making use of the compact optical spectra of DWDM-feeder-type/re-modulation OFDM.

3.1.1 Task 2.1: Network architecture and elements [M1-M15]

Task 2.1 mainly fulfils Objective 1: "Definition of a novel access/metro network architecture achieving convergence among heterogeneous technologies (optical, wireless fibre)". However, in conjunction with studies performed within WP3 it also addresses partly 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).

Significant results:

The main body of the work related with T2.1 was performed already during Y1 and the relevant results were reported in Deliverable D2.1 (delivered in M8). As explained in D1.5 (first year annual report), the main goals of T2.1 have been to (a) provide important architectural definitions necessary for giving feedback to the rest of the project and (b) provide an extensive study of possible technological options for all features of ACCORDANCE (i.e. OFDM transmission schemes, wireless-wireline convergence methods etc.)

The first goal was already achieved through the publication of Deliverable D2.1 (the latter serving as a common reference for all other tasks within the project) while an in-depth review of a wide range of technologies for both OFDM transmission and wireless-wireline convergence was reported in the same document. Therefore, work in T2.1 continued after the publication of D2.1 with the focus shifting towards the clear definition of a narrow list of technological options considered for the ACCORDANCE downstream/upstream operation. Furthermore, one of them was chosen as the most appropriate for being implemented within WP3 in order to ultimately showcase the ACCORDANCE concepts in the final experimental verification during Y3. Hence, the most significant result from T2.1 during Y2 has been the publication of Deliverable D2.2 in M15, which (apart from offering an overview of the ACCORDANCE architecture and a slight update on the ACCORDANCE wireless centralized scheme – to be detailed in Section 3.4.4) mainly elaborates on the above topics. As mentioned above, six OFDMA-PON solutions were chosen, offering different cost/complexity and performance trade-offs:

- *Solution #1*: Direct detection in DS / seeded intensity modulation in US
- *Solution #2*: Direct detection in DS / non-seeded intensity modulation in US
- *Solution #3*: Direct detection in DS / optical IQ modulation in US
- *Solution #4*: Coherent transmission in both DS and US
- *Solution #5*: Intensity modulation / direct detection in both DS and US
- *Solution #6*: Direct detection with optical pre-selection in DS / slotted intensity modulation in US

The table below summarizes the choices implied by each solution:

Table 1: The OFDMA-PON solutions considered by ACCORDANCE.

Solution	**Downstream**				**Upstream**				
	OLT Tx		ONU Rx		ONU Tx			OLT Rx	
	oIQ	IM	DD	CO	Non-seeded oIQ	Non-seeded IM	Seeded IM	DD	CO
#1	✓		✓				✓		✓
#2	✓		✓			✓			✓
#3	✓		✓		✓				✓
#4	✓			✓	✓				✓
#5		✓	✓			✓		✓	
#6	✓		✓			✓		✓	

Legend:

oIQ: Optical I/Q

IM: Intensity Modulation

DD: Direct Detection

CO: Coherent reception (polarization diversity for the OLT Rx, using synchronized LO for the ONU Rx)

Non-seeded IM: Independent WDM lasers using IM, with Optical Beat Interference (OBI) mitigation

Non-seeded oIQ: Independent WDM lasers using oIQ, with Optical Beat Interference (OBI) mitigation

In Deliverable D2.2 the principles of operation and the corresponding OLT/ONU system architectures for all the aforementioned solutions were presented, while the main benefits and disadvantages for each solution were elaborated. Then, with the support of transmission studies performed in WP3, and taking into account the range of deployment scenarios targeted by ACCORDANCE, it was possible to estimate the feasibility of each solution for each scenario. This is shown in the following table:

Table 2: Mapping of the ACCORDANCE solutions to the deployment scenarios based on their performance.

Reach (km)	Splitting	Bitrate per λ (Gbps)	In-line Amplification (Y/N)	Solution #1	Solution #2	Solution #3	Solution #4	Solution #5	Solution #6
20	1:64	40	N	✓	✓	✓	✓	✓	✓
20	1:128	40	N	✓	✓	✓	✓	✘	✓
20	1:256	100	N	✘	✘	✘	✓*	✘✗	✘
40	1:64	40	N	✓	✓	✓	✓	✘✗	✘✗
100	1:128	40	Y	✓	✓	✓	✓	✗	✗

✘ *Passive attenuation budget limited.*

✗ *Dispersion limited.*

* *Polarization mode multiplexing employed.*

Below we summarize the main findings from the overall assessment of the solutions performed in D2.2:

- The lower-cost/complexity solutions (#5, #6) are limited to < 40km scenarios (due to both passive attenuation and dispersion).
- All solutions require optical amplification to achieve a 100 km reach.
- Coherent reception at the OLT side can be justified due to the cost sharing among many users.
- Solutions #2, #3, #4 require extremely fine tuning of ONU lasers to avoid loss of orthogonality among the US signal components. Solution #1 overcomes the issue by adopting a seeded approach (colorless ONUs).
- Bitrate in a single λ in almost all solutions is limited to approximately 40Gbps, due to challenges in the associated electronics (ASIC, DAC/ADC). Only solution #4 could offer 100Gbps/λ via polarization mode multiplexing, however it is not deemed feasible for the near future.

Therefore, the consortium decided to support Solution #1 as the most realistic alternative for implementation in the course of the project, since it offers the optimal trade-off regarding the multiple criteria set. As a result, it was used as the basis for further work in other tasks, e.g. in T2.2 and T3.2. Solution #1 consists of optical I/Q modulation at the OLT transmitter and direct detection at the ONU receiver for the downstream, together with seeded intensity modulation (IM) at the ONU Tx and coherent detection at the OLT Rx for the upstream.

The benefit of using a seeded approach is that since all ONUs in this group share the same optical source, the US OFDM signals are perfectly aligned and no optical frequency drifts among ONUs need to be accounted for. Hence, the idea behind upstream OFDMA can be fully applied. The baseband OFDM US signal is generated by the ONU electronics (FPGA in the ACCORDANCE implementation), and after DAC, RF up-converted to the electrical band assigned for the US ONU information. A reflective EAM intensity-modulates the RF up-converted signal over the seeded optical carrier with an optical spectral guardband used to separate the carrier from the data in order to reduce the effect of Rayleigh back-scattering in the US data signal and also to avoid the detrimental effect of inter-modulation products. After optical amplification the US optical signal is fed to the same fibre of the DS direction. The OLT receiver consists of a polarization diversity 90-degree hybrid that performs a homodyne reception with a low phase noise optical LO. The optical signal is then sent to a pair of balanced photodiodes, one detecting the real part and the other the imaginary. Both electrical signals (real and imaginary) are then sampled, digitalized and sent to a conventional OFDM receiver.

Note that, as explained above, certain deployments may necessitate amplification due to passive attenuation budget limitations. In that case, the amplifier could be placed at the OLT (for shorter reach scenarios) or be collocated with the seeding site in longer reach cases (e.g. more than 40 km). For the support of > 100 Gbps aggregate bandwidth per OLT, the use of three wavelengths operating at 40 Gbps is proposed, while further scaling up of the capacity can be achieved by increasing the modulation levels (when allowed by the passive attenuation budget constraints).

3.1.2 Task 2.2: Benefits and feasibility [M7-M16]

This task contributes to Objective 1: "Definition of a novel access/metro network architecture achieving convergence among heterogeneous technologies (optical, wireless fibre)" and Objective 5: "Multi-operator, multi-service support" by analyzing the pros and cons of OFDM in the PtMP access network.

Significant results:

The main outcome of T2.2 has been the publication of Deliverable D2.3. This document provides a detailed study of the benefits resulting from the ACCORDANCE concepts and the techno-economic issues associated with their deployment.

In that respect, for the purposes of the evaluation of the ACCORDANCE solution as a potential candidate for next generation PONs, it was chosen to be compared with its main foreseen contenders. Therefore, the following basic technical approaches were considered:

- Massively time-domain multiplexed networking (G-PON/XG-PON reference)
- Massively wavelength multiplexed networking (UDWDM contender)
- Massively subcarrier-space-multiplexed networking (ACCORDANCE OFDM/OFDMA)

For each of the solutions a short description of the key performance parameters was given in D2.3. Based on the studies performed in T2.1 and T3.1 (see also Section 3.1.1), for the ACCORDANCE concept, a transmission solution was selected for closer economic analysis which in downstream makes use of a transmitter with quadrature field modulation for compact and highest capacity transmit spectra (oIQ). Optically pre-amplified direct-detecting receivers (DD) with electrical tuner for sub-spectrum processing are used in the ONUs. Polarisation division multiplexing is not exploited, as it would not allow the use of cost-effective DD receivers in the ONUs and would not work with lower cost intensity modulation (IM) there. The upstream transmitter uses a separate, centrally provided remote seed signal which is being intensity (re-) modulated (IM). The ensemble of OFDMA upstream signals is detected with a pre-amplified, polarisation- diversity coherent receiver. In-line amplification is considered for long-reach metro distances and high splitting PONs.

This selection is deemed to form the best compromise in reach capabilities, complexity/cost and throughput performance for the targeted access application, i.e. a 40Gbit/s per wavelength, 1:64 split and 20 km+ reach capability. For the extended case of 40 to 100 km fibre lengths, it is projected that the seed source can be co-located at the anyhow existing remote-amplification site and the dominating feeder single mode fibre span then not contributing to the detected Rayleigh backscatter.

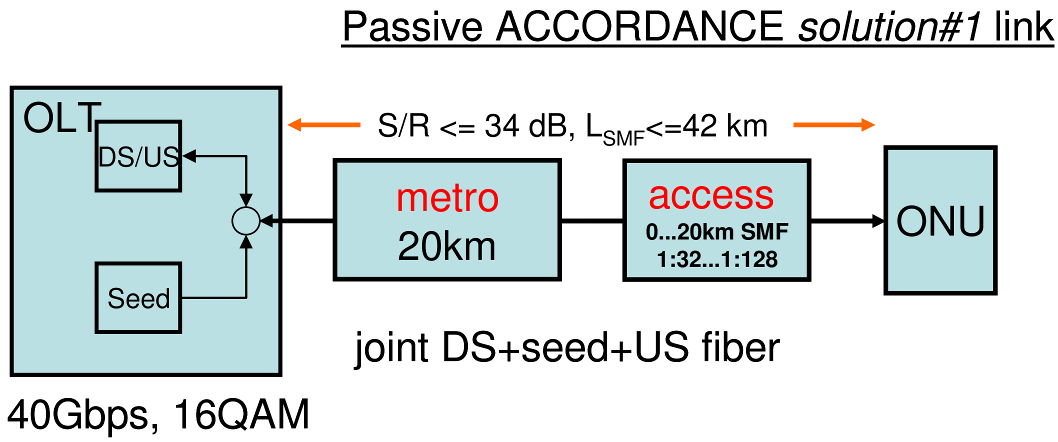


Figure 1: High-level view of the passive ACCORDANCE Solution #1.

Independent from the exact modulation format solutions, Outside Plant (OSP) case studies have been performed and reported in D2.2 in order to prove the benefits of a high-splitting PON approach from an infrastructure point of view. In a first study, a comparison of FTTC/B/H using PtP and FTTH using PON was made that clearly shows the cost advantages of FTTH deployment using PON. Based on those results, the study was extended to cover the metro and access part for PtP and PON, as well as a long reach converged metro-access network solution. As shown in Figure 2(a), it was proven again that the PON solution provides significant cost savings compared to the PtP approach, while with a converged metro-access network there is a further reduction in CAPEX/user compared to standard PON approaches through the long reach access infrastructure. In a second case study, the projected OSP deployment cost savings of high-splitting PONs (with splitting ratios up to 1:512 - irrespective of the underlying supporting technology to achieve this, with one solution of course being the ACCORDANCE paradigm) have been studied. The results [Figure 2(b)] show that PONs with high splitting ratio provide OSP building cost savings of around 25% as compared to legacy approaches with 1:16 splitting. Moreover, it appears that splitting ratio above 256 will not contribute significantly to higher savings. All those results are well aligned with the goals and deployment scenarios considered within ACCORDANCE and justify the project's architectural approach.

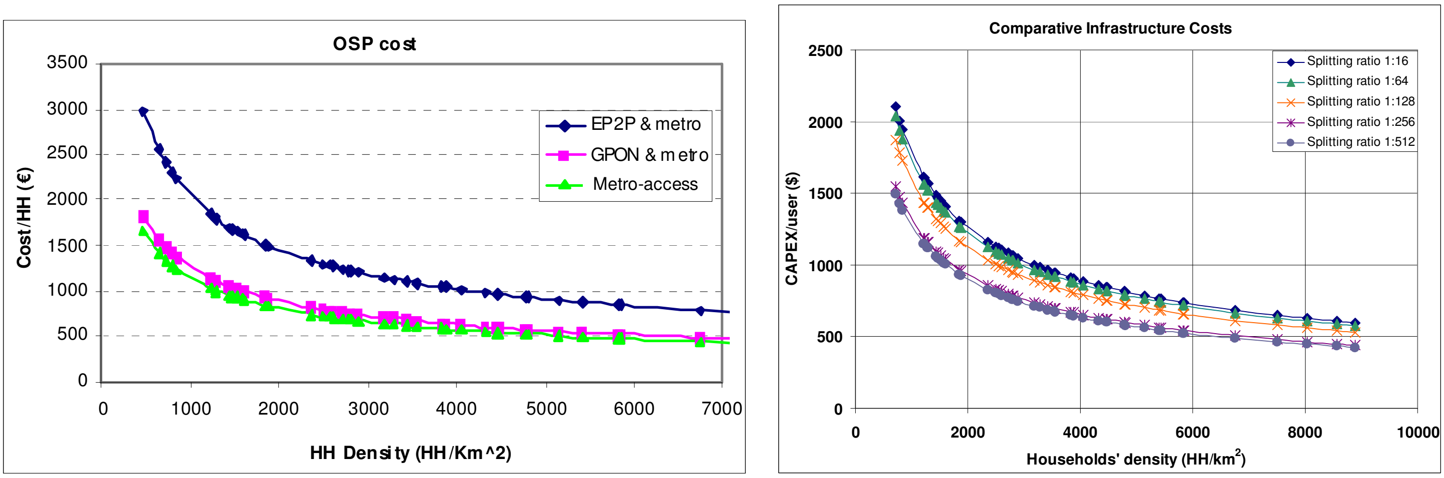


Figure 2: OSP CAPEX costs comparison between (a) typical point-to-point, GPON and converged metro-access architectures and (b) PON architectures with different split ratios.

Subsequently, the ACCORDANCE architecture (enabling node consolidation with a converged metro/access network), has been analyzed by means of a detailed techno-economic study considering both CAPEX and OPEX and has been compared with the GPON/XGPON and UDWMD solutions. The CAPEX model included infrastructure costs, system equipment costs (OLT, ONU etc.), Remote Node costs (including amplification if needed) as well as the backhauling costs to (if required). The OPEX model included operation and maintenance, footprint and power consumption. The operation and maintenance efforts have been amalgamated into an averaged sum per connected home and has been given a premium with reference to the distance to the central zone in order to account for the higher time and transport efforts needed to approach remote CO-located equipment for servicing and repair. With the intention of designing a scenario as realistic as possible, an area of up to 70 km radius around a typical big major European city was analysed containing three different area types: Dense urban, Urban, Suburban. Based on those results, a topology model was defined and was used for calculations. For the purpose of benchmarking the ACCORDANCE OFDM/OFDMA approach in terms of CAPEX/OPEX against, on the one hand, concurrent access network technologies (G-PON/XG-PON-1) and on the other hand against the future-generation UDWDM contender approach, a simple cost model has been developed. It comprises the major CAPEX cost elements for G-PON, XG-PON1, UDWDM and OFDM/OFDMA in the form of the selected 40Gbit/s tentative design, respectively. The model is organized on the equipment level and contains pricing for the key components as are the ONU, OLT, racks and similar. Two costs models have been used. The "Component-assessment based price model", which is based on price level information gained from the component level analysis and under a significant cost reduction assumption. The "Optimistic price model" assumes that a lower and, due to given technical similarities of the both future-time contender systems, uniform price level has established, which would be equal to the current XG-PON1 level.
Four scenarios have been analysed, created by varying the parameters for access equipment costs and the OPEX cost per customer:

- *Scenario 1*: Component-assessment based price model – 100€/yr·customer OPEX base
- *Scenario 2*: Component-assessment based price model – 20€/yr·customer OPEX base
- *Scenario 3*: Optimistic price model – 100€/yr·customer OPEX base
- *Scenario 4*: Optimistic price model – 20€/yr·customer OPEX base.

These scenarios are based on the following technological configurations:

- G-PON (G.984) with 1:64 split ratio
- 10 G-PON (XG-PON1 according to G.987) with 1:64 split ratio
- UWDM with 1:64 split ratio

- UWDM with 1:256 split ratio
- OFDM-P (P = passive ODN based on power splitters) with 1:64 split ratio
- OFDM-A (A = ODN based on power splitter and in-line amplification) with 1:256 split ratio

From all results obtained, it can be noticed that there are cost savings in the OSP part as well as for the OPEX by the solutions with higher optical power budget, enabling a higher degree of node consolidation (UWDM and OFDMA). Here the UWDM and the OFDM solutions are showing benefits over the existing solutions. But with a cost assumption based on the "Component-assessment based price model", the access equipment cost (factor 2 and 3 for the UWDM and OFDMA PON respectively compared with XG-PON) overcompensates the saving by several factors, especially in scenario 2, where the OPEX cost per customer is lower compared to scenario 1. Even in scenario 1, with higher OPEX cost per customer, there is only the OFDMA solution, which slightly outperforms the XGPON solution.

Assuming that the cost of the upcoming solutions will decrease to the same level of today's system cost (like what is considered in scenario 3 and 4), then the concepts enabling a high degree of node consolidation and a high splitting ratio are outperforming the XG PON solutions. The total savings are strongly dependent on the OPEX cost assumptions. It is expected that the real value is closer to the lower end of the considered OPEX span. This is shown in Figure 3 for the most promising upcoming solutions (UDWDM, OFDM-Active, each with a 256 split) in reference to XG-PON1, for the four price model/OPEX combinations.

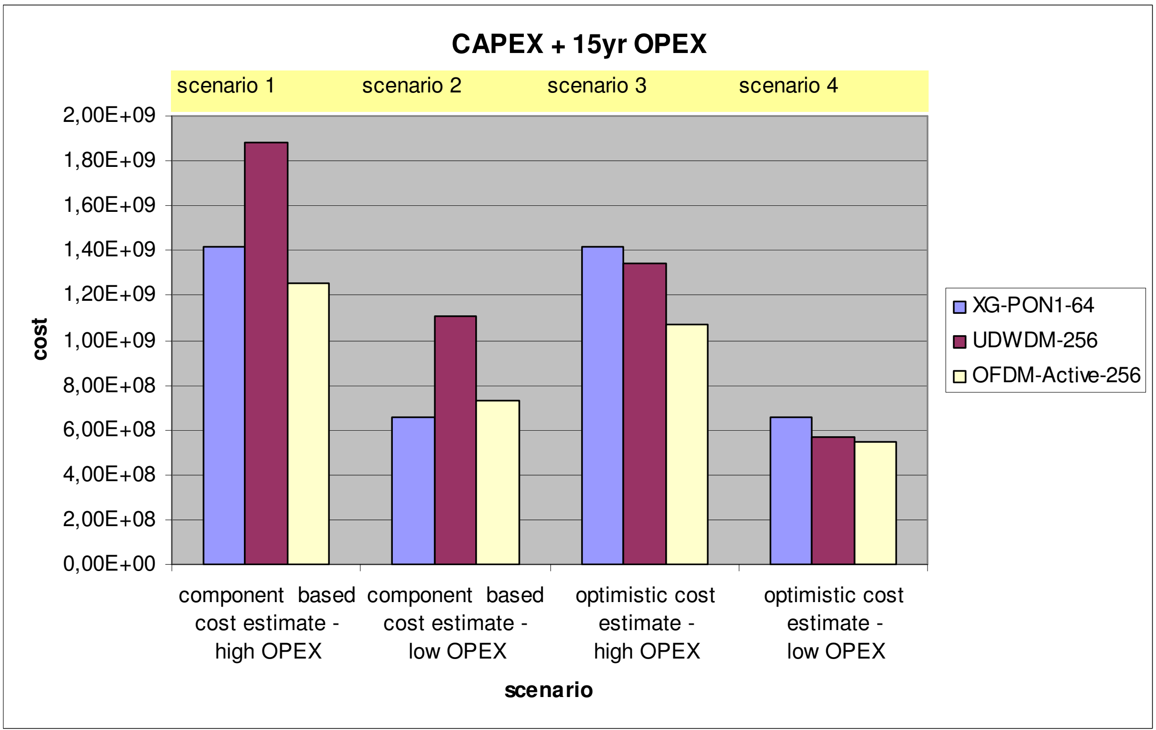


Figure 3: Comparison of the selected solutions vs. the four price model/OPEX combinations.

To gain a clear benefit from the higher degree of node consolidation (compared to what is provided by G-PON/XG-PON), the cost of the upcoming systems needs to reach cost levels similar to the costs of G/XG-PON technology, even if capacity is increased. That provides a huge challenge for the system vendors and especially for the component vendors because it implies massive reduction of optical component costs and major breakthroughs in photonic integration. In all considered cases, the active OFDM solution outperforms the contender approaches (in the 40 Gbit/s class) in the 15 years total cost view.

Furthermore, apart from the purely techno-economic studies, several additional qualitative benefits arising from the OFDM/ACCORDANCE network concept have also been discussed in Deliverable D2.3:

- A very important benefit of OFDMA-PON in contrast to TDMA-PON is that the transceiver hardware of the ONUs does not need to run on the aggregate line speed, since the multicarrier concept allows the use of bandwidth dilution techniques i.e. processing of only the bandwidth slot relevant to them (either in the optical or electrical domain). As a result, there is an opportunity for significant reductions in both hardware requirements and power consumption.
- The OFDM transmission can easily scale to higher constellation sizes, higher bit rates and higher dispersion values without a need of increasing the complexity of the receiver hardware. The use of multilevel modulation formats allows for an efficient use of the spectrum and the adaption to different conditions. That is a key feature which alleviates issues related to migration and coexistence with other technologies in the network. OFDM also permits an adaptable oversampling. Other benefits coming from the digital Tx and Rx are the easy reconfigurability and the ability to adapt and compensate for low-performance (and hence low-cost) components by using channel adaptation algorithms.
- The fixed–mobile convergence of the ACCORANCE architecture concept allows a more centralized processing of radio network data, which helps to avoid cell interference, provides more flexibility and helps reduce the remote site cost, size and power consumption.
- From the MAC perspective, OFDM offers a high degree of scalability by enabling dynamic subcarrier allocation, which provides more bandwidth flexibility than WDM approaches. Moreover, pure OFDMA can be further improved by combing it with TDMA. In addition, the ACCORDANCE OFDMA MAC uniquely opens the possibility to use a different QAM depth for the subcarriers assigned to each ONU at each time (leveraging on the associated PHY capabilities described above). This feature can result in higher total effective capacity and lead to either lower-latency or higher-bandwidth applications, depending on the exact resource assignment strategy.

3.1.3 Task 2.3: Migration and convergence scenarios [M12-M24]

Fulfils Objective 4 “Provision of smooth migration from and coexistence with legacy access solutions” and Objective 5 “Multi-operator, multi-service support”. Task 2.3 addresses the convergence aspects of the ACCORDANCE approach, i.e. the inclusion or substitution of legacy access technologies, the transition to integrated metro/access networks and the transition processes from current to converged networking for wireline and wireless access.

Significant results:
The main outcomes of the work performed in Task 2.3 were included in Deliverable D2.4. Below we summarize the key contents of this document.

In order to define the target architecture for a converged ACCORDANCE network arising from a brownfield GPON-type status, a set of requirements regarding wireline (metro/access converged) and wireless networks have been initially set up for the evaluation of fixed network migration and networks convergence: For the fixed network part, a maximum reach of typically 60km (but up to 100km in some cases) and total split ratios of 64 up to 1024 (feeder fibre sharing ratio) have been assumed. Peak bitrates per subscriber of up to 1 Gbps is the objective. For the mobile backhauling, two possible transport mechanisms have been studied, one involving digital backhauling, and the other analog wireless signal transport. For the digital transport, the capacities reported in WP5 (D5.3) have been adopted for the set of interface levels (b-f) under consideration. For the common transport of wireless and wireline services (networks convergence) the analog transport option was investigated with respect to spectral insertion and extraction into and from the OFDM optical signal band. However, the three orders of magnitude width disparity (20 MHz LTE vs. 20 GHz total width per wavelength channel) and the sub-kHz wavelength stability requirements inherited from the GHz radio domain for the coherent US receiver detection in the OLT, make this approach appear very challenging and hence costly to implement. At the same time, there is only a minor flexibility gain from a joint multiplex signal with fronthauling data streams having constant bitrate.

Moreover, for networking reasons, it seems advantageous to use separate wavelengths for the numerous wireline and wireless signals, which can be joined and separated with passive filter means, i.e. not requiring local electrical power at the flexibility points. This applies in the same way to digital as well as to analog transport. With the optical insertion loss of future PON access sections and the fact that baseband processing units of wireless operators are typically separated from wireline operators installations, the availability of a high attenuation budget from digital transmission is mandatory to preserve signal integrity of the transported wireless antenna signals in the preferred fronthauling case.

On the basis of the before mentioned facts, a converged networking model has been developed which recognizes the major types of antenna stations (macro, metro, femto). Traffic considerations and the need to keep costs equivalent to the number of user served by each endpoint, a tailored model has been developed under the timing constraints from fronthauled remotes as well as through cooperating heterogeneous cells. Femto base stations are most efficiently served by the OFDM packet transport system of the ACCORDANCE wireline OFDM. Metro station sites are served by wavelength reuse-1 CWDM links, while macro sites are served by a transparent DWDM scheme accommodating the higher capacity needs there in combination with an optional link protection in place.

The integration of wireline and wireless links follows the below overview with the legacy optical access also integrated. Fronthauling uses the capabilities of a lean 2x2 λ CWDM scheme and DWDM links, respectively, limiting to a high extent the inventory problem and achieving premium service segregation. Flexible interworking among wireless and wireline operators can be achieved. The corresponding wavelength plan has been selected in view of migration needs. Finally the consolidated ACCORDANCE network model (Figure 4) has been defined.

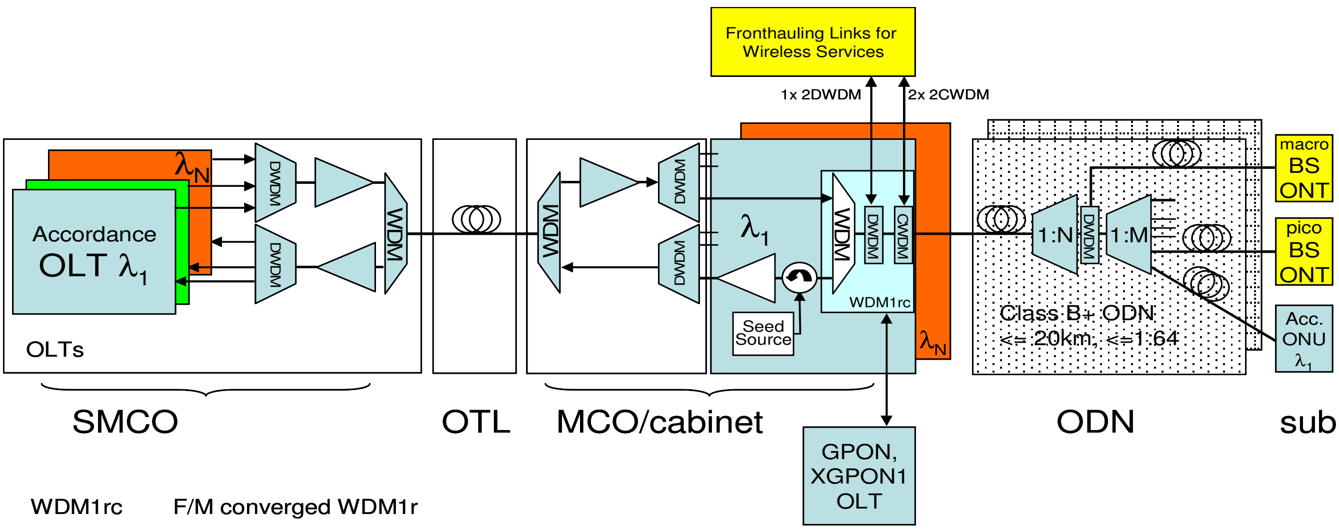


Figure 4: The ACCORDANCE consolidated network model.

The corresponding heterogeneous network topology is shown in Figure 5 below with the different size of wireline and wireless service areas. The wireless service area per BBU hotel is smaller to reduce fiber propagation delays otherwise degrading wireless performance and (in the future) COMP gains. It especially tailors service areas per BBU hotel to reasonable clusters within which participating cells could interact to the benefit of cell capacity, which is given by radio wave propagation characteristics and risk group considerations.

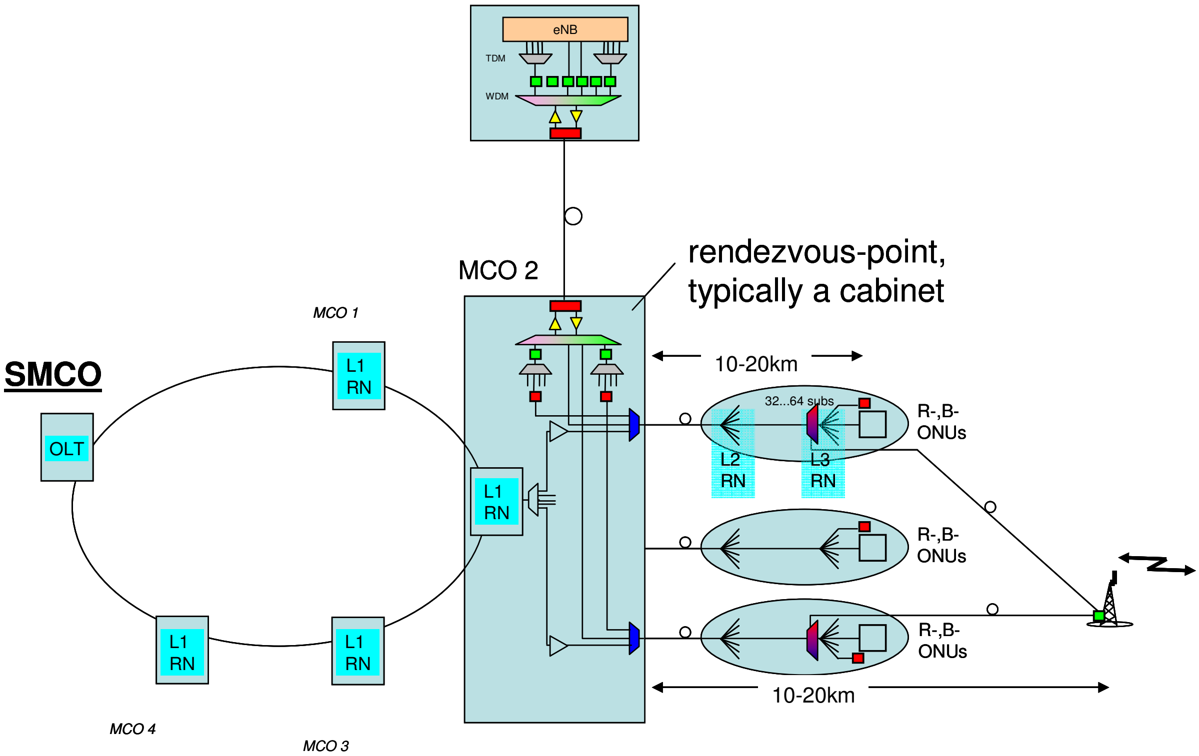


Figure 5: The ACCORDANCE heterogeneous network topology.

All the above findings have served as the basis for defining the demo system in WP6.

Regarding legacy GPON networks' migration into next generation PONs, four basic coexistence types have been considered, as shown in Figure 6:

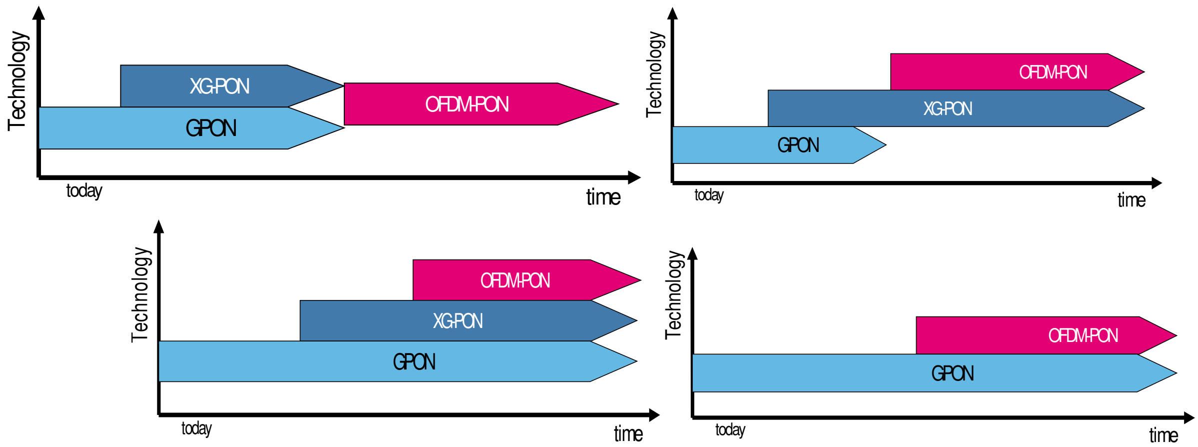


Figure 6: The considered coexistence types (N, X, GX, G).

Subsequently, addressing possible migration processes from GPONs to ACCORDANCE-type NGPONs (i.e. in a brownfield situation) and the variety therein, a set of 12 basic migration scenarios have been defined and subsequently analyzed:

- *Scenario 1*: Shared access feeder, distribution & drops
- *Scenario 2*: WDM metro feeder
- *Scenario 3*: Drop-by-drop switchover
- *Scenario 4*: WDM metro feeder/drop-by-drop switchover
- *Scenario 5*: WDM metro & access
- *Scenario 6*: Mid-ODN mixed AWG-PS insertion

- *Scenario 7*: Shared access feeder
- *Scenario 8*: Independent overbuild
- *Scenario 9*: Switched-over feeder & drops
- *Scenario 10*: Upper-ODN parallel-AWG
- *Scenario 11*: Upper-ODN PS-AWG swap
- *Scenario 12*: Mid-ODN AWG insertion

The assessment metrics included criteria like ODN upgrade needs (AWG), impact on legacy system power budgets and service interruption time, among others. Note that the benchmarking criteria and their weighting were based on operators' inputs. After the analysis performed and reported in D2.4, Scenario #2 (WDM metro feeder with shared access feeder, distribution & drops) not unexpectedly turned out to be the overall superior solution. For Scenario #2, the migration steps were detailed for a typical power-splitting approach representative. For the preferable AWG-based solution (Scenario #10) and a complete overbuild (Scenario #8) the procedures have been also detailed for the sake of comparison. The prevalence of WDM-metro scenarios providing and exploiting coexistence on an unmodified ODN over potentially higher capacity solutions with filtering in the ODN was proven, as expected.

In order to support the aforementioned studies, an analysis of the attenuation impact of splitters vs. AWG-routers (arrayed waveguide grating) and optical in-line amplification was also included in D2.4. The link setup used to assess the corresponding reach and splitting capabilities is shown in Figure 7:

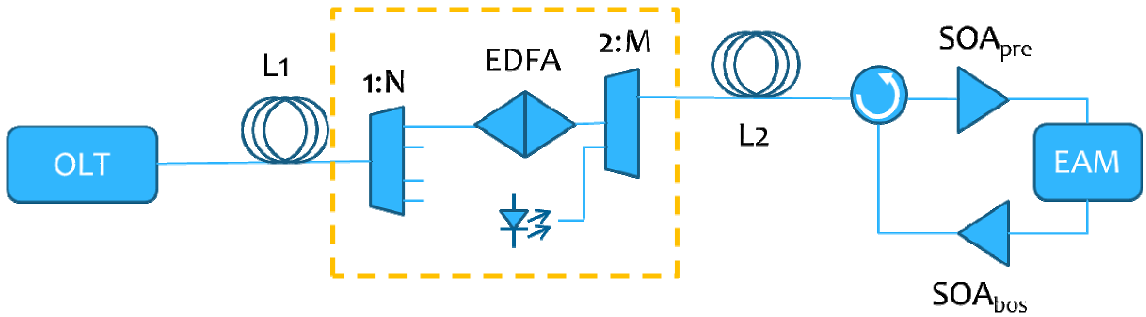


Figure 7: The considered link setup for evaluating the impact of splitters versus AWG routers and optical in-line amplification.

The limit contour values for log_2(NxM) at a bitrate of 40Gb/s OFDM per wavelength are depicted in Figure 8 for the pure splitting case (left) and a combined splitting/AWG (right). Depending on the distribution of the fibre links the optimum splitting varies, and a maximum of 128 users can be served with pure splitting while up to 256 users can be communicated with a combination of splitter/AWG.

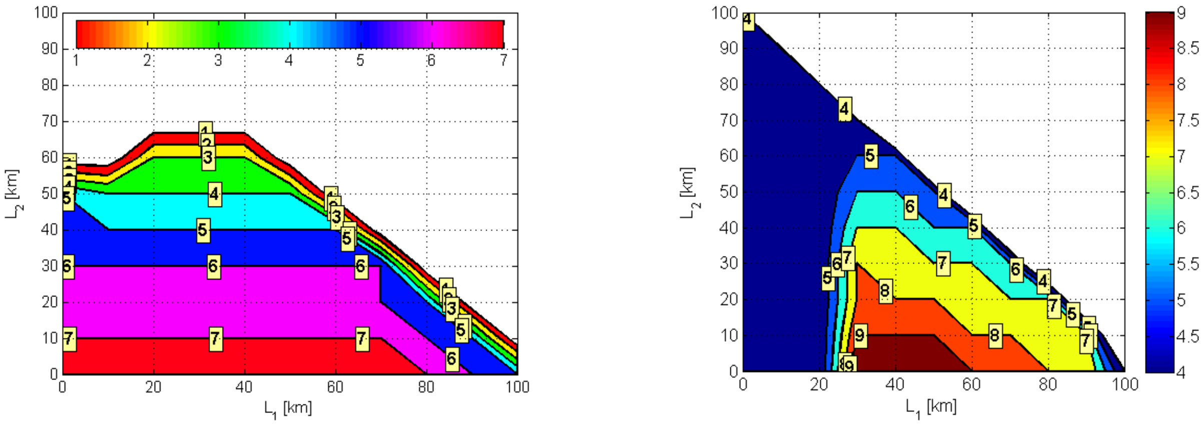


Figure 8: Simulation results for (left) pure splitting, and (right) combination of splitting/AWG.

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

Workpackage number	**3**	**Start date:** M1 **End date:** M30
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 / Y2	D3.2 - Transmitter and Receiver design and implementation (M18) D3.3 Modulation format studies – Detailed study and transmission analysis including QAM dynamic Reconfigurability – Update of D3.1(M20) D3.4 Transmitter and Receiver design and implementation – Update of D3.2 (M24) D3.5 Design and implementation of FPGA modules (M24)	
Milestones / Y2	M3.2 - Transmitter and Receiver design (M17) M3.3 - Requirements and high-level design of FPGA modules (M20)	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 2 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	12.0	12.0	40.0	26.1	2.0	2.0	8.5	8.5	1.0	0.5	-	-

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
46.0	29.4	24.0	20.0	-	-	***133.5***	***98.4***

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

- 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 second year the work has focused mainly on objective 2 in particular the design and implementation of the OLT and ONU transceivers. This includes the selection and assembly of optical and electrical components as well as the development of real-time capable FPGA code. All components were tested and characterized within Task 3.2. In the course of Task 3.3 the digital signal processing (DSP) concept was designed and implemented. Simulations proofed the functionality of the real-time processing blocks that are realized on the target FPGA. Therefore an adequate FPGA was selected and, since no commercially available evaluation boards support the functionality needed for the ACCORDANCE demonstrator, the development of a custom FPGA board was triggered.

3.2.1 Task 3.1: Access Requirements and Modulation Format Studies [M1-M20]

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) by giving insight on the possible devices that will be needed for implementation. The modulation formats were extensively evaluated in the previous year and for this period the OFDM technological options were narrowed down. The performance of the selected alternatives presented in D2.2 was fully evaluated in downstream and upstream. The implementation complexity and cost were also considered for comparison and selection of the OFDM format that could best fulfil the ACCORDANCE requirements. Besides, the effect of optical transmission impairments such as fiber nonlinearities and optical beat interference (OBI), Rayleigh Backscattering and PAPR, and techniques to counteract them, were also studied. The task formally ended on month 20 with the submission of deliverable D3.3.

Significant results:

The six alternative systems described in D2.2 were further considered in this deliverable and both downstream and upstream were simulated with VPI® for all of them. The simulations were performed using a 256-point Fast Fourier Transform, and a modulation format of 16QAM at 40Gb/s with a 10% of cyclic prefix. In particular, results from solution 1 are presented in Figure 9 (downstream left and upstream right) with a laser linewidth of 1MHz and a pre-amplifier with 20dB gain and 6.5dB of noise figure. The performance was evaluated in terms of the splitting budget available for up to 100km of optical fibre, which is the target of ACCORDANCE. For downstream, several launched powers were evaluated Previously, an optimization of the power ratio between the optical data signal and the optical carrier for each launched power was carried out, because it wasfound that due to the fiber nonlinearities, for higher launched powers, it is best to increase the percentage of power in the optical carrier relative to the OFDM sideband The results in Figure 9 indicate that a splitting ratio of 1:64 is available at medium reach distances (<40km). For longer distances the splitting ratio is lower but it can be enhanced using a remote amplifying stage in the network. In the upstream case, two identical ONUs were simulated to emulate a multipoint-to-point network. Both ONUs launched the same optical power (3dBm) and same OSNR in order to avoid noise from one user to cover its neighbour. The results are given also in terms of the splitting budget available, since the optical signal will face the same network losses in both directions. As can be noticed, even at this high speed chromatic dispersion is not affecting severely the signal. Both plots of Figure 9 show that this solution can give a symmetrical datarate:

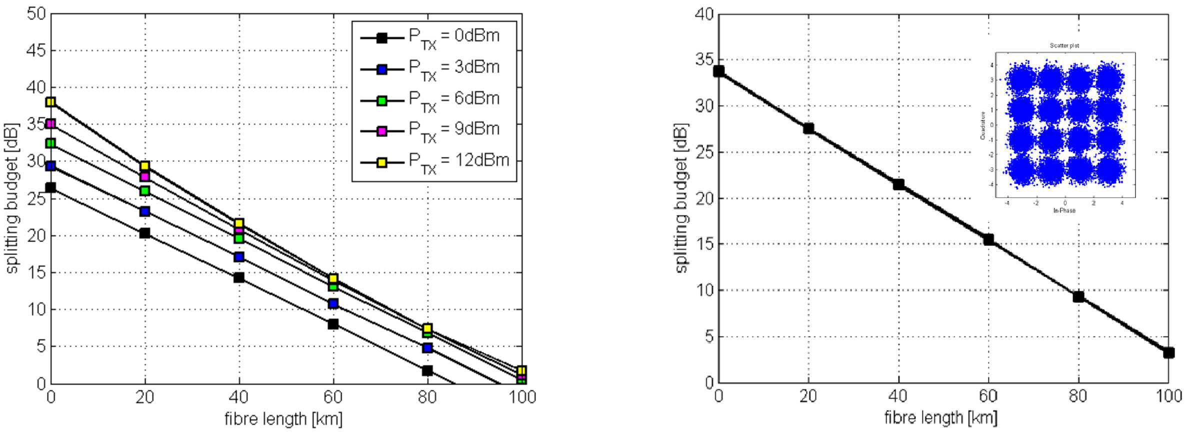


Figure 9: Performance evaluation of solution 1 in terms of total splitting budget available for several fibre links with 0.3dB/km attenuation: (left) downstream, (right) upstream)

The performance of the other solutions was also evaluated, and the 6 alternatives were then classified with regard to their expected performance, cost, and present practical feasibility (Figure 10). The last consideration was extremely important for the testbed definition. According to the findings, a preferred alternative (Solution 1 in D2.2) with downstream based on optical IQ modulation with auxiliary optical carrier and direct-detection and with upstream relying on reflective intensity modulation and coherent detection, has been identified for the ACCORDANCE OFDMA optical access network alternative to be studied in more detail and also as the base of the experimental testbeds. Additionaly a low-cost solution based on IM-DD and temperature control of ONU independent lasers (Solution 5 in D2.2) has been found promising for short-reach applications.

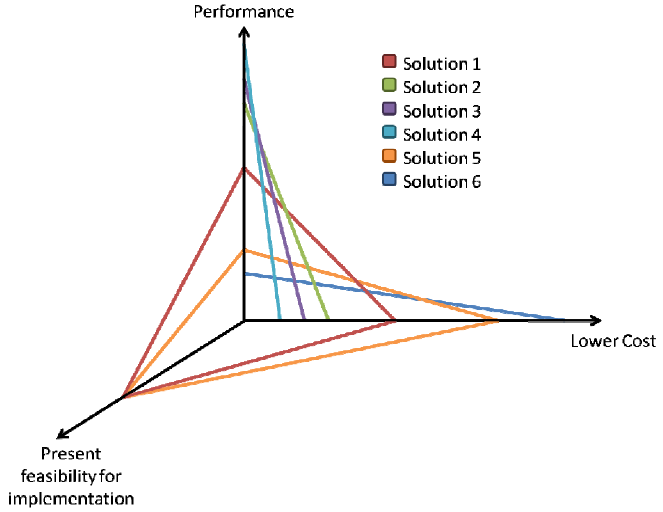


Figure 10:Qualitative comparison of solutions in terms of performance, cost and present implementation feasibility solutions that, currently, seem unfeasible for implementation appear only in the performance and cost plane.

Besides the evaluation of the six alternatives, the following impairments were also studied: optical beat interference (OBI), Rayleigh backscattering (RB), and peak to average power ratio (PAPR). Alternatives for reducing their detrimental effects were included. In particular, an algorithm for OBI management based on temperature tuning of independent lasers at the ONUs, the use of wavelength and radio frequency shifting for RB mitigation and adaptive modulation and nonlinear distortion techniques for PAPR reduction.

3.2.2 Task 3.2: Transmitter and receiver design and implementation [M6-M24]

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:

This task deals with the transmitter and receiver design and implementation for both the optical line termination (OLT) and the two optical network units (ONU) of the Accordance demonstrator setup. First, the overall architecture for the demonstrator has been proposed and designed. Optical and electrical devices have been carefully chosen in order to meet the criteria of high performance in terms of throughput and split ratio and scalability. Furthermore economic aspects have been emphasized. The proposed network architecture, i. e. the schematic setup of OLT and ONUs, is pictured below.

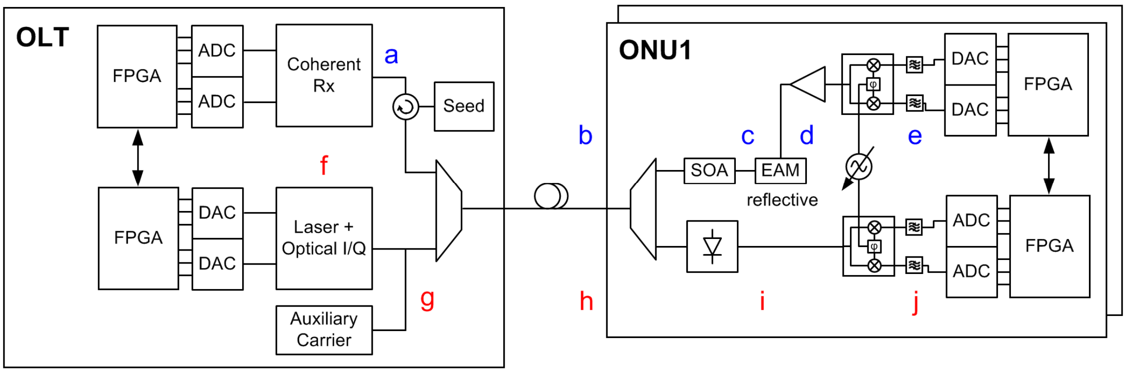


Figure 11 - Schematic setup of the Accordance demonstrator OLT and ONUs.

For first tests of the OLT and ONU components, arbitrary waveform generators (AWG) and real-time oscilloscopes serve as electrical transmitters and receivers respectively. For the OLT transmitter, two synchronized FPGAs store offline generated orthogonal frequency division multiplexed (OFDM) data. We use the digital-to-analog converters (DAC) that will be deployed in the final setup. The auxiliary carrier generation has been successfully demonstrated and heterodyne reception of the OFDM signal is performed using a broadband photo-detector (PD). The broadband electrical output of the PD is fed to the assembled down-converter and a sub OFDM band is selected and received by a "narrow-band" real-time oscilloscope. A commercially available "narrow-band" AWG provides the ONU OFDM signals that are electrically up-converted to the 25 – 50 GHz band. The electrical signal is amplified and drives a broad-band electro absorption modulator (EAM). Eventually the EAM optical signal is coherently received by the OLT receiver and sampled using a broad-band oscilloscope. The OLT and ONU optical and analog electrical frontends have been assembled and tested for basic functionality. Results are described in the deliverable D3.4.

The broadband downstream signal is detected by the photodiode in the ONU. The electrical output of this Photodiode is investigated with an electrical spectrum analyzer the output of which is shown below in Figure 12 (a). The electrical signal is down-converted from the 25 – 50 GHz band and sampled by the real-time oscilloscope. The spectrum is depicted in Figure 12 (b).

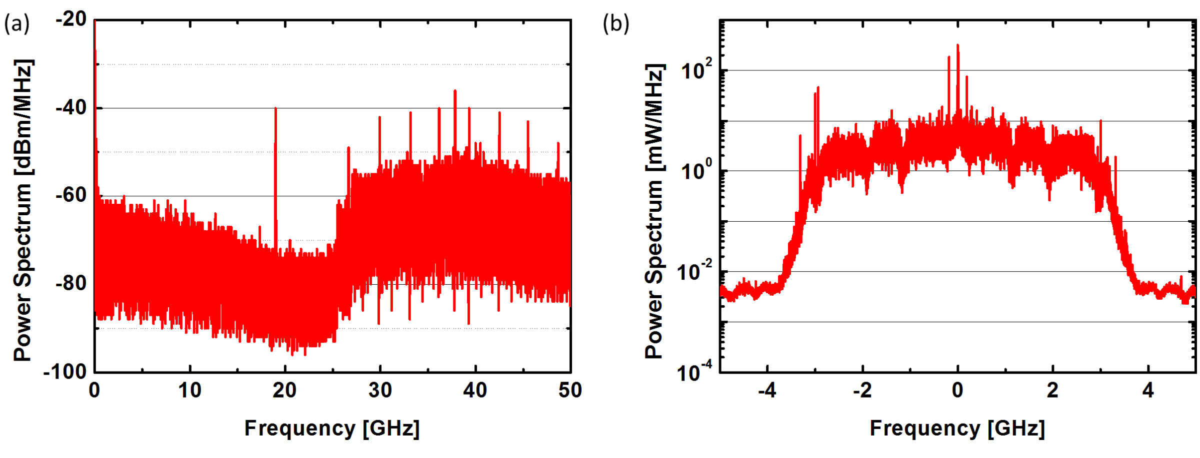


Figure 12 - Downstream signals after optical detection (a) and after electrical down-conversion (b).

The optical uplink signal modulated by the EAM and the local oscillator (LO) for the coherent OLT receiver are measured with an OSA is shown in Figure 13 (a). The black curve represents the LO and the blue curve is the EAM output. We see a strong center carrier due to the intensity modulation and two modulated OFDM sidebands. The black LO nicely coincides with the lower OFDM sideband which is to be detected by the OLT coherent Rx. The offset between LO and lower sideband is due to the fact that an uplink sub-band with a center frequency of 33 GHz has been chosen whereas the center of the combined uplink sub-bands is located at 37.5 GHz. A shift in frequency to the left translates to a shift in wavelength to the right.

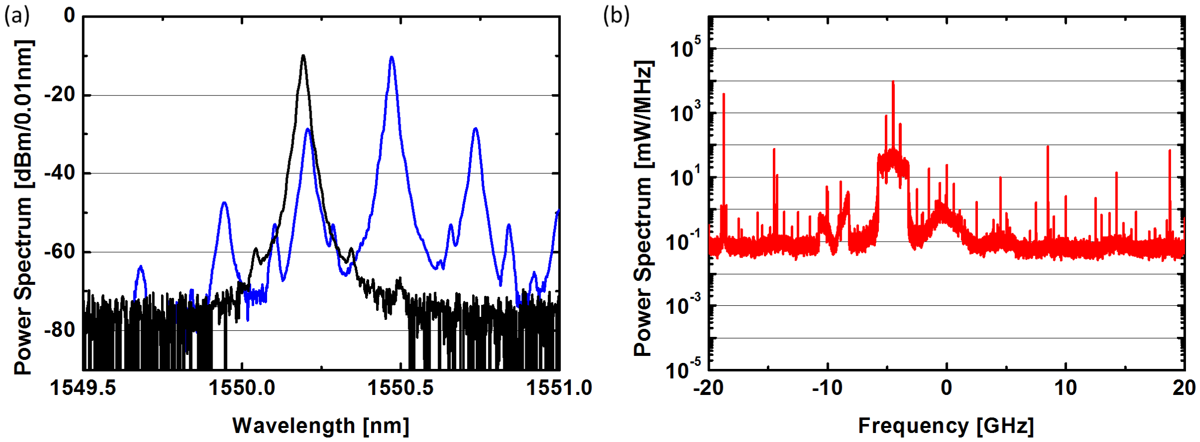


Figure 13 - Uplink and LO spectra measured with an OSA (a) and after coherent detection (b).

The coherent receiver of the OLT uses the LO to down-convert the lower sideband into the baseband. The signal is then sampled by a real-time oscilloscope. The obtained signal spectrum is seen in Figure 13 (b). The ONU sub-band can be found between −5 GHz and −2.5 GHz. Spurious spectra are due to two reasons. Not properly removed alias-spectra of the AWG can be found around −10 GHz. For the future use of the FPGA and DACs these parts will be suppressed. Another issue is receiver induced non-linearity which can be well minimized if the proper input power levels of signal and LO into the coherent frontend are chosen. By tuning the electrical up-converter's oscillator we can relocate the OFDM sub-band to a different center frequency.

We have further evaluated the system performance by basic network experiments. In these experiments, OFDM signals similar to the ones generated by the real-time processing blocks are used. For the downlink, we transmit 256 QPSK modulated subcarriers in a 25 GHz OFDM band and receive the signal by two ONUs after transmission over up to 100 km of feeder fiber. All ONUs use semiconductor optical amplifiers (SOA) only and are able to detect more than 10 Gbit/s of downlink data. For the uplink experiment each ONU transmits a 5 GHz OFDM band with QPSK modulated subcarriers. Both ONUs are seeded by the OLT and thus do not require a laser source. We successfully demonstrated uplink transmission of two ONUs with up to 10 Gbit/s each over 75 km of feeder fiber. Both experiments (up- and downlink) have been submitted to the access and in-house communications meeting (ANIC). Further experiments will be performed for optimization and in-depth characterization of the network.

3.2.3 Task 3.3: Design and implementation of FPGA modules for the OLT and the ONUs [M12-M24]

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:

In the first part of this task the digital signal processing concept of the ACCORDANCE demonstrator was developed in detail. It includes the definition of a subcarrier map containing detailed information on the position of data subcarriers, pilot tones and unmodulated subcarriers within the available subcarriers at the OLT and the ONU. Further a frame format was defined consisting of a sequence of OFDM symbols including synchronization pattern and network control symbols and a concept for local and sampling oscillator synchronization at very high symbol rates was developed.

In the second part of this task FPGA modules for all OFDM processing related tasks were implemented. This includes modules like e.g. FFT, IFFT, CORDIC, NCO, PID controller, divider, correlator, equalizer, modulator and demodulator for various clock speeds and throughput.

Figure 14 and Figure 15 show the block diagrams for OLT transceiver and ONU transceiver respectively.

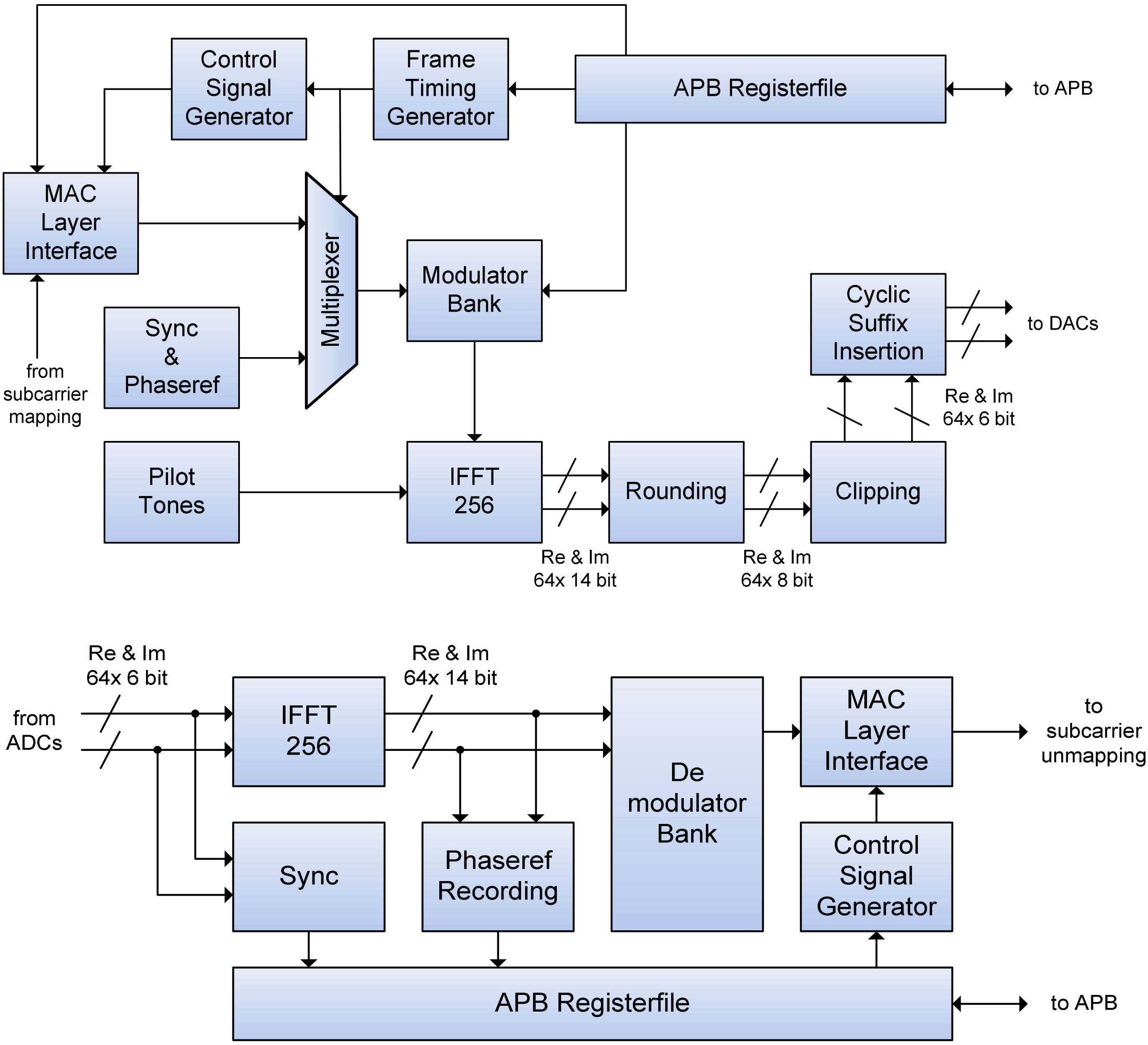


Figure 14 - OLT transceiver

Besides the implementation of the signal processing components also the subcarrier mapping and the OFDM symbol sequence of the demonstrator was defined in a way which is possible to be realized as a real digital signal processing system. Furthermore a concept on how to reliably carry control and payload data via the ACCORDANCE demonstrator was specified.

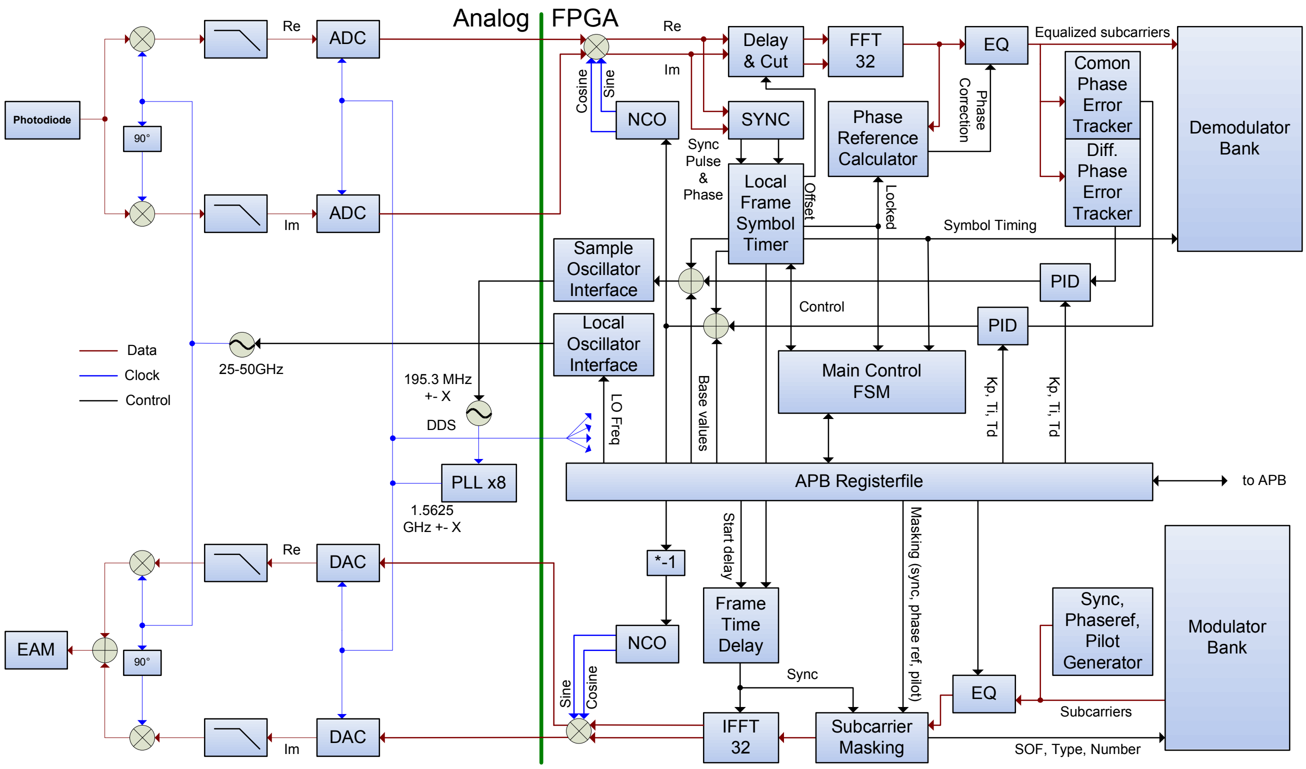


Figure 15 - ONU transceiver

The whole system was extensively simulated and optimized with Modelsim and a test bench reflecting the non ideal characteristics of channel and oscillators like noise, jitter and frequency offsets.

The upcoming work will focus on the integration of the OLT and ONU physical layers into the whole demonstrator system. Therefore the MAC layer has to be designed to fulfill the requirements of work package four and to interface smoothly to the optical transmitters and receivers. Also, additional to the simulations performed with Modelsim, real world experiments have to be done to verify the functionality of the system.

3.2.4 Task 3.4: Implementation of the OLT and the ONUs [M21-M30]

In the beginning of this task the FPGA printed circuit board (PCB) preparation has been initiated. All requirements with regard to power supply and high-speed design were specified. First interfacing steps of a test Virtex 6 FPGA, coming from the same chip family as the target Virtex 6, and the high-speed data converters (DAC and ADC) were performed.

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 / Y2	D4.2 - Definition of MAC protocols supporting FDM/OFDM operation (M14) D4.3 - Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE (M22) D4.4 - MAC layer requirements for the ACCORDANCE network (M18)	
Milestones / Y2	M4.1- First definitions of ACCORDANCE MAC protocols (M10)	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 2 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	30.7	22.6	-	-	-	-	5.3	5.3	-	-	33.0	25.7

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
-	-	5.0	4.8	-	-	***74.0***	***58.3***

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

- 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 if 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 has been disseminated through the timely submission of deliverable D4.4, providing an update to the requirements of the ACCORDANCE MAC, D4.2 that has demonstrated new protocol designs for OFDM-PONs and D4.3 providing the algorithms for efficient bandwidth allocation.

Critical parameters, influencing the ACCORDANCE MAC design, are updated in D4.4 with reference to the specifications for a passive and long reach Optical Distribution Network, efficient synchronization mechanisms and centralization of base station equipment. D4.4 concludes on the specifications of the MAC models, developed in OPNET, used for the evaluation of the propagation of data over ACCORDANCE. These parameters define the network reach, the subcarrier and ONU numbers, the Upstream/Downstream bitrates and modulation schemes and the explored bandwidth allocation schemes.

In parallel D4.4 provided the guidelines for the design of a MAC protocol in support OFDMA-PONs. It described the requirements of such a protocol, the necessary operations that need to be performed by the MAC layer as well as the specifications for the protocol fields to be used. In addition, suggestions are provided on how to upgrade the existing 10G-EPON and upcoming XG-PON standards to include the functionalities of ACCORDANCE.

In succession, D4.3 reported a series of algorithms distinguishing between EPON and GPON-based scheduling, allocation only in the subcarrier domain or jointly in subcarrier and time domains, promoting hybrid OFDMA/TDMA schemes and finally on the mechanism used by the OLT to allocate bandwidth to ONUs.

3.3.1 Task 4.1: MAC layer requirements for the ACCORDANCE network [M1-M18]

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 associates also with the activities of Objective 1 being the definition of a novel Access Network architecture achieving convergence among heterogeneous technologies (optical, wireless, copper). T4.1 receives inputs particularly from T2.1 and as a result makes use of specific outcomes of objective 1 to initially define and subsequently update the MAC requirements for dynamic bandwidth allocation and end-to-end service delivery over the ACCORDANCE architecture.. Deliverable D4.4 has therefore served the purpose of bringing up to date the requirements originally reported during Y1 in D4.1. D4.4 coincided with the completion of T4.1

Significant results:

The ACCORDANCE network supports diverse connectivity terminations. Apart from legacy PONs and xDSL, it portrays the convergence of OFDMA in a wireline fashion as well as in combination with wireless networking. With the scope of providing recommendations for original protocols and algorithms, applicable to OFDMA-PONs, an update of the network parameters influencing the MAC design and bandwidth allocation schemes have been presented. These distinguish between network dimensioning parameters (network reach, subcarriers and ONUs number, the Upstream/Downstream Bitrates), the network architectural options, (AWG in L1 RN or an all power-splitting network), the US/DS modulation schemes for increased network granularity and the bandwidth allocation criteria. The first two criteria have resulted in the requirement of, 20km and 40 km ACCORDANCE OPNET processing models with 64, 128, and up to 256 ONUs and 40 Gbps and/or 100 Gbps aggregate bit rates defining the propagation delay figures of the simulator, the processing delay and overall network load.

A table summarising the details of the network scenarios, implemented in order to evaluate the ACCORDANCE MAC is shown below.

Parameters	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total network capacity	40 Gbps	40 Gbps	100 Gbps
Distance between OLT and ONU	40 Km	20 Km	20 Km
Total subcarriers	256	256	256
Total ONUs (SLA0 : SLA1 : SLA 2)	64	128	256
	4 : 20 : 40	8 : 40 : 80	16 : 80 : 160
Data rate per subcarrier	156.25 Mbps	156.25 Mbps	156.25 Mbps
ONU offered load 1.0	625 Mbps (40 Gpbs/64)	312.5 Mbps (40 Gpbs/128)	390.625 Mbps (100 Gpbs/256)

Table 3 - Network scenarios implemented in OPNET for the ACCORDANCDE MAC evaluation

The intended protocol functionalities of subcarrier adaptive modulation and hybrid OFDMA/TDMA operation, specified as the state-of-the-art concept in ACCORDANCE for augmented network granularity, are envisaged to demonstrate dynamic bandwidth allocation. As a result, the requirements of the new frame control fields have been defined, allowing for the operation of four distinctive protocol modes. Ranging from fixed and dynamic pure OFDMA to dynamic and rectangular hybrid

OFDMA/TDMA, the devised protocols could mutually exhibit transparent pipes for distinctive ONUs (e.g. wireless BSs), statistical multiplexing, increased granularity and 2-dimensional allocation. To achieve the set objectives in a converged optical/wireless network, the CO must be able to also acquire instant bandwidth requirements from mobile users and adhere to the performance evaluation figures, e.g. latency of the converged wireless standards. In addition, efficient bandwidth utilization with SLA and CoS differentiation, have been concluded critical in ACCORDANCE for practical network implementation. LTE latency requirements, the cross-reference between its QoS features and that of EPON and GPON as well as fundamental requirements for the optical/wireless MAC have been exploited as a result.

3.3.2 Task 4.2: Definition of MAC protocols supporting FDM/OFDM operation [M6-M25]

T4.2 is widely associated with the activities of Objective 3, i.e. the introduction of flexible bandwidth allocation concepts using dynamic OFDM sub-carrier assignment but also addresses some concepts of Objectives 4 and 5 with respect to the provision of smooth migration from 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. The work in this task was initiated during Y1 and the main outcomes were reported in Deliverable D4.2 which was submitted in M14. Further work performed in the course of T4.2 was reported in D4.5, submitted in M26.

Significant results:

The purpose of Task 4.2 has been the definition of a MAC protocol able to leverage on the innovative functionalities of an OFDMA-PON like ACCORDANCE. In that respect, the following process was followed: First, the principles of operation for the MAC layer of existing TDMA-PONs, i.e. (10G)-EPON and (X)GPON were studied in depth and reported in D4.2. The rationale was that it was deemed unnecessary to reinvent a full protocol stack for ACCORDANCE. On the contrary, a wide range of functionalities were assumed to operate similarly to the aforementioned protocols, and care was taken to identify the specific messages and control operations that required a novel approach due to the underlying OFDMA technology. Having this in mind, we proceeded in addressing additional control protocol fields as well as new control messages and processes required in the ACCORDANCE MAC in terms of:

- *ONU Registration*: The ONU communicates to the OLT critical information regarding its capabilities, e.g. optical transmitter/receiver tuning time, list of supported wavelengths and supported modulation formats [needed for the Adaptive Subcarrier Modulation (ASM) – see below], maximum number of supported subcarriers per ONU (due to cost limitations each ONU is not able to process the full subcarrier range in its operating wavelength). In order to complete the ONU activation process, the OLT conveys to the ONU the following information: selected modulation format, (for determining the value of this field, the ASM process needs to run first), transmitter wavelength, (the identifier for the chosen upstream wavelength to be used by the ONU within its Tx operating waveband) and receiver wavelength.
- *Bandwidth assignment*: Bandwidth assignment in ACCORDANCE operates on the inter-segment and the intra-segment level. In the first case, spectral segments (subcarrier groups) must be provisioned to different services (either in a fixed or dynamic manner). Then, based on the current inter-segment assignment, the exact subcarriers allocated to each ONU within each segment are determined by the individual intra-segment processes associated with each service. The inter-segment process exchanges control information continuously with the individual intra-segment ones in order to update them on their subcarrier operation range. Intra-segment bandwidth assignment is more dynamic and more challenging from a MAC point of view:

  Upstream

  The intra-segment DBA in ACCORDANCE performs the mapping of each ONU to a two-dimensional (subcarriers, time) structure. The following rules are proposed: (1) the assigned subcarriers are adjacent and (2) start/finish times are equal in all of them. This largely simplifies

the MAC protocol since only two extra fields (*Low_SC*, *High_SC* for the assigned low/high subcarrier respectively - note that the subcarrier indexing refers to the operation wavelength of the specific ONU) are required per grant in the 10G-EPON MPCP GATE messages, apart from the start and end transmission timeslots. A Subcarrier Allocation identifier (SCA) field is used by the OLT in order to specify the bandwidth assignment mode used for allocating bandwidth to the specific ONU, which for example could be the hybrid OFDMA/TDMA way of operation described above, or even fixed subcarrier allocation. More details can be found in D4.2.

<u>*Downstream*</u>

New control messaging is introduced that allows the OLT to notify ONUs regarding the downstream subcarriers they should be expecting traffic at. It is obvious that this was not needed in TDMA-PONs, since all ONUs received and processed the common downstream wavelength. In contrast, in ACCORDANCE only a limited amount of downstream subcarriers is processed by each ONU in order to reduce cost and complexity of ONU receivers. Therefore, it is mandatory to introduce a new message type that conveys the exact subcarriers (*Low_SC*, *High_SC*) that are destined for each ONU in the upcoming downstream transmission so that they can configure their Rx appropriately.

- *Adaptive Subcarrier Modulation (ASM)*: In ACCORDANCE, modulation takes places using the *m*-QAM format, where the exact bitrate is dependent on the choice of *m*. ACCORDANCE uses a different modulation format per ONU, depending on their transmission performance and aiming at cross-layer optimization benefits. Therefore the MAC has to take into account different bitrates per subcarrier during DBA. The same modulation format is considered across all subcarriers assigned to each ONU to ensure that ONU complexity is kept at low levels. The choice of modulation format for an ONU takes place only during registration, since (a) link transmission properties are normally not expected to change that much so as to justify lowering the QAM depth during normal operation and (b) ASM involves a considerable amount of control message exchanges (testing a different modulation format each time until the calculated BER is below a predefined threshold), therefore, a periodic repetition of the negotiations would unnecessarily hinder the DBA process.

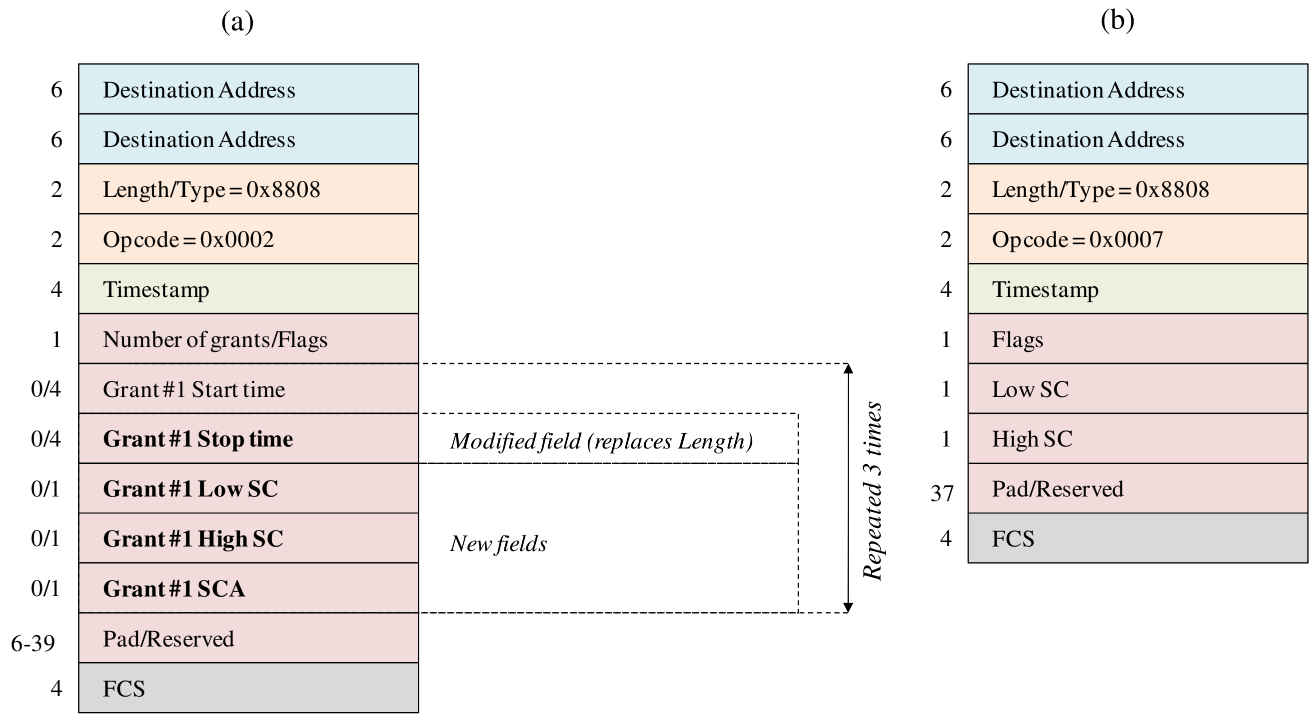


Figure 16: (a) The proposed modifications to the EPON GATE MPCPDU and (b) the newly proposed RX_CONFIG MPCPDU for downstream subcarrier assignment.

Additionally, in support of legacy protocols and their updates, the necessary modifications in order to upgrade the 10G-EPON and XG-PON standards for accommodating the ACCORDANCE OFDMA-PON functionalities have also been analyzed in D4.2. As an example, Figure 16(a) depicts how the EPON GATE MPCPDU can be modified to host three grants, each including both time and subcarrier domain information for achieving the two-dimensional assignment dictated by ACCORDANCE. Similar guidelines (i.e. modifications to existing messages) have been provided for all ACCORDANCE MAC functions listed above. Moreover, an additional downstream control message [called RX_CONFIG and shown in Figure 16(b)] has been foreseen to realize the downstream subcarrier allocation. Note that this could be adjusted, if needed, to include timeslot assignment information as well by using some of the reserved bytes.

Work in T4.2 after the publication continued towards elaborating on how the exact ACCORDANCE FPGA system implementation performed in WP3 can be leveraged in order to experimentally validate the potential of the novel MAC features proposed here.

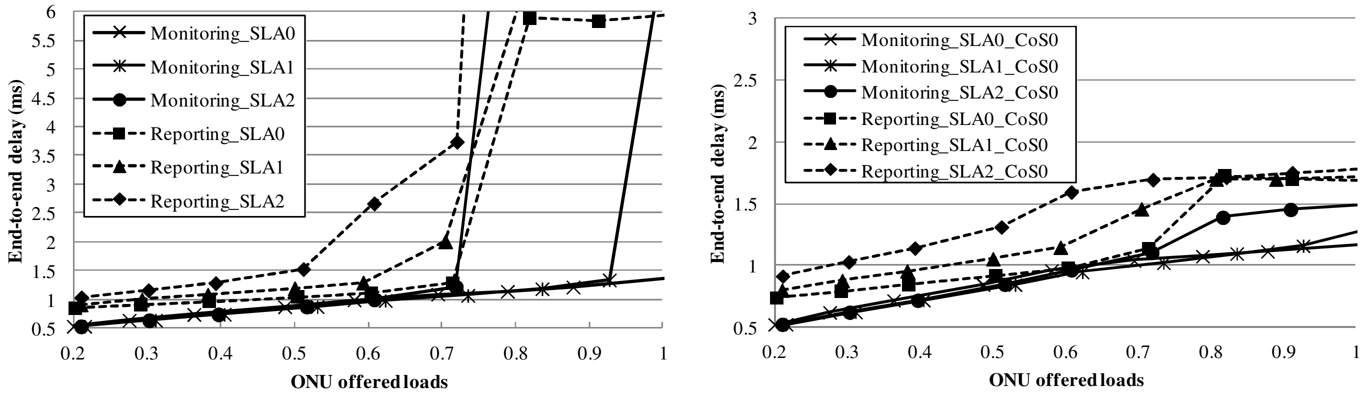
3.3.3 Task 4.3: Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE [M10-M30]

Objective 3 of the ACCORDANCE project is achieved directly by the development of algorithms that can provide the necessary dynamicity to demonstrate service level agreement and class of service differentiation for resourceful bandwidth allocation and condensed packet delay. Deliverable D4.3 has reported on the algorithms implemented and evaluated for this purpose. The ACCORDANCE network architecture also allows through the use of subcarriers the overlay of FDM bands that support multiple providers (inter-segment bandwidth assignment). This property of Objective 5 will be studied at the MAC layer level but it will be the outcome of D4.6, the update of D4.3, due to be submitted in alignment with the completion of T4.3.

Significant results:

D4.3 investigates the development and performance evaluation of new algorithms, exhibiting SLA and CoS differentiation over 20, 40 and 100 km reach, and 32, 64, 128 and 256-split OFDMA-PONs. The DSCA algorithm was initially explored to allow bandwidth distribution in the frequency domain, providing simple MAC protocols and high throughput utilization. Hybrid OFDMA/TDMA algorithms have been consequently examined to provide increased granularity. The evaluation of these algorithms has been conducted by employing monitoring and reporting in the OLT to distribute bandwidth to ONUs. The GPON-based SDSCA and EPON-based RDSCA algorithms have been reported as a result.

Performance measurements based on 32 ONUs and 40 km network reach, have displayed a significant, 1.95 Gbps, increase in channel throughput over extended network loads, with an improvement also in packet delay and packet loss rate, using the monitoring SDSCA algorithm. Figure 17(a) exhibits the end-to-end packet delay for all three SLAs versus ONU offered load for the monitoring and reporting SDSCA algorithms, defining the proportion between each ONU loading and the simulated ONU capacity. It can be observed that the threshold ONU loadings to achieve low transmission delay (below 1.5ms) are 0.50 and 0.70 respectively. The monitoring algorithm demonstrates significantly lower mean packet delay, exhibiting almost five and three times reduction at around 80% and 70% ONU loading for SLA0 and SLA2, respectively, and approximately seven times reduction at around 90% loading for SLA1. Significantly, before the packet delay reaches the 3 ms limitation for time-sensitive traffic, the offered load for SLA2 ONUs has been extended from 187.5 Mbps to 218.75 Mbps. The additional, 31.25 Mbps bandwidth can support supplementary multimedia services, such as online gaming, education-on-demand, and video conferencing.



(a) (b)

Figure 17: (a) End-to-end packet delay for the monitoring and reporting SDSCA algorithms with SLA and (b) SDSCA algorithm end-to-end packet delay for CoS0.

In assigning the network bandwidth in monitoring, SDSCA processes the following steps.

<u>*STEP 1*</u>: By the end of each window, the OLT calculates the average time slots used per ONU during the preceded monitoring window time.

<u>*STEP 2*</u>: As a result ONUs are partitioned into two groups; the *overperforming* and *underperforming* ONUs:

- *overperforming* group: *Pre_TS = Used_TS*.
- *underperforming group: Pre_TS < Used_TS.*

<u>*STEP 3*</u> (*underperforming* group from *STEP 2*): The OLT compares *Used_TS* with *SLA_TS* using different reference time slots to distinguish SLA grades. The following cases are considered:

- *If Used_TS is smaller than or equal to SLA_TS, then the OLT defines Assigned_TS based on the Used_TS, subtracts Used_TS from SLA_TS and assigns the difference to the group of "remaining time slots".*
- *If Used_TS is greater than SLA_TS, then the OLT defines Assigned_TS equal to SLA_TS because it is not aware at this stage if there are "remaining time slots".*

<u>*STEP 4*</u> (*overperforming* group from STEP 2): The OLT compares *Pre_TS* with *SLA_TS* without considering *Used_TS* since it has already determined in STEP2 that ONUs require more time slots. The additional time slot allocation is performed as follows:

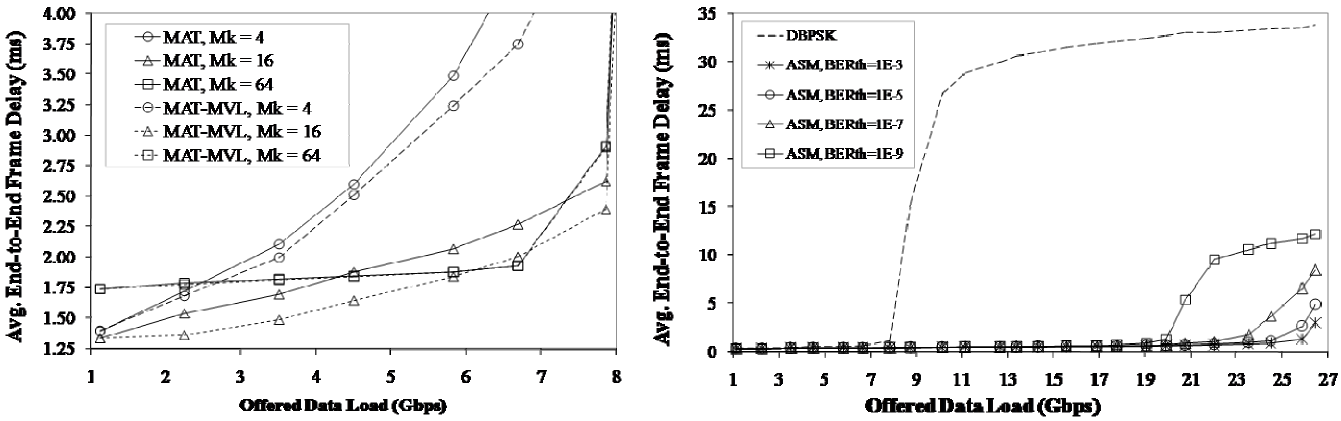
- *If Pre_TS is smaller than SLA_TS, then the OLT increments Pre_TS by 2 (high priority SLAs, Pre_TS + 2) or by 1 (middle and low priority SLAs, Pre_TS + 1) and allocates it to Assigned_TS. Assigned_TS should be less than or equal to SLA_TS. Then it subtracts Assigned_TS from SLA_TS and assigns this difference to the "remaining time slots". A note should be made that the Pre_TS increase specified here has been the outcome of optimizing the algorithm performance for different number of increments per SLA.*
- *If Pre_TS is greater than or equal to SLA_TS, then the OLT defines Assigned_TS equal to SLA_TS because it is unaware at this stage if "remaining time slots" are available.*

<u>*STEP 5*</u>: After completing STEPs 2, 3 and 4 the OLT gathers the "remaining time slots" from the first case of STEP 3 and STEP 4 and distributes them to requesting ONUs based on their SLA priority.

<u>*STEP 6*</u>: Following STEP 5 if there are "remaining time slots" the OLT assigns them to ONUs based on SLA priority.

Considering CoS differentiation in ONUs, low delay transmission is achieved for CoS_0 time-sensitive traffic, in support of QoS for VoD and/or UHDTV services under any network offered load. Figure 17(b) exhibits CoS_0 traffic performance at all three SLAs with increasing ONU offered load for both the monitoring and reporting algorithms. A reduction of 1.5 times is observed at around 70% of the ONU offered load, allowing the monitoring algorithm to administrate congestion in the backbone network. D4.3 includes further results that show 3 and 10 times reduction in packet delay for CoS1 and CoS2 traffic respectively, demonstrating the advancement of the monitoring SDSCA in managing the network capacity to support increased volume multimedia services. Longer reach, increased split, networks have also been evaluated following the proposed network scenarios with ONU numbers reaching up to 256 and network spans even beyond 40 km, to 100 km. The long reach SDSCA algorithm was shown to utilize efficiently the prolonged idle periods of the transmission links, demonstrating high throughput and low packet-delay figures.

Regarding the RDSCA scheme, developed for ACCORDANCE based on EPON scheduling, the MAT algorithm assigns upstream bandwidth in rectangles trying to minimize the average delay of each reservation. The MAT-MVL variant of MAT manages to slightly increase utilization and improve delay performance however at the cost of increased complexity (which is already considerable even in the case of MAT). In that respect, the proposed RSSP scheme was employed to significantly reduce the computational complexity of MAT by pruning the rectangle search space. The comparison between MAT and MAT-MVL for different maximum number of subcarriers per ONU is shown in Figure 18(a). Finally, the combined use of MAT with ASM was shown to greatly boost delay performance (even with $\mathrm{BER_{th}} = 10^{-9}$, but especially for higher $\mathrm{BER_{th}}$ values). In particular, for OLT-ONU distances between $0 - 50\mathrm{km}$ the offered load for $\mathrm{BER_{th}} = 10^{-3}$ can reach up to almost 13Gbps while keeping average delay at reasonable levels (i.e. 5ms), as opposed to around 8Gbps in the DBPSK case. ASM performance in shorter-reach networks [OLT-ONU distances between $0 - 25\mathrm{km}$, Figure 18(b)] shows even more significant performance benefits, since more ONUs have the opportunity to select higher-order modulation formats.



(a) (b)

Figure 18: Delay performance comparison (a) between the MAT and MAT-MVL algorithms (distances 0-100km) and (b) for ASM with different BER thresholds (distances 0-25km).

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 / Y2	D5.1 - First concepts for combined optical and wireless access (M14) D5.2 - Requirements of wireless/wireline systems and their impact on the optical network (M18) D5.3 - Combined optical and wireless/wireline access based on existing requirements (M21) D5.4 - Mapping of radio signals to optical resources and distribution of mapping within the network (M23)	
Milestones / Y2	M5.2 - Definition of the combined optical and wireless PHY layer (M21) M5.3 - First definition of the centralized wireless MAC and initial results on radio-optical mapping (M21)	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 2 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	5.0	3.0	40.0	33.0	1.1	1.0	-	-	8.9	8.9	24.0	21.1

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
-	-	-	-	-	-	***77.0***	***67.1***

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

- 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.

During the second year a converged architecture (for wireless and wireline services) has been developed and analysed for both being able to harvest on the gains coupled with the convergence of wireline and wireless services at the same time still being able to deliver wireless services with high performance. To achieve the latter some trade-offs had to be made with respect to the former. To even more harvest on the gains of a converged network future evolutions of LTE/LTEadvanced are to be tailored taking such a converged platform into account. The following sections describing the results of the single tasks go into more detail with respect to this architecture and the trade-offs made. Additionally the aspects of LTE/LTEadvanced constraining the convergence the most are given - a valuable input for future standardization activities.

3.4.1 Task 5.1: First concepts for combined optical and wireless access [M1-M18]

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

Significant results:
The main aim of this task was to identify various possible options for the optical/wireless convergence in the ACCORDANCE as well as to define transmission formats capable of successfully serving the connected wireless/wireline networks. Some of the options were already presented in the first year report however in the second year of the project they were further evaluated, in terms of their requirements and performance, in order to provide an optimum solution for the ACCORDANCE network.

Deliverables directly associated with this task (i.e. D5.1 and D5.3) provided detailed analysis of the ACCORDANCE optical/wireless and wireline network architectures and elements, including its extended features and technological challenges. To that extent, various interfacing points in a typical LTE baseband transmission chain (described in figures below) that could be connected to the ACCORDANCE PON were evaluated. These are: IP backhauling (a), split eNB ((b)-(e)), CPRI (f) and RoF (g).

In addition to the above, the comparative analysis between WiMAX (worldwide interoperability for microwave access) and LTE (long term evolution) suggested LTE as the preferred technology to be supported within the ACCORDANCE project, as it is expected to have the biggest commercial impact and impose the stringiest requirements on real time parameters. This technology is also used as a baseline to extract service requirements (mainly in Task 5.2) for base stations front- and backhauling.

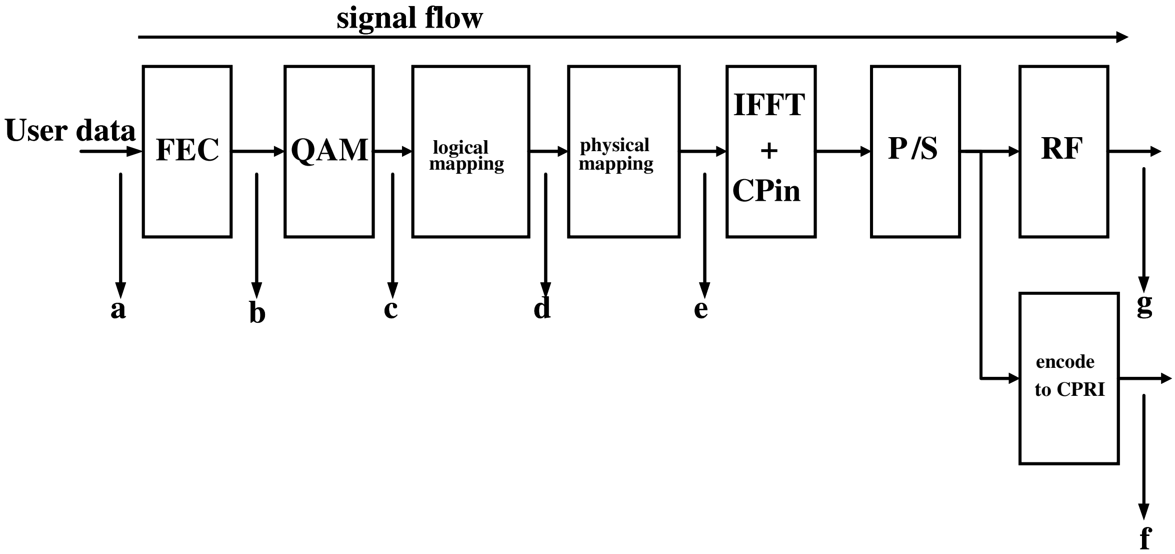


Figure 19: Baseband processing chain – downlink.

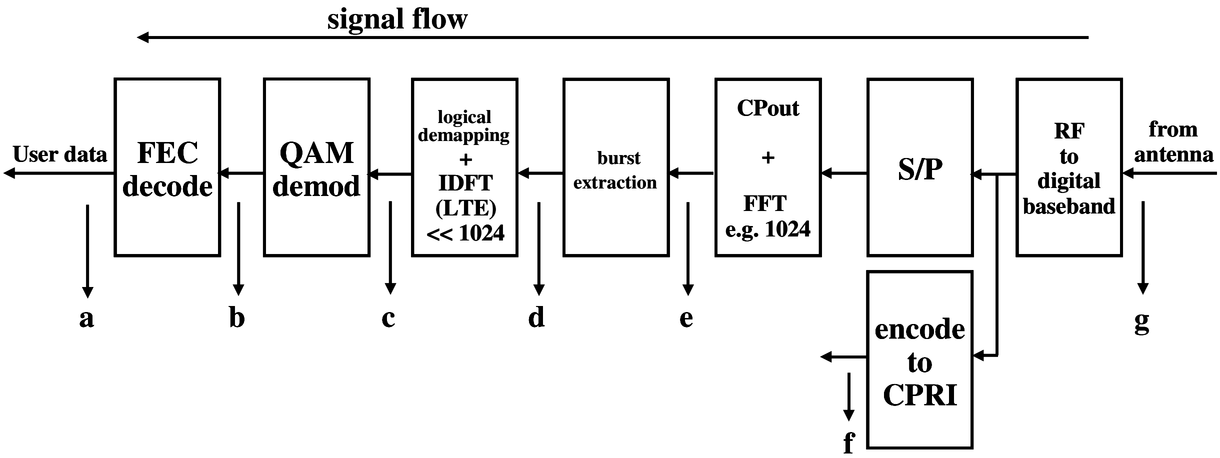


Figure 20: Baseband processing chain – uplink.

Each interfacing point has various implications to the operation of the system and the architectures both within the CO and eNB. For instance, in terms of bandwidth requirements, for digital fronthauling it ranges from several hundreds of Mbit/s (soft-bit fronthauling) up to several Gbit/s (CPRI fronthauling) for the given scenario (10 MHz, 4 Rx antennas). The analog (RoF) requires minimum bandwidth (around 300 MHz per site) but it is more susceptible to errors. This is further analysed in Task 5.2 as described in the next sub-section.

From the obtained analyses it was concluded that there is not a unique solution that would provide all the desired benefits for all deployment scenarios. Therefore, the indentified preferred choices for different scenarios are described below:

Rural (low user density, high inter-site distances):

- Decentralised architecture with IP backhauling. The sites are equipped with complete eNBs (full PHY, MAC and RLC processing). The ACCORDANCE network is the tunnel between the eNB and the serving gateway transporting IP packets. Share of transmission resources with wireline services (FTTH) possible. Transport of wireless data can be included into the optical OFDM.

Urban (high and heterogenous user density, low inter-site distances):

- MAC/RLC centralisation and partial baseband centralisation ('burst' fronthauling in UL, 'soft-bit' fronthauling in downlink) at the MCO, if transmission resources are scarce between MCO and site. MCO connected to SCO via IP transported within OFDM/OFDMA.
- MAC/RLC centralisation and full baseband centralisation ('CPRI' fronthauling), if transmission resources are abundant (between MCO and site), transport via WDM. MCO connected to SCO via IP transported within OFDM/OFDMA.
- MAC/RLC centralisation and baseband centralisation in the form of radio over fibre (RoF) where, similarly to above, transport of mobile fronthauling analog data must be separated from wireline services (FTTH). This is mainly because analog carrier insertion in the optical OFDM spectrum not feasible.

3.4.2 Task 5.2: Requirements of wireless/wireline systems and their impact on the optical network [M7-M21]

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

Significant results:
After having proposed various options to include wireless back/fronthauling into the ACCORDANCE network in T5.1, they have to be confronted with the requirements the wireless subsystem has for delivering wireless services with high performance. Therefore, we have thoroughly analyzed the protocols and mechanisms of today's dominating wireless and wireline access solutions – namely LTE and LTE advanced and xDSL, respectively. The impact to the feeding network is diverse:

- Transport and processing latency:
  The overall latency including the processing and transport (round-trip) connected to the feeder links and the processing connected to the transport of wireless services must not exceed 3 ms to meet the timing of the UL HARQ process. This is the most stringent timing requirement connected with the definitions of LTE and LTE advanced:

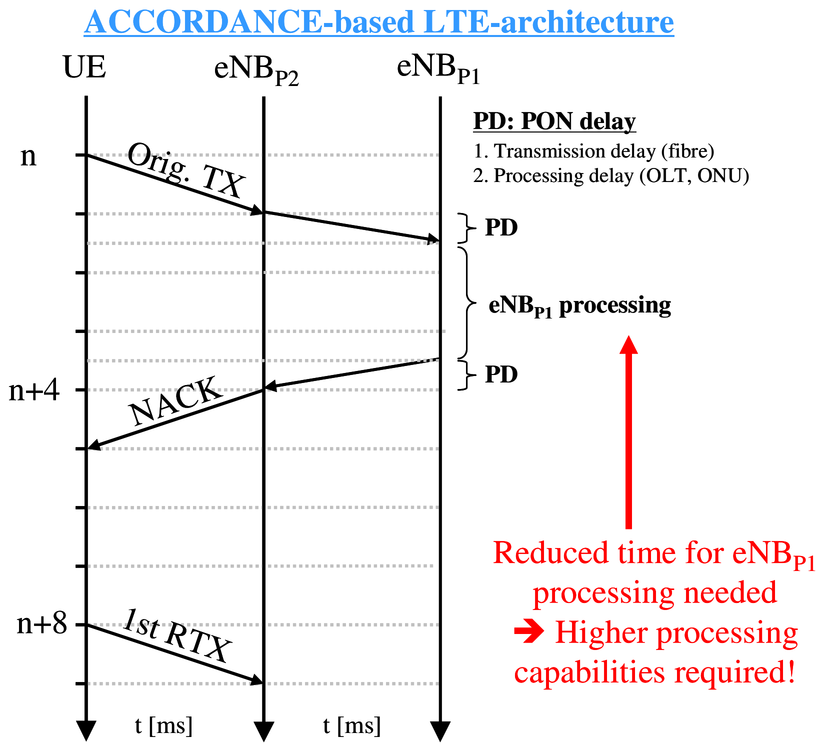


Figure 21: Timing of UL HARQ, impact of site aggregation.

- Another impact to be taken into account is channel ageing. The higher the grade of aggregation (i.e. the more notes are consolidated at a single central office) the longer the average feeding link gets and thus the longer measurements performed at layer 1 have to travel before being used by the higher layers, e.g. for frequency selective scheduling. Unfortunately, the wireless channel is time variant and thus those measurements may become outdated (i.e. the correlation between measurement and actual channel shrinks):

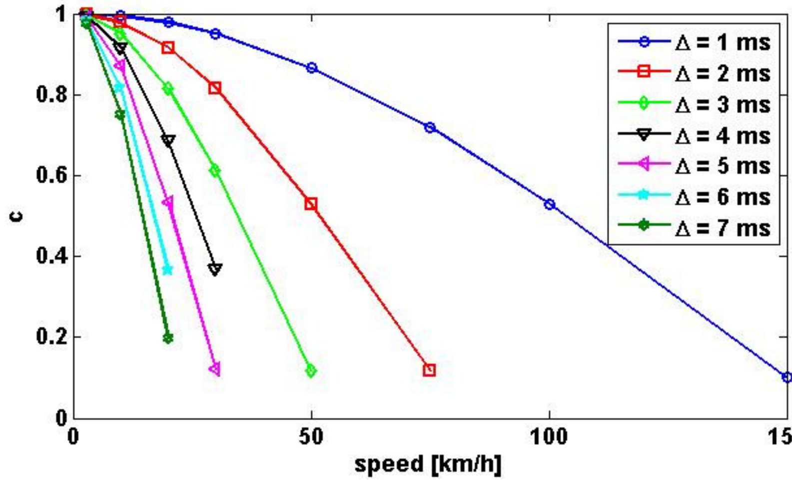


Figure 22: Channel ageing.

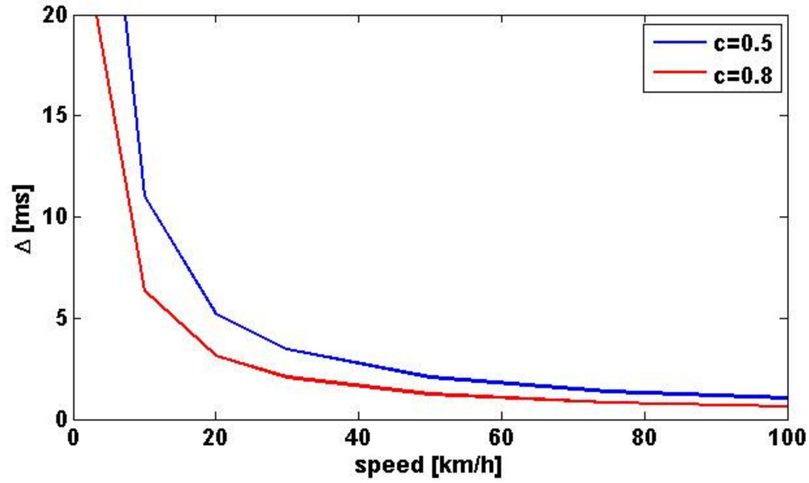


Figure 23: Channel ageing (picked correlation coefficients).

The required resolutions for feeding the signals without introducing without leading to significant quantization noise have beed assessed via comprehensive simulation runs:

	QPSK	16 QAM	64 QAM
soft-bit fronthauling	5	5	5
burst fronthauling	5	6	6
frame fronthauling	7	7	7
CPRI fronthauling	15	15	15

Table 4 - Least required resolutions for the diverse digital fronthauling options

The resulting rates required on the fronthauling network are (peak, w/o overhead):

	10% load	30% load	50% load	100% load
R_b	19.6	54.7	91.2	165.9
R_d	31.1	87.6	146.0	265.4
R_e	470.4			
R_f	2457.6			

Table 5 - Required rates on the fronthauling network (UL, peak, for various loads, from top to bottom: soft-bit fronthauling, burst fronthauling, frame fronthauling, CPRI fronthauling)

	10% load	30% load	50% load	100% load
R_b	4.5	12.3	20.6	37.7
R_e	470.4			
R_f	2457.6			

Table 6 - Required rates on the fronthauling network (DL ,peak, for various loads, from top to bottom: soft-bit fronthauling, frame fronthauling, CPRI fronthauling)

- For analog feeding (radio over fibre) the key requirements have been assessed (such as ACLR, EVM per modulation order, properties of the analog and digital devices).
- For backhauling DSL services the physical layer requirements for the transport via fibre have been assessed (such as the threshold for the opical power and the required bandwidth).
- Furthermore in T5.2 architectures both for the central unit and the remote unit have been elaborated. Weighing the requirements and the addressable gains the most promising solution is:

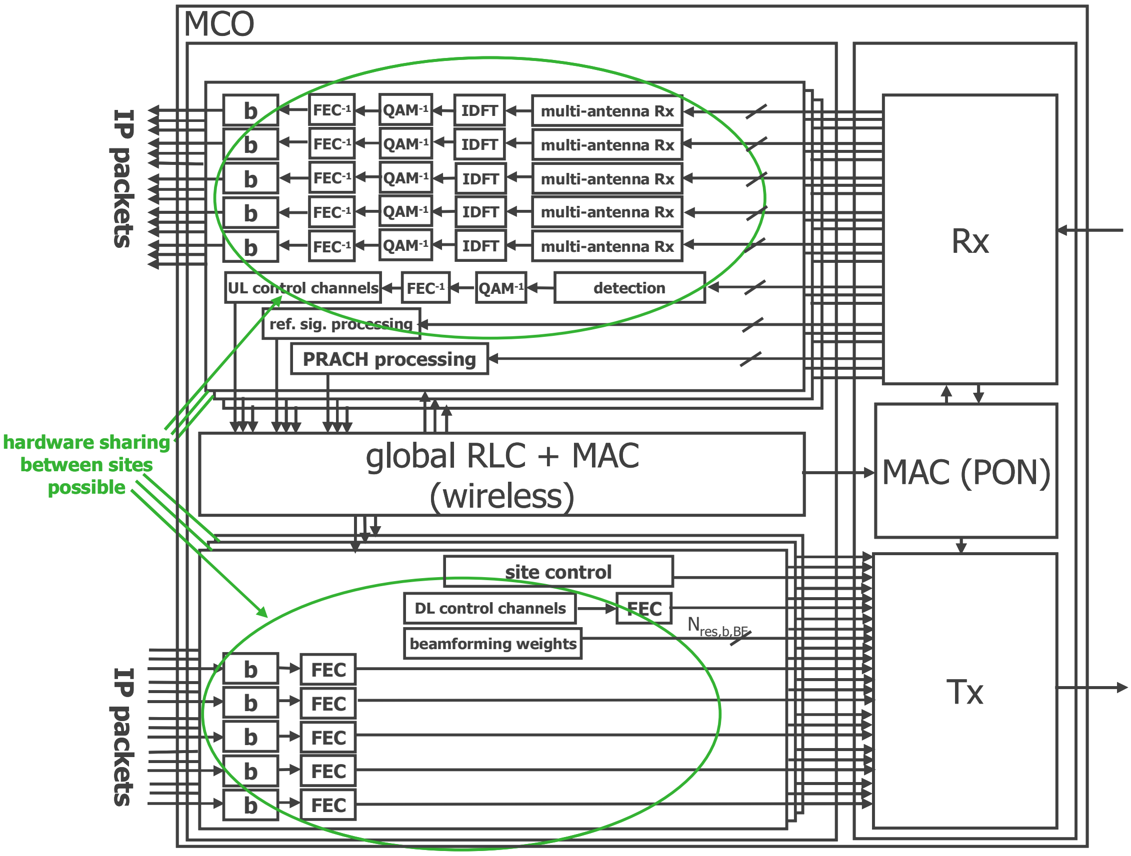


Figure 24: Architecture of the central office for wireless fronthauling.

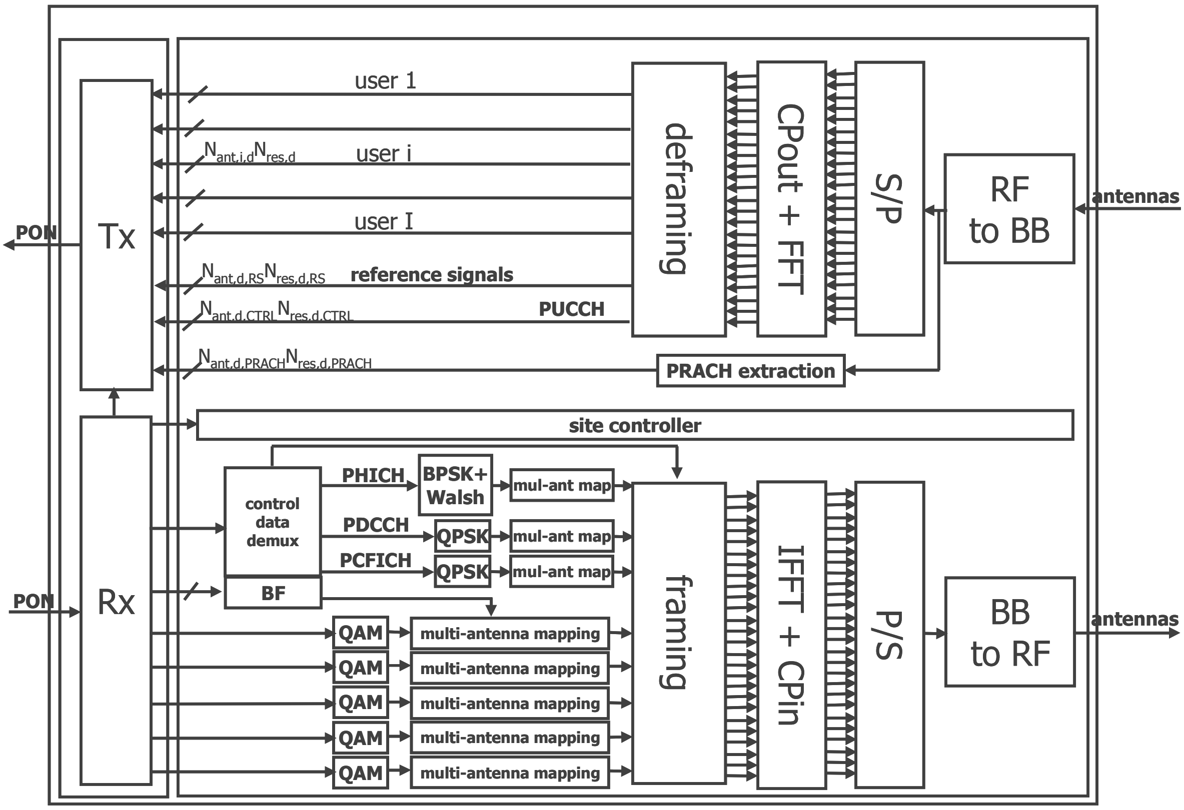


Figure 25 Architecture of the remote unit for wireless fronthauling.

3.4.3 Task 5.3: Mapping of radio signals to optical resources and distribution of mapping within the network [M13-M23]

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

Significant results:

This task deals with the aspects of mapping radio signals to optical resources, to satisfy the stringent QoS requirements of both the wireless and optical networks in the converged ACCORDANCE topology. The architectural options considered for the optical/wireless convergence have been extensively described in Task 5.1 and are used in this task for the performance evaluation. Among them, the centralised options include the Common Public Radio Interface (CPRI) and analog Radio-over-Fibre (RoF). Since they are fully transparent to the optical MAC, no modifications are required to the individual layer-2 protocols. This argument is augmented further by the fact that these solutions wave any need for buffering at either the central office or radio base stations proclaiming full independence to the ACCORDANCE MAC. On the contrary, the split-eNB architecture, distinguishing between its various implementation scenarios, and significantly the IP backhauling option, require the account of certain properties of the optical MAC.

- Split-eNB fronthauling:

For split-eNB the mapping mechanism of radio signals to optical resources requires efficient packetisation, resource allocation and signal generation. This mechanism should be able to provide priorities to wireless packets in order to avoid additional delays as well as the packets should meet the choosen periodicity. The packets to be transmitted via the PON must have several fields carrying the various signal components in addition to a header field for signalization.

An example of the packet formats for soft-bit fronthauling in downstream (DW) and upstream (UP) are given below:

Header	site control	DL control channels	beamforming weights	user data

Figure 26: Packet format (soft-bit fronthauling, DW)

Header	PRACH	UL control channels	SRS	user data

***SRS: Sounding Reference Signal**

Figure 27: Packet format (soft-bit fronthauling, UP)

Significantly, the optical mapping mechanism should be able to prioritize wireless packets with respect to wireline transmissions. Additionally the transmission of the packets to the single cells should be prioritized according to the respective fiber distance to be bridged. If this is not possible the overall latency is increased degrading the performance of the wireless data transmission.

Finally, the packet serialisation prior to transmission over the PON is another important aspect with split-eNB solutions since LTE uses multi-dimensional resource grid. The proposed solutions are evaluated in D5.4 that is directly associated with this task.

- IP backhauling:

With IP backhauling, in order to achieve a truly integrated scheduler, an effective mapping mechanism is required between the OFDMA PON priority queues and the QCI/bearer-based LTE IP flows. In particular, mapping has to identify which LTE IP flow should be stored in which OFDMA PON priority queue for the equivalent QoS.

To that extent, the focus of this task was to optimise the OFDMA MAC protocol and algorithms to accommodate wireless eNBs for QoS mapping. Various implementations of QoS mapping, namely non-mapping, 1:1 and group mapping have been developed. QCI latency and throughput performance figures have been drawn for increasing number of wireless users per cell, in consideration of both a rural and urban network scenario.

The figure below demonstrates an example of the group mapping of LTE bearers to ACCORDANCE ONU queues.

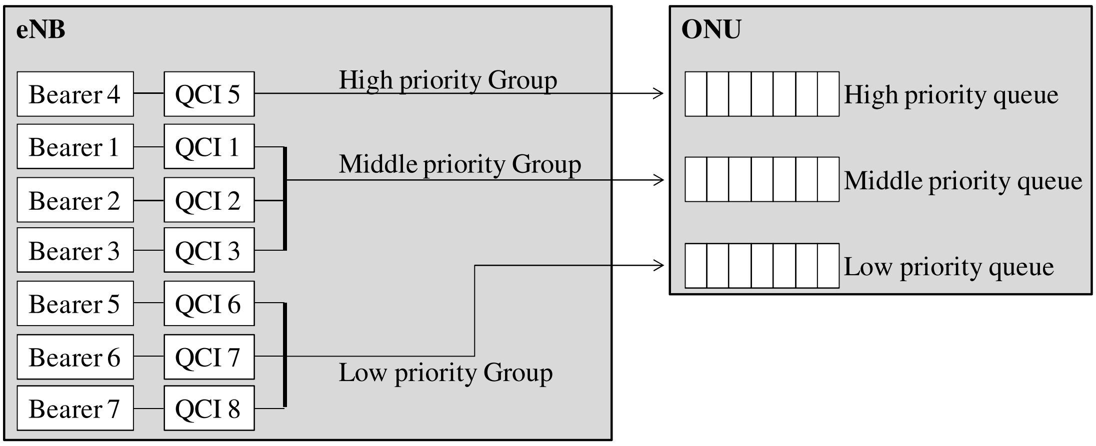


Figure 28: Group mapping between the eNB and ONU (IP backhauling)

Group mapping assumes the number of wireless queues is greater than that of the ONU queues. For LTE mapping to a GPON-like OFDMA-PON the above assumption is directly true. Even for mapping LTE queues, to the same number, EPON-based ACCORDANCE protocol queues, grouping of wireless services to individual optical queues might be proven beneficial with respect to the observed performance figures. The wireless groups are then mapped to their corresponding optical queues, as shown in Figure 28, in strict priority order.

Using developed architectures and parameters for the ACCORDANCE OFDMA-PON and standard LTE, various mapping mechanisms between an eNB and ONU were thus investigated in upstream (similar concepts would also apply for downstream). Therefore, one of the key outcomes with respect to group mapping (that is expected to be implemented in real deployments) is presented below following the application of the monitoring SDSCA MAC algorithm, developed in ACCORDANCE, for dynamic bandwidth allocation.

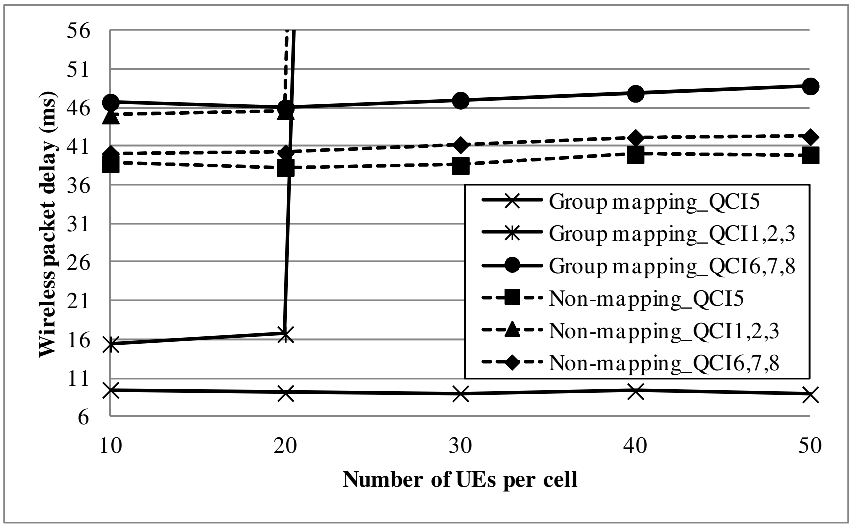


Figure 29: Packet delay for group mapping versus non-mapping (7 bearers forwarded to the low priority ONU queue) in the urban scenario

Finally, it was also concluded that in the rural scenario, QoS mapping between the eNB and ONU might not be necessary.

3.4.4 Task 5.4: Centralized wireless MAC: Definition of architectures making use of the centralized processing. Assessment of performance and complexity [M17-M28]

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

Significant results

When designing a converged network today's trends in wireless communications have to be taken into account to be future proof. Two major ones are site densification (wireless networks become much more heterogeneous in terms of cell sizes and power levels) and the direct consequence there from: the introduction of collaborative inter- and intra-cell schemes (collaborative multi-point, CoMP). Those trends are responding to the wireless data explosion expected to come in the next years. Thus, the key focus followed in this task has been (and will be) to inspect the solutions proposed in ACCORDANCE with respect to their capability to enable CoMP (the centralization aspect followed in ACCORDANCE helps to implement CoMP more efficiently) and the impact thereof.

The key CoMP scheme taken into account here is collaborative scheduling (CoSCH) in downlink. Here, the transmissions to the respective users take the positions of users in adjacent cells into account (in connection with beamforming this leads to interference-reduction). The following figure depicts the principles:

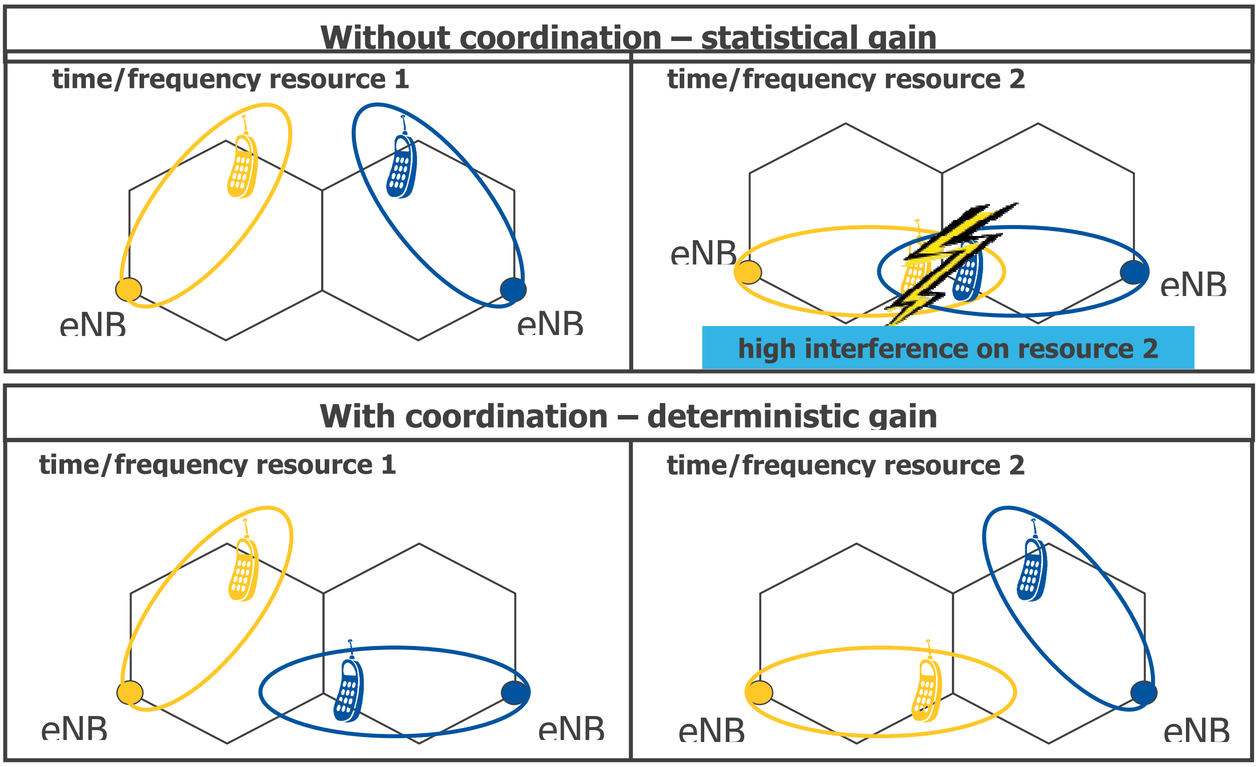


Figure 30: Principal of CoSCH (important to note: the UEs sharing a quadrant in the figure are scheduled onto the same time frequency resource).

Nowadays, CoSCH is realized iteratively in a distributive manner with the exchange of constraints between the respective basestations. The architecture proposed in ACCORDANCE enables a centralized scheme as the required data is available at a single point.

The cost drivers and capabilities for cost saving for the various options proposed have been investigated (e.g. the possibility for reducing the required per cell rate on the feeding network by exploiting statistical multiplexing and the potentiality for harvesting on pooling gains). For example the following figure depicts the amount of fronthauling required per cell if x cells share the available resources (UL, soft-bit fronthauling):

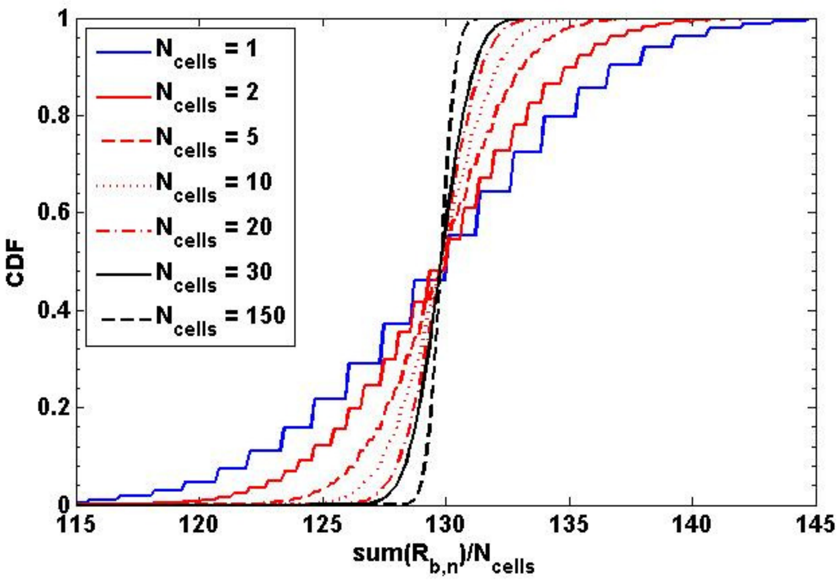


Figure 31: Required rate per cell when using a shared pool of resources on the fronthauling network.

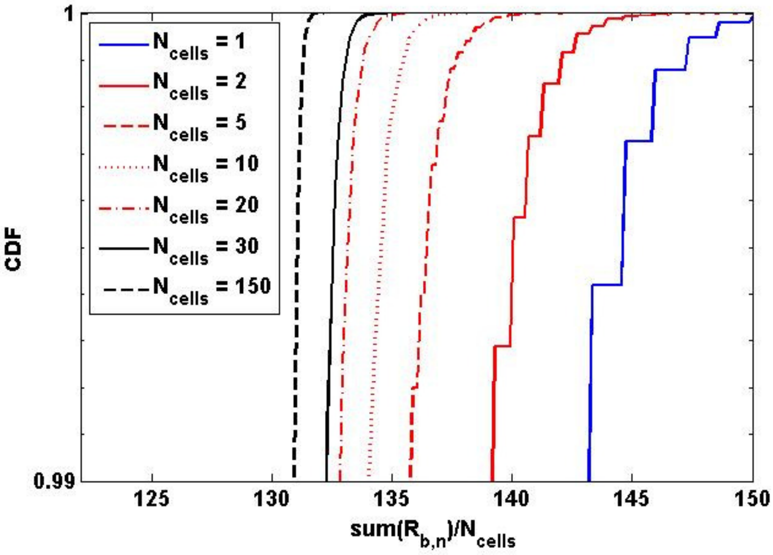


Figure 32 Required rate per cell when using a shared pool of resources on the fronthauling network (zoomed).

Obviously, the more cells share the pool of resources the less resources per cell are required (assuming a lower-than peak strategy, e.g. 99%, 99.9%, 99.99% guaranteed bit rate on the fronthauling network).

Channel ageing already has been introduced in T5.2 as a phenomenon. In T5.4 we go one step further and assess its impact to link quality and to system performance:

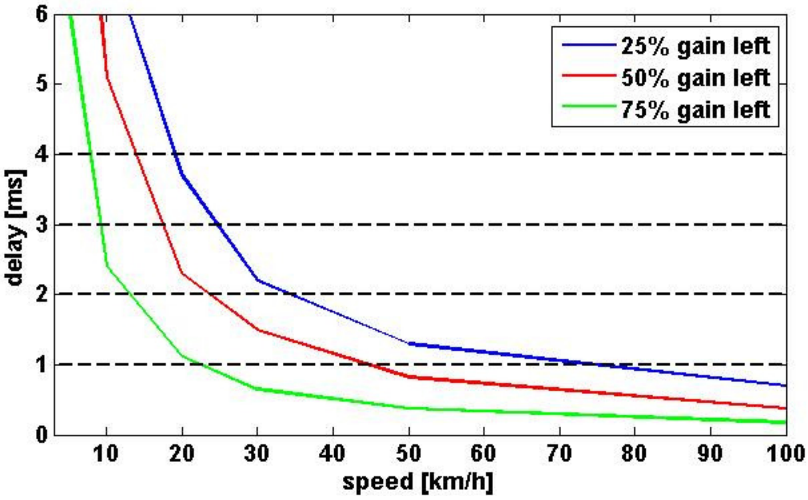


Figure 33: Upper bound of the overall delay acceptable for various UE speeds for maintaining at least [25%, 50%, 75%] gain through frequency selective scheduling.

delay	75 %	50 %	25 %
1 ms	23 km/h	45 km/h	75 km/h
2 ms	13 km/h	24 km/h	34 km/h
3 ms	9 km/h	17 km/h	24 km/h
4 ms	7.5 km/h	14 km/h	19 km/h

Table 7 - Upper bounds of the UE speeds up to which [75 %, 50 %, 25 %] frequency selective scheduling gain can achieved:

The figure and table indicate the amount of delay acceptable for various user speeds, while maintaining a given amount of gain through frequency selective scheduling.

Finally, investigations have been done to be able to decide on a smart grade of site aggregation (i.e. how big of an area is reasonably consolidated into a single central office). Key aspects here are the latency requirements assessed in T5.2 and the outcomes in T5.4 dealing with collaborative multi-point schemes.

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

Workpackage number	**6**	**Start date:** M18 **End date:** M36
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 / Y2	None	
Milestones / Y2	M6.1 - Testbed definition and availability check of required elements (M25)	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 2 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
-	-	8.0	1.5	11.0	2.6	-	-	-	-	11.0	3.2	2.0	0.2

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
14.0	1.0	9.0	2.0	-	-	***55.0***	***10.4***

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.

During the second year WP6 kicked-off and there was significant progress in defining the experimental testbeds, both wireless and wireline through interaction with other WPs. Major efforts were devoted towards definition of a converged test bed which could enable to evaluate concurrently the wireless and wireline part. The description of the testbeds and required elements was included in milestone M6.1 and work is progressing within the tasks that will finish in the following year.

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 nominally in June 2011.

Significant results:

Major progress has been achieved in defining the wireline and wireless testbeds, both with respect to their architectures and constituting elements and the tests to be performed. The key features to be demonstrated are:

- Compliance with Next-Generation Networks Access (NGA) expected performance (in terms of power budget, reach and BW per user)
- Dynamic Bandwidth Allocation (DBA)
- Convergence of mobile-fixed networks, i. e. routing of mobile backhaul through the network.

The general setups down to the single elements have been defined, their availability has been checked and where required orders have been made.

The wireline testbed heavily builts upon equipment designed and constructed within the project (the OLTs and ONUs). A sketch of the proposed setup follows:

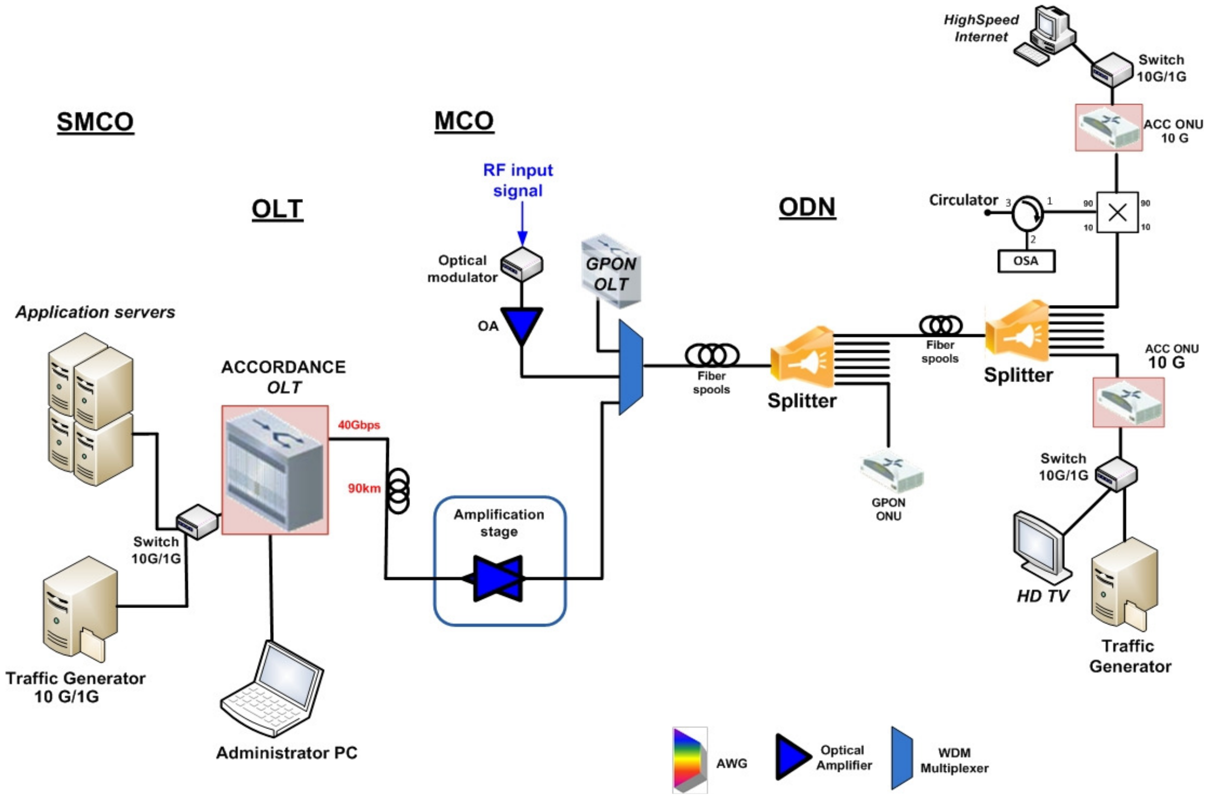


Figure 34 - Wireline experimental setup

As shown in Figure 34, the experimental setup comprises several sections. The first section is the Super Metro Central Office (SMCO) that includes the ACC OLT, a 10G/1G optical switch, a traffic generator and application servers. The second section is the Metro Central Office (MCO) composed of a GPON OLT, RF video overlay equipments, AWGs and optical amplifiers. The third section is the optical distribution network (ODN) containing the first and second splitting levels and fibre spools and finally, the last section includes two ACC ONUs, 90/10 splitters, an optical spectrum analyzer (OSA), GPON ONUs, different client devices (such as PCs and HD TVs) and other measurement and test equipment.

The tests to be run over the wireline testbed are divided in six groups: the first group is related to the management and operation tests, the second contains the OLT physical layer tests, the third group focuses in the ONU physical layer tests, the fourth group contains the long reach tests, the fifth group includes the operation service tests and the six group involves the coexistence tests.

The wireless testbed is concerned with the demonstration of wireless-wireline convergence concepts. Fom the different options for convergence studied within the project, a solution based on WDM and CPRI fronthauling has been adopted as the most feasible for practical implementation as outlined in D2.4. The setup, shown in Figure 35, is based on off-the-shelf equipment.

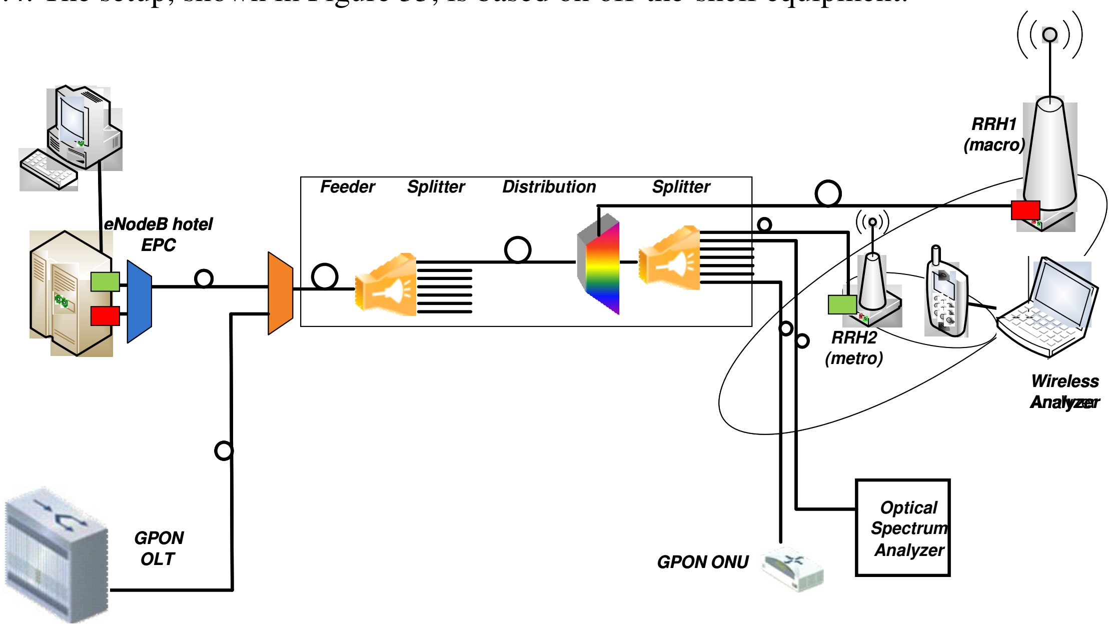


Figure 35: Wireless general setup

The depicted setup incorporates an eNodeB hotel consisting of 2 eNodeBs, e.g. feeding a single macro cell and a single metro cell. The respective interfaces of the eNBs towards the PON are optical CPRI interfaces. The interfacing (i.e. optical signal generation) between eNB and fibre is done by optical transceiver modules (SFPs, XFPs).

A cascade of two WDM filters combines the signals (here: 2 wireless CPRI links and GPON signals) to be transported via the PON for downlink and separates them for uplink. The optical network consists of a feeder link, two splitter stages, the distribution part, and another WDM filter. As outlined in D2.4 the signal for the macro station is extracted before the second splitter stage due to power budget reasons.

The interface between the remote radio heads (RRH1 and RRH2) and the PON are again SFPs./XFPs The task of the RRHs is to extract the complex baseband signal out of the CPRI stream and to perform the required signal processing to prepare the signals for radiation (and naturally vice versa in case of uplink transmissions).

The wireless analyzer equipped with a LTE terminal (USB-stick) finally terminates/starts the chain at the user side. A GPON ONU and an optical spectrum analyzer conclude the setup.

Tests dealing with link budget measurements and the overall performance of the optical links are to be performed. These tests aim to assess the achievable grade of local aggregation for the wireless subsystems. Once these basic tests dealing with the fronthauling network have been passed, the impact to the wireless subsystem will be assessed (both signal quality and quality of experience of the delivered wireless services are checked).

Additionally, an option for a converged testbed including both wireless and wireline components has been identified consisting in the setting up of a portable version of the wireless testbed (a subset thereof) to be sent from ALUD-Stuttgart to the TID labs in Madrid. Figure 36 shows the proposed scheme for a converged testbed.

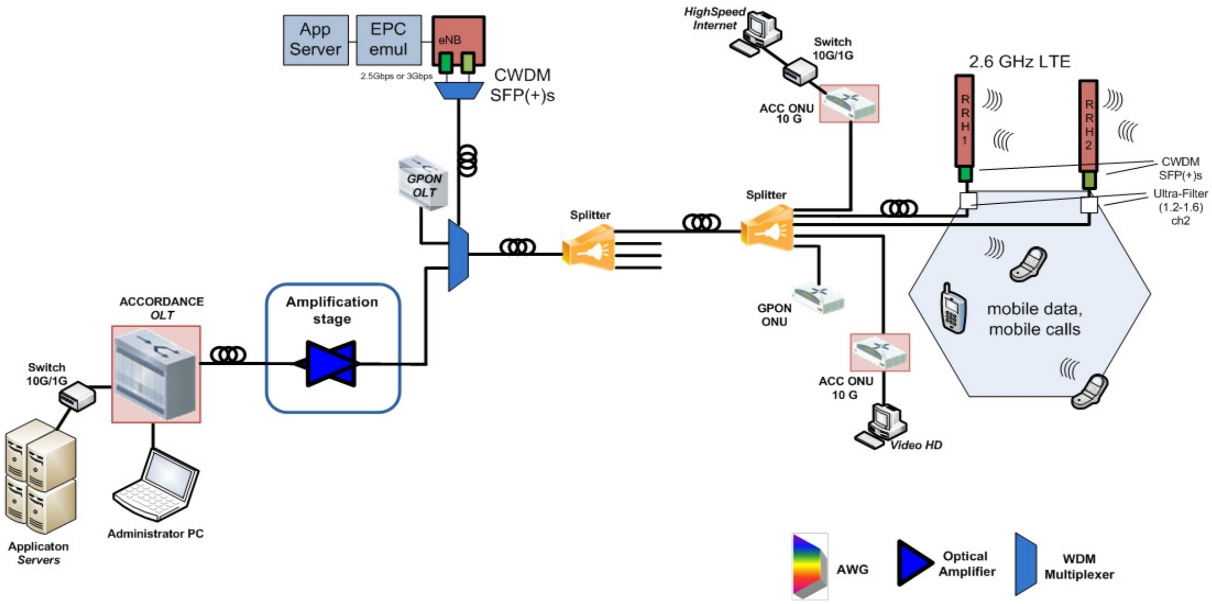


Figure 36 - scheme for a converged testbed

The following are the most relevant conclusions obtained throughout the task:

- The general reference model used in the test scenarios basically is based on a point-to-multipoint passive optical network model, composed by an OLT, an optional reach extender/amplification stage (located in the metro central office), several ONUs (located at the home user) and different splitters and fibre spools which compose the ODN.
- The wireline testbed had been designed keeping in mind that the OLT and ONU consist of several laboratory prototype boards with 10 GbE SFP+ port interfaces.
- The ACCORDANCE long reach system is based on the use of a reach extender. Different alternatives have been proposed in order to obtain a maximum reach of 100 km.
- The optical distribution network of the ACCORDANCE network is based on power splitters. This allows maintaining the compatibility with the outside plant of most operator companies; also allowing migration and reuse of the outside plant faster and easier.
- Coexistence between ACCORDANCE network system with GPON technology, OTDR monitoring mechanisms and RF video overlay distribution will be tested during the validation tests.
- The key aspects to be dealt regarding the inclusion of wireless fronthauling signals into the network are to assess the boundary conditions to be met to enable wireless service delivery with high quality.
- The options for combining the wireless and wireline setups into a single convergent one have been checked and a promising solution has been found and described.

3.5.2 Task 6.2: FPGA board preparation [M24-M30]

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:
The required FPGAs (2x XC6VHX380T and 2x XC6VHX565T) are available now and have arrived already at the KIT. Also the design of a PCB layout capable to hold FPGA, several required DACs and ADCs as well as multiple 10 GBit/s Ethernet interfaces and DDR3 memory has started. The board will be ready approximately by mid of 2012.

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 will be necessary to assess their performance quantitatively and qualitatively through a set of multimedia services. In order to do 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.

After the verification phase, both test beds will be integrated to setup a single demonstration platform located in TID’s premises located in Madrid. This demonstration test-bed will 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 this integrated test-bed is to demonstrate end-to-end wireline and wireless convergent services. This task starts nominally in July 2012.

WP7 – DISSEMINATION, STANDARDIZATION AND EXPLOITATION ACTIVITIES

Workpackage number	7	**Start date:** M1 **End date:** M36
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 / Y2	D7.3 Dissemination activities (M24) D7.4 Standardization activities (M24)	
Milestones / Y2	None	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 2 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
3.0	0.4	6.2	1.9	4.0	1.8	5.8	3.3	1.0	1.0	5.0	2.2	1.0	0.6

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
2.0	1.0	1.0	0.7	3.0	2.5	***32.0***	***15.3***

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 2011 in continuing and maintaining awareness of the project in the research and industrial community as well as in promoting major project results. Details are given in the task-specific sections below as well as in the deliverable D7.3 on the year 2 project dissemination activities delivered in December 2011.

3.5.4 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:
From the beginning of the project, an ACCORDANCE project web site has been created (http://www.ict-accordance.eu). A poster and a leaflet of the ACORDANCE project have been prepared and have been used at several conferences.

A total of 26 conference publications resulting from work within ACCORDANCE have been performed and presented at several prestigious international conferences in 2011, in particular at

OFC/NFOEC 2011 (Los Angeles, USA), PIERS 2011 (Marrakesh, Morocco), ICT 2011 (Ayia Napa, Cyprus), ANIC 2011 (Toronto, Canada), Future Network & Mobile Summit 2011 (Warsaw, Poland), ICTON 2011 (Stockholm, Sweden), ISCC 2011 (Corfu, Greece), NOC 2011 (Newcastle, UK), INDIN 2011 (Lisbon, Portugal), FITCE (Palermo, Italy) and ECOC 2011 (Geneva, Switzerland). At Future Network & Mobile Summit 2011 (Warsaw, Poland), a next generation converged access networks workshop has been organized by ACCORDANCE partner DT and a ACCORDANCE-related presentations were given during that workshop by ACCORDANCE partners AIT, ALUD and DT.

Two patent applications have been filed during year 2011 by ACCORDANCE partner ALUD.

Exchange with other projects active in neighbouring fields with similar focus has been started by having a joint workshop with the EU FP7 project OASE in Athens (Greece) in 2010 and will be continued by having a joint meeting in Tallinn (Estonia) in February 2012.

Based on work performed within the project, three scientific articles prepared by ACCORDANCE partners and submitted during Y2 have been accepted for publication in major journals in the field (IEEE/OSA JLT, IEEE PTL, OSA Optics Express). Finally, a scientific article on the ACCORDANCE concept has been submitted to the IEEE Communications Magazine as a joint work of several ACCORDANCE partners and is currently under review.

Moreover, ACCORDANCE Consortium contributed to the joint Photonics21-Net!Works white paper: “Next Generation Optical Networks: Enabler for Future Wireless and Wireline Applications” and to the white paper issued by CaON cluster regarding regarding OFDMA-PON architectures technologies.

The deliverable D7.3 “Dissemination activities – Year 2 update” summarizing the dissemination activities in project year 2 (2011) – containing more details regarding the above mentioned activities – has been delivered in December 2011.

3.5.5 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:

Optical Access Network Standardization has been followed closely in FSAN. Active contribution have been increased in year two now.

ALUD has given a second presentation on the ACCORDANCE approach, now with more details, at the May 2011 meeting titled "OFDM for NGPON2 Network Convergence".

The OFDM-PON access idea as developed in the ACCORDANCE project has been submitted to the FSAN Vendor White Paper currently in preparation.

The ACCORDANCE concept is one out of three concepts submitted to the White Paper and the only proposal originating from Europe.

3.5.6 Task 7.3: Exploitation Plans [M25-M36]

Task 7.3 has not yet started, however, ALUD has already begun to promote the solutions internally. Especially, the outcomes of WP5 are fed to the business units shaping LightRadio.

4. DELIVERABLES AND MILESTONES

Del. no.	Deliverable name	WP no.	Lead participant	Nature	Dissem. level	Due delivery date	Delivered Yes/No	Comments
D5.1	First concepts for combined optical and wireless access	WP5	ALUD	R	PU	M14	**Y**	-
D4.2	Definition of MAC protocols supporting FDM/OFDM operation	WP4	AIT	R	PU	M14	**Y**	Delivered with 1-day delay due to internal peer review
D2.2	Final report on network architecture and elements' requirements	WP2	AIT	R	PU	M15	**Y**	Delivered with 2-day delay due to comments expressed on 1st periodic review
D2.3	Benefits and feasibility	WP2	DT	R	CO+PU[3]	M16	**Y**	Delivered with 3-day delay due to internal peer-review process
D4.4	MAC layer requirements for the ACCORDANCE network	WP4	UH	R	PU	M18	**Y**	-
D3.2	Transmitter and Receiver design and implementation	WP3	KIT-U	R	CO	M18	**Y**	-
D3.3	Modulation format studies – Detailed study and transmission analysis including QAM dynamic reconfigurability	WP3	UPC	R	CO	M20	**Y**	-
D5.2	Requirements of wireless/wireline systems and their impact on the optical network	WP5	UH	R	PU	M18	**Y**	-
D5.3	Combined optical and wireless/wireline access based on existing requirements	WP5	UH	R	PU	M21	**Y**	-
D4.3	Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE	WP4	UH	R	PU	M22	**Y**	-
D2.4	Migration and convergence scenarios	WP2	ALUD	R	PU	M23	**Y**	-
D5.4	Mapping of radio signals to optical resources and distribution of mapping within the network	WP5	UH	R	PU	M23	**Y**	-
D1.6	Second year Annual Report	WP1	JCP	R	PU	M24	**Y**	-
D3.4	Transmitter and Receiver design and implementation	WP3	KIT-U	P	CO	M24	**Y**	-
D3.5	Design and implementation of FPGA modules	WP3	KIT-U	P	CO	M24	**Y**	-
D7.3	Dissemination activities	WP7	DT	R	PU	M24	**Y**	-
D7.4	Standardization activities	WP7	ALUD	R	PU	M24	**Y**	-

[3] Two versions of deliverable are issued

Milestone no.	Milestone name	Due date From Annex I	Achieved Yes/No	Actual / Forecast achievement date	Comments
M1.4	Quarterly Management Report (QMR)	M15	**Y**	-	-
M3.2	Transmitter and Receiver design	M17	**Y**	-	-
M1.5	Quarterly Management Report (QMR)	M18	**Y**	-	-
M3.3	Requirements and high-level design of FPGA modules	M20	**Y**	-	-
M1.6	Quarterly Management Report (QMR)	M21	**Y**	-	-
M5.2	Definition of the combined optical and wireless PHY layer	M21	**Y**	-	-
M5.3	First definition of the centralized wireless MAC and initial results on radio-optical mapping	M21	**Y**	-	-

5. PROJECT MANAGEMENT

Workpackage number	**1**	**Start date:** M1 **End date:** M36
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 / Y2	D1.6 Second Year Annual Report (M24)	
Milestones / Y2	M1.4 Quarterly Management Report (QMR) (M12)	
	M1.5 Quarterly Management Report (QMR) (M15)	
	M1.6 Quarterly Management Report (QMR) (M18)	

Participant MM expenses – Total Project (TP) / Cumulated expenses Year 2 (CE)

JPC		**AIT**		**ALUD**		**DTAG**		**ICOM**		**TID**		**UH**	
TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE	TP	CE
7.0	1.4	2.0	0.7	1.0	0.3	1.0	0.4	1.0	0.1	1.0	0.4	1.0	0.3

KIT-U		**UPC**		**EPC**		***TOTAL***	
TP	CE	TP	CE	TP	CE	*TP*	*CE*
1.0	-	1.0	-	15.0	5.1	***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.

5.1.1 Task 1.1 - Project Organization and Management

Work in Task 1.1 was strictly followed by the objectives, that are stated towards this task in description of work (technical annex). Below is shown in details, what activities and achievements were conducted within this task:

2nd year is probably the most important time for the ACCORDANCE due to high concentration of technical developments and finalisations of key architectural issues. Thus, it is very important to ensure the daily management of the Project and monitor the overall progress of the work, Task 1.1 has addressed needed administrative matters relative to ensuring continuation of the project i.e.:

- Budget distribution (launching General Assembly meetings, 1 payments) ;
- Organization of changes in the consortium
- Organization and coordination of changes to description of work
- Organization of re-distributions of workload
- Organization of plenary, monthly and technical meetings (physical and phone calls)

Further to the emails exchanges requested by the daily activity of the project (assistance to partners), WP1 has organized 3 (three) plenary meetings 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 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 31 phone conferences during 2011).

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 joint workshop at FTTHC conference with FP7 ALPHA, OASE, SARDANA and GIGAWAM projects, participation in EC spring and fall concertation meeting and CaON cluster workshops, etc.

Optimization of the project efficiency was constantly followed and during whole 2011 WP1 gathered information about small inconsistencies in technical annex and launched slight modification of it.

However, several activities within WP1 were dedicated to leveraging impact of changes within ACCORDANCE consortium (more detailed in chapter 5.4 below). To ensure secure continuation of project and minimize possible negative impacts of changes WP1 organized smooth takeover of workload by respective partners, worked with admistrative and financial issues, secured information flow between involved partners, as well as between EU and Consortium.

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

- 4th Quarterly Management report (QMRM13-M15) has been delivered on May 30th , 2011;
- 5th Quarterly Management report (QMRM16-M18) has been delivered on August 30th, 2011;
- 6th Quarterly Management report (QMRM19-M21) has been delivered on November 29th, 2011.

Total cumulated consumption of person-month during years 2010-2011 can be found from table below:

	JCP	AIT	ALUD	DT	ICOM	TID	UH	KIT	UPC	EPC	Total
PM Total	**3.3**	**58.2**	**76.8**	**20.6**	**15.3**	**33.3**	**58.0**	**35.0**	**35.6**	**13.7**	**349.9**
WP1	2.9	1.3	0.6	0.7	0.5	0.8	0.5	0.1	0.3	11.2	18.9
WP2	-	16.0	12.7	13.5	-	17.7	10.0	3.6	8.0	-	81.5
WP3	-	12.0	26.1	2.0	8.5	0.5	-	29.4	20.0	-	98.4
WP4	-	22.6	-	-	5.3	-	25.7	-	4.8	-	58.3
WP5	-	3.0	33.0	1.1	-	8.9	21.1	-	-	-	67.1
WP6	-	1.5	2.6	-	-	3.2	0.2	1.0	2.0	-	10.4
WP7	0.4	1.9	1.8	3.3	1.0	2.2	0.6	1.0	0.7	2.5	15.3

5.1.2 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 2nd year tasks and Tables of Contents (ToC) were generated for the deliverables.

Each technical deliverable produced undergone peer review process, where 1-2 peer reviewers are 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
D5.1	First concepts for combined optical and wireless access	WP5	Antonis Valkanas and Nikos Markos (ICOM)
D4.2	Definition of MAC protocols supporting FDM/OFDM operation	WP4	Josep Segarra (UPC) and Frank Schaich (ALUD)
D2.2	Final report on network architecture and elements' requirements	WP2	Thomas Monath (DT), Jose Lazaro (UPC) and Wolfgang Pöhlmann (ALUD)
D2.3	Benefits and feasibility	WP2	Marianna Angelou (AIT) and José Alfonso Torrijos Gijón (TID)
D4.4	MAC layer requirements for the ACCORDANCE network	WP4	Jean-Charles Point (JCP)
D3.2	Transmitter and Receiver design and implementation	WP3	Pandelis Kourtessis (UH)
D3.3	Modulation format studies – Detailed study and transmission analysis including QAM dynamic reconfigurability	WP3	Milos Milosavljevic (UH)
D5.2	Requirements of wireless/wireline systems and their impact on the optical network	WP5	José Alfonso Torrijos Gijón (TID)
D5.3	Combined optical and wireless/wireline access based on existing requirements	WP5	Dirk Breuer (DT), José Alfonso Torrijos Gijón (TID), Rafael Canto (TID)
D4.3	Definition and evaluation of algorithms for dynamic bandwidth allocation in ACCORDANCE	WP4	Josep Segarra (UPC)
D2.4	Migration and convergence scenarios	WP2	Pawel Parol[4], Philipp Schindler (KIT)
D5.4	Mapping of radio signals to optical resources and distribution of mapping within the network	WP5	James Malcolm (UH)
D1.6	Second year Annual Report	WP1	All Partners
D3.4	Transmitter and Receiver design and implementation	WP3	Heinz-Georg Krimmel (ALUD), Ivan Cano (UPC), Pandelis Kourtessis (UH)
D3.5	Design and implementation of FPGA modules	WP3	Christoforos Kachris (AIT)
D7.3	Dissemination activities	WP7	All Partners
D7.4	Standardization activities	WP7	All Partners

[4] External reviewer from Telekommunikacja Polska SA. This reviewer was invited to ensure independent review by operator

5.1.3 Task 1.3: Web Site and Maintenance

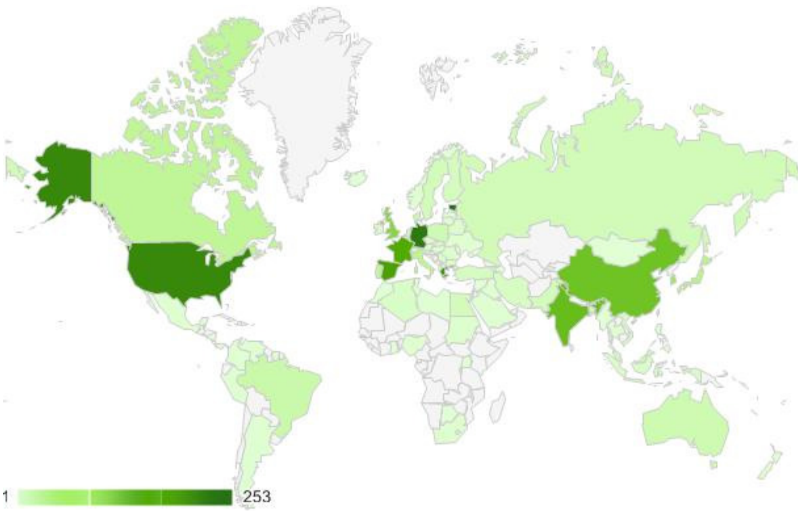
Website (http://ict-accordance.eu) was continuously updated during 2nd year of the project. Tables of contents, executive summaries and in some cases also introduction sections of 2nd year deliverables are uploaded to website and this was made for two purposes:

- Keeping technically related text uploaded to website for making it well visible to search engines
- In case of visitor interest to deliverables we prefer to be contacted directly, in order to make statistics of website visitors, how ACCORDANCE website was found etc.

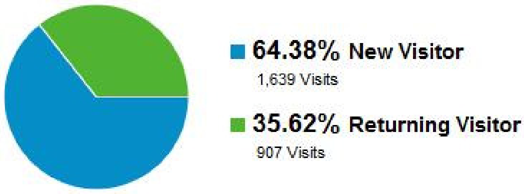
Structure of website didn't changed significantly and only visual appearance of front page was slightly updated with flash tagcloud.

Additionally, project is often (several times a week) updated with the mostly related industry and science news.

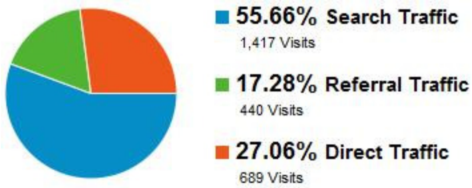
All those measures helped to increase visibility of website and to achieve significant increase of unique visitors. Thus, totally during 2011 ACCORDANCE website was visited 2546 times with 8936 pageviews, that was made by 1672 totally unique visitors from 93 countries:



As we can see, increased number of visitors made smaller number of pageviews (in comparison to 2010), that can be interpreted, that majority of visitors are returning visitors, whos behavior on the website is more concrete. This is also reflected by statistics:



Finally, we can see that majority of visits are coming from search engines or referring sites, that can be undoubtedly reported as positive trend:



5.2 PROBLEMS AND SOLUTIONS

No significant problems to be reported with regard to technical quality of the project or deviations from planned cost or schedule. However, of course ACCORDANCE was impacted by decision of partner ICOM to withdraw its participation, as well as shifting of someWP3 and WP5 workload from Partner DT to other partners. However, all needed shifting of workload went smoothly and finally ACCORDANCE was able even to use those changes for increasing of workload in WP3 and additionally plan implementation of converged testbed.

5.3 LIST OF PROJECT MEETINGS AND OTHER VENUES

- Plenary meeting: 7-8 February 2011 in Milan, Italy was co-located with FTTHC Conference and workshops.
- Plenary meeting: 31 May – 1-2 June 2011. In Barcelona, Spain, hosted by UPC.
- Plenary meeting: 25-26 October 2011. In Hatfield, UK, hosted by UH.
- 3rd General Assembly: 5th of September 2011. Via phone conference.
- 4th Extraordinary General Assembly: 18th of October 2011. Via phone conference.
- 11 monthly phone conferences
- 20 specific technical phone conferences

5.4 PROJECT PLANNING AND STATUS

The ACCORDANCE consortium is currently in the course of intensive implementation of theoretical and simulation concepts into hardware setup and planning of testbeds. The project is kept well in line with the expected schedule, cost and performance therefore no critical deviations are to be reported by the end of 2011.

5.5 IMPACT OF POSSIBLE DEVIATIONS FROM THE PLANNED MILESTONES AND DELIVERABLES

In 2011 project stays within planned milestones and deliverables and no deviations are reported.

5.6 BENEFICIARIES LEGAL STATUS

No legal status changes for ACCORDANCE consortium in 2011

5.7 USE OF FOREGROUND

Two patent applications are filled in the course of ACCORDANCE project:

- "Apparatus, Method, and Computer Program for a Remote Unit and a Central Unit" (INPI Paris, application no. 11 306 097.4)
- “OBI mitigation for electrical-OFDM based MPTP networks” (EPA 11290125.1)

6. EXPLANATION OF THE USE OF THE RESOURCES

TABLE 6.1.1 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 1 FOR THE PERIOD JCP			
Work Package	Item description	Amount in €	Explanations
WP1, WP7	Personnel direct costs	10 773.44 €	Related to J.C Point (0,36 MM), E. Malesys (0,36MM) and M. Wilmet (0,77 MM) activities
	Travel costs	2 032.24 €	Travel expenses for J-C. Point attending review meeting in Brussels, FIA meeting in Poznan
	Other direct costs	1 355.03 €	Administrative expenses : website hosting, bank financial costs, ProjectPlace annual fee
	Indirect costs	8 496.00 €	
	TOTAL COSTS AS CLAIMED ON FORM C	**22 657.00 €**	
	ADJUSTMENT TO Y1	5 875.00 €	Following to 2011 EC audit in JCP, Adjustment to MM average hours cost rate

TABLE 6.1.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 2 FOR THE PERIOD AIT			
Work Package	Item description	Amount in €	Explanations
WP1, WP2, WP3, WP4, WP5, WP6, WP7	Personnel direct costs	145 869.61 €	Total cost of 0.66 PMs for MGT (WP1) and 37.92 PMs for RTD (WP2, WP3, WP4, WP5, WP6, WP7)
WP1, WP7	Travel costs	8 489.21 €	• Plenary meeting in Milan, Italy (6-10/02/2011), I. Tomkos • Plenary meeting in Milan, Italy (6-10/02/2011), K. Kanonakis • Y1 review in Brussels, Belgium (24-25/03/2011), I. Tomkos • Y1 review in Brussels, Belgium (24-25/03/2011), K. Kanonakis • Plenary meeting in Barcelona, Spain (30/05-02/06/2011), A. Kavatzikidis • Conference FNMS 2011, Warsaw, Poland (13-16/06/2011) , E. Giacoumidis • Conference ICTON 2011, Stockholm, Sweden (27-30/06/2011), M. Angelou • Conference ECOC 2011, Geneva, Switzerland (18-21/09/2011), I. Tomkos • Plenary meeting in Hatfield, UK (23-26/10/2011), K. Kanonakis
	Indirect costs	107 943.51 €	Overhead rate 74% (based on 2010 financial data)
	TOTAL COSTS AS CLAIMED ON FORM C	**262 302.33 €**	
	ADJUSTMENT TO Y1	-3 203.51 €	Adjustment to the INDIRECT COSTS (overheads) amount claimed in Y1 upon finalization of the overhead rate for year 2010

TABLE 6.1.3 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 3 FOR THE PERIOD **ALUD**			
Work Package	Item description	Amount in €	Explanations
WP1, WP2, WP3, WP5, WP6, WP7	Personnel direct costs	362 235.00 €	Management (WP1) and research (WP2, WP3, WP5, WP6, WP7)
WP1, WP2, WP3, WP5, WP6, WP7	Travel costs	7 706.00 €	• Plenary meeting in Milan, Italy (6-10/02/2011), F. Schaich, H. Krimmel • Y1 review in Brussels, Belgium (24-25/03/2011), F. Schaich, H. Krimmel • Plenary meeting in Barcelona, Spain (30/05-02/06/2011), F. Schaich, H. Krimmel • Conference FNMS 2011, Warsaw, Poland (13-16/06/2011) , F. Schaich • Plenary meeting in Hatfield, UK (23-26/10/2011), F. Schaich
	Indirect costs	221 945.00 €	
TOTAL COSTS AS CLAIMED ON FORM C		**591 886.00 €**	

TABLE 6.1.4 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 4 FOR THE PERIOD **DT**			
Work Package	Item description	Amount in €	Explanations
WP1, WP2; WP7	Personnel direct costs	68 438.00 €	7 experts part-time; 8,5 PM
WP1, WP2; WP7	Other direct costs	4 297.00 €	• Plenary meeting in Milan, Italy (6-10/02/2011), E. Weis • Y1 review in Brussels, Belgium (24-25/03/2011), C. Lange • Conference FNMS 2011, Warsaw, Poland (13-16/06/2011) , C. Lange • Plenary meeting in Hatfield, UK (23-26/10/2011), E. Weis
	Indirect costs	41 476.00 €	
TOTAL COSTS AS CLAIMED ON FORM C		**114 212.00 €**	

TABLE 6.1.5 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 5 FOR THE PERIOD[5] **ICOM**			
Work Package	Item description	Amount in €	Explanations
WP1, WP3; WP4 WP7	Personnel direct costs	46 706.17 €	Personal costs
	Indirect costs	39 850.64 €	
TOTAL COSTS AS CLAIMED ON FORM C		**86 556.00 €**	

[5] Major costs for the period 01.01.2011 – 31.05.2011

TABLE 6.1.6 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 6 FOR THE PERIOD TID			
Work Package	Item description	Amount in €	Explanations
WP1, 2, 3, WP5,6,7	Personnel direct costs	154 679.00 €	Personnel cost: 151871 € (RTD) + 2808 € (MGT)
	Travel costs	4 405.00 €	• Plenary meeting in Milan and FTTH Conference, Italy (6-10/02/2011), S. Romero, R. Canto • FSAN meeting in Berlin, Germany (22/05/2011), R. Canto • Plenary meeting in Barcelona, Spain (30/05-02/06/2011), S. Romero, J. Gijon
	Indirect costs	148 123.00 €	
TOTAL COSTS AS CLAIMED ON FORM C		**307 207.00 €**	

TABLE 6.1.7 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 7 FOR THE PERIOD UH			
Work Package	Item description	Amount in €	Explanations
WP1, WP2, WP4, WP5, WP6, WP7	Personnel direct costs	110 563.00 €	Full-time costs for Dr Milos Milosavljevic, Dr Wansu Lim and allocated costs for Dr Pandelis Kourtessis and Prof John Senior
	Travel costs	8 895.00 €	• Plenary meeting in Milan, (6-10/02/11), M. Milosavljevic, P. Kourtessis, W. Lim, J.M. Senior • Y1 review in Brussels, Belgium (24-25/03/2011), P. Kourtessis • Plenary meeting in Barcelona, (30/05-02/06/2011), M. Milosavljevic, P. Kourtessis, W. Lim • Conference FNMS 2011, Warsaw, Poland (13-16/06/2011), W. Lim • Conference ICTON 2011, Stockholm, Sweden (27-30/06/2011), M. Milosavljevic
	Indirect costs	71 674.00 €	Flat rate 60%
TOTAL COSTS AS CLAIMED ON FORM C		**191 132.00 €**	

TABLE 6.1.8 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 8 FOR THE PERIOD KIT-U			
Work Package	Item description	Amount in €	Explanations
WP2, WP3, WP6-7	Personnel direct costs	73 830.00 €	Personnel costs
	Travel costs	6 070.00 €	• Plenary meeting and FTTH conference in Milan, Italy (6-8/02/2011), 2 persons • OFC Los Angeles, US (02-12/03/2011), R. Schmogrow • Y1 review in Brussels, Belgium (24-25/03/2011), R. Schmogrow, M. Dreschmann • Plenary meeting in Barcelona, Spain (30/05-02/06/2011), R. Schmogrow, M. Dreschmann • SPPCom, Toronto, Canada (8-19/06/2011), R. Schmogrow • INDIN Conference, Caparica Portugal (25-29/06/2011), 1 person • Plenary meeting in Hatfield, UK (23-26/10/2011), R. Schmogrow, M. Dreschmann
	Other direct costs	117 336.00 €	Equipment costs: Micram 25 GSa/s signal converters for OLT, semiconductor optical amplifiers for ONUs, electrical amplifiers, radio frequency (rf) components, passive optical components, balanced photo-detectors for OLT Rx, optical hybrid for OLT Rx
	Indirect costs	118 341.00 €	
TOTAL COSTS AS CLAIMED ON FORM C		**315 577.00 €**	

TABLE 6.1.9 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 9 FOR THE PERIOD UPC			
Work Package	Item description	Amount in €	Explanations
WP2, WP3, WP4, WP6, WP7	Personnel direct costs	92 437.00 €	RTD personnel costs of 18.55 PM corresponding to: one Full Professor (4.8 PM); 3 Professors (1.9, 2.5 and 3.6 PM respectively); and 2 Postdoctoral researchers (4.1 and 1.6 PM respectively)
	Travel costs	6 253.00 €	• Plenary meeting in Milan and FTTH Conference, Italy (6-10/02/2011), M. Santos, I. Cano • Y1 review in Brussels, Belgium (24-25/03/2011), M. Santos • Conference ICTON 2011, Stockholm, Sweden (27-30/06/2011), 1 person • Conference ECOC 2011, Geneva, Switzerland (18-21/09/2011), 1 person • Plenary meeting in Hatfield, UK (23-26/10/2011), 1 person
	Indirect costs	69 005.00 €	
TOTAL COSTS AS CLAIMED ON FORM C		**167 695.00 €**	

TABLE 6.1.10 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 10 FOR THE PERIOD EPC			
Work Package	Item description	Amount in €	Explanations
WP1, WP7	Personnel direct costs	37 250.00 €	Personnel costs
WP1	Travel costs	4 487.00 €	• Plenary meeting and FTTHC workshop in Milan, Italy (6-9/02/2011), R. Kaurson • Photonics21 annual meeting in Brussels, Belgium (24/02/2011), R. Kaurson • Y1 review in Brussels, Belgium (24-25/03/2011), R. Kaurson • Plenary meeting in Barcelona, Spain (30/05-02/06/2011), R. Kaurson • Conference FNMS 2011, Warsaw, Poland (13-16/06/2011) , R. Kaurson • Plenary meeting in Hatfield, UK (23-26/10/2011), R. Kaurson
	Indirect costs	25 041.00 €	
TOTAL COSTS AS CLAIMED ON FORM C		**66 778.00 €**	

7. 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.

8. 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		Expenditure threshold not reached
2	AIT		Expenditure threshold not reached
3	ALUD		Expenditure threshold not reached
4	DTAG		Expenditure threshold not reached
5	ICOM		Expenditure threshold not reached
6	TID		Expenditure threshold not reached
7	UH		Expenditure threshold not reached
8	KIT-U		Expenditure threshold not reached
9	UPC		Expenditure threshold not reached
10	EPC		Expenditure threshold not reached

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