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SEVENTH FRAMEWORK PROGRAMME

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FLEXIBLE OPTICAL CROSS-CONNECT NODES

ENABLING NEXT-GENERATION FLEXIBLE OPTICAL NETWORKING

SPECIFIC TARGETED RESEARCH PROJECT (STREP)

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Definition of system testing activities

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This deliverable describes the structure and required elements for the final FOX-C test-bed and defines the test and measurement procedures. The required test-bed structure is identified including the type of the key modules developed under FOX-C project in WP3 and WP4 that will be integrated together for the final measurements. Moreover, the testing processes and the measurement targets are defined in detail providing also the relative time plan of the activities.

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Executive Summary

The testing activities are defined with the goal to evaluate the performance of the innovative switching solutions and to demonstrate the flexible-node functionalities that are enabled from these solutions. The final target is to show that the Flex-Channel (FCh) contents of a Super-Channel (SCh) can be processed (i.e. dropped, added and passed-through) all optically, achieving ultra-fine switching granularity of FCh in the order of 10Gb/s, within an ultra-high capacity network, transporting several SCh, each up to 1Tb/s. Several flexible SCh transceiver schemes developed within WP3 are delivered for the final evaluation of the project's concepts including at least the spectrally overlapping scheme of O-OFDM and the non-overlapping schemes of NWDM and multi-band eOFDM. Moreover, two switching solutions are delivered for the testing of the second stage of the node, namely, the high spectral resolution filter based switching scheme (HSR-WSS) that is applicable for the switching of FChs without overlapping spectra and the all-optical Interferometric switching scheme (TIDE) that is applicable for the switching of FCh with overlapping spectra. Although each of these two innovative solutions on their own is capable to meet the initial FOX-C objectives, the plan of the FOX-C consortium is to demonstrate if possible both solutions with the equivalent SCh schemes. Also a redesigned WSS with finer resolution than the currently available solutions will be considered and tested as the first switching stage of the node, which selects the SChs for processing. According to the above three testing activities are defined related with: a) the testing of flexible SCh/FCh signal format performance, b) the testing of the 1st stage of FOX-C node and c) the testing of the whole FOX-C system.

The experimental transmission test-bed for the evaluation of the project's concept and developments is provided by OrangeLabs. It includes two designs that have been already tested and evaluated in various related experiments. The first design considers two separate recirculating loops. The switching node in this case can be placed in between the loops in order to examine the performance of a dropped signal (i.e. one or several FChs or even a complete SCh) after transmission and the performance of the added and neighbouring signals again after transmission. The second design considers the placement of the node within the loop and can be used to examine the cascadability effects. A more advanced design will also be investigated based on a dual-recirculating loop structure able to combine both the aforementioned designs in one common scheme for testing. Finally, the available testing resources include all the materials required to build a multi-carrier source, the recirculating loop designs and the coherent detectors for BER evaluation.

All the three testing activities have been defined and described in detail, including the targeted measurements and the required experimental set-up to obtain them. Additionally, an initial work plan and time plan for the execution of the testing activities has been defined. This plan considers two phases that relate initially with the test-bed implementation and evaluation of the flexible transmission schemes and next with the node integration and the overall FOX-C system evaluation. This is an open process that will be re-evaluated once the different testing activities progresses and according to the integration of the different elements in the test-bed. Also the possible implementation risks are identified and certain alternatives are provided. One of these key alternatives highlights the possible use of a second transmission test-bed provided by partner ASTON for the testing of the O-OFDM scheme with the TIDE switching node in parallel to the remaining activities tested at OrangeLabs test bed. This solution will relax significantly the strict implementation and testing time plan and primarily it will minimize the risk of a failure for the TIDE solution due to transport from ASTON to OrangeLabs. This alternative will be evaluated before the start of the testing activities.

An addendum is included at the end of the document describing in detail the updated work plan for the final testing activities as this is agreed by all partners with effect from 1/1/2015. The addendum follows the guidelines received by the EC project office after the project review on the 21st of November 2014 and is pending approval by the EC project office. The updated work plan considers a 3-month extension to the project duration, in order to complete safely and accurately all the planned testing activities, demonstrating experimentally the full potentials of the developed elements and subsystems. It is noted that the original plan as this is presented in section 3 of this deliverable is still valid for the fulfilment of the project objectives, and the extra 3 months are proposed for testing all the different solutions developed until now in the project.

1 FOX-C system testing purpose and targets

This introductory section provides the overall purpose of the FOX-C testing activities and sets the targeted goals and expected outcomes. It describes also the type of modules that will be integrated and tested according to the expected outcomes from WP3 and WP4, as well as the key network operation functions that can be supported.

1.1 The purpose of system testing activities in FOX-C

The purpose of the testing activities in FOX-C is to demonstrate the capabilities of the innovative switching solutions developed within the project and examine the flexible-node functionalities that are enabled from these solutions. Such functionalities include primarily the ability to add and drop flex-channels (FCh) – i.e. the contents of a super-channel (SCh) – from/to a SCh that transverses the node, while also allowing other SCh to be dropped and added as a whole or go through the node. In terms of flexible optical networking, the goal is to demonstrate the fine switching granularity approach that is enabled by the innovative solutions in FOX-C, which allows the dynamic allocation and routing of adaptable and optimised SChs directly in the optical domain.

It is important to highlight at this point that the FOX-C enabled networking concept considers the dynamic generation of spectrally flexible SChs between the nodes of the network, rather than the fixed allocation of flexible SChs on an end-to-end basis (i.e. according to the demands at the edge nodes), which is mainly considered by most of the common flexible networking scheme. This approach allows the aggregation of traffic at intermediate nodes, maximizing the spectrum utilization and minimizing the use of resources in the core part of the network. The strong benefit of the FOX-C solutions is that the aggregation process is performed in the optical domain and utilizes high spectrum resolution techniques that actually allow the all-optical grooming of traffic in nodes.

The successful testing of the add/drop function at the FCh level, combined with the appropriate generation transmission and reception of the individual FCh, as well as the generation and processing of complete Tb/s SChs is required in order to demonstrate the flexible networking approach enabled by the FOX-C project solutions.

1.2 Testing objectives

The main goal of the testing activities is to assemble the different developments in WP3 and WP4, under a common multi-Terabit/s optical test-bed, in order to validate the performance of a complete FOX-C system that includes all the identified functionalities.

The detailed objectives and targeted outcomes from the successful implementation of the testing activities are:

- The redesign of the OrangeLabs optical-multi-carrier test bed, in order to include at least one and preferably both types of spectrally efficient formats, namely: a) the optical OFDM or NWDM format without spectral guard bands and b) the multi-band scheme (based on electronic OFDM or f-OFDM or NFDM multiplexing) with minimized spectral guard bands. The implemented scheme(s) will demonstrate the generation and transport of multiple super-channels with total capacity beyond 1Tb/s.
- The assembly and testing of the FOX-C node with both coarse and fine switching granularity layers, performing SCh routing and FCh switching (add/drop/pass-through) and demonstrating fine switching granularity at 10Gb/s with Tb/s SCh routing.

- The integration of the FOX-C node in the transmission test-bed to evaluate the performance degradation effects and the node cascadability of the proposed system solutions.
- The collection of detailed measurements and performance evaluation results for the characterization of the developed technologies and the identification of important design limitations and tolerances.

1.3 Targeted solutions and functions to be tested

The development activities within FOX-C are performed in WP3 and WP4. WP3 activities focus on different flexible data transmission schemes, while WP4 activities focus on the flexible switching node solutions. Until the end of the 2nd year of FOX-C project the development activities in these two WPs have progressed independently, based though on common system level specifications defined in WP2. The system testing activities within WP5, defined in this deliverable, target the integration of the examined solutions according to their characteristics and the performance evaluation of them over a common transmission test-bed.

1.3.1 Proposed and examined transceiver solutions

The flexible transmitter-receiver schemes proposed in FOX-C are categorized according to the spectral position of the FChs (i.e. overlapping or non-overlapping spectra) and include the following cases:

A. TxRx signal formats with spectral overlap
   - Case A-1. Optical OFDM (O-OFDM)
     - Refer to D3.2 section 3
   - Case A-2. Optical Fast-OFDM (O-fOFDM)
     - Refer to D3.2 section 3
   - Case A-3. Nyquist WDM (NWDM)
     - Refer to D3.3

B. TxRx signal formats without spectral overlap
   - Case B-1. Multi-band Nyquist FDM (NFDM)
     - Refer to D3.3
   - Case B-2. Multi-band Electronic OFDM (e-OFDM)
     - Refer to D3.2 section 2
   - Case B-3. Multi-band Electronic Fast-OFDM (e-fOFDM)
     - Refer to D3.2 section 2
   - Case B-4. Quasi-Nyquist WDM (qNWDM)
     - Refer to D3.3

1.3.2 Proposed and examined switching solutions

The flexible switching solutions for the implementation of the FOX-C node functions include a coarse WSS based switching element for the processing of the fibre spectral contents (i.e. the add drop and pass-through of SChs) and a fine-resolution switching element for the implementation of the processing of the SCh contents (i.e. the add, drop and pass-through functions of FChs).

The coarse WSS element for the FOX-C node is a redesign of a LCoS-based WSS prototypical Finisar implementation, offering a 7.5 GHz optical resolution, spectral addressability of 6.25 GHz, 20 output ports and an insertion loss of ≤5 dB.

- Refer to D4.3 Section 2

The key innovation in FOX-C project was on the development of the solutions addressing the fine switching resolution requirement for the processing of the SCh contents (i.e. the FCh). The two solutions that have been examined and developed are:

A. A high spectral resolution HSR filter based switching element – (HSR-WSS)

- This is an innovative solution that achieves spectral resolution at 0.8GHz and can implement a WSS element that operates over 200GHz bandwidth (i.e. the SCh spectral length) achieving add/drop and block of FCh with minimum guard band spacing.
- Refer to D4.3 Section 3

B. An All-optical Interferometric switching element – (TIDE)

- This is an innovative scheme able to process (add, drop and extract) any type of optically multiplexed FChs even when they have overlapping spectra as in the case of O-OFDM
- Refer to D4.5

1.3.3 Remarks concerning the selection of the targeted system solutions to be tested

Valid combinations between flexible switching and flexible transceiver solutions

At the fibre level of the switch, the processing of any type of SCh, regardless the multiplexing scheme and data format, is performed by the redesigned LCoS-based WSS from Finisar. It is noted that at this level any type of WSS (even commercial ones with coarser resolution) can be used without affecting the main goals of FOX-C project, which primarily targets the switching of SCh contents. The effect will be simply on the allocated spectral guard band between neighboring SChs.

At the SCh level, which concerns the switching of the SCh contents (i.e. the FChs), there are two separate cases that can be examined:

- FOX-C testing case 1: Switching of FChs without spectral overlap, separated by a minimum spectral guard band. This is implemented with the HSR-WSS solution and applies for any of the Case B TxRx signal formats. It does not apply for the Case A formats.
- FOX-C testing case 2: Switching of FChs with spectral overlap (or no spectral guard band). This is implemented with the TIDE solution and applies for any of the Case A TxRx signal formats as well as the Case B-4 format.

Each one of the cases mentioned above satisfies on its own the targeted testing objective and the main concept of the project, since it is able to provide switching of SCh contents at a much finer granularity than any of the technologies currently available. However the planned testing activities consider the evaluation of both schemes. It is noted though that the two cases are required to be tested separately.

Selection remarks concerning the flexible transceiver solutions

The flexible transceiver signal formats that are fully ready and available to be used for the FOX-C testing purposes are:

- The multi-band eOFDM scheme (Case B-2), provided by OrangeLabs
- The multi-band NFDM scheme (Case B-1), provided by ETHZ
- The O-OFDM scheme (Case A-1), provided by ASTON

The availability of these schemes can implement both FOX-C testing cases mentioned above, in combination with the HSR-WSS and the TIDE switching solution.

The fast-OFDM variants in electronic domain, e-fOFDM (Case B-3) and in optical domain O-fOFDM (Case A-2) have also been examined and are required first to be tested and evaluated separately. Although these options are not required for the proof of FOX-C concept, they can offer a significant added value on the overall performance evaluation of the concept by increasing the compared cases.

Finally, the Nyquist WDM format, either without guard-band, NWDM (Case A-3), or with a small guard band, qNWDM (Case B-4), is in principle the same as the NFDM scheme. The key difference is that the rectangular spectral shaping function in NWDM format is performed in the optical domain via optical spectrum pre-shaping, whereas in NFDM is performed electronically based on the way that the data are generated and multiplexed. The NWDM cases have been evaluated theoretically but their implementation and testing is not required, since the NFDM case can cover these extra options.

Remarks on the applicability of the different HSR-WSS solutions

For the HSR filter based switching element, two different solutions have been examined and implemented

- An AWG based filtering solution achieving 0.8GHz resolution over a contiguous 200GHz band
- A bulk grating dual WSS solution achieving 1.5GHz resolution over 20nm within the C-band

The first solution is the one promoted for the implementation and testing of the fine-resolution switching functions in the FOX-C node due to its finer resolution, in order to allow the minimum possible spectral guard band between FChs with non-overlapping spectra. Also this solution can apply over the whole fibre operating window but on individual (pre-selected) SCh, due to the cyclical properties of the AWG.

The second solution will be considered for the implementation of the fine filtering function in the TIDE switching element in order to increase its performance. The fine resolution dual-WSS solution is more relevant here due to the multi-port configuration required to divide and combine a SCh. Another important issue is the low insertion loss of this solution which alleviates the need for extra amplification.

1.4 List of targeted systems and functions to be tested

The complete FOX-C system to be tested is composed of:

1. The SCh generation and evaluation subsystems with the FCh transmitters and receivers
2. The recirculating loop based transmission test-bed
3. The two stage FOX-C switching node

The transmission test-bed is a common platform for all testing cases and is modified accordingly in order to include the various transmitter-receiver subsystems and the FOX-C node. The test-bed and its capabilities, including some performance evaluation metrics are described in section 2 of this deliverable.

The first stage of the FOX-C node (at the fibre level) is also common in all testing cases and used the redesigned WSS from Finisar. Its purpose is to process (i.e. drop, pass-through and add) complete SChs from a group of SChs transmitted in the test-bed. It can be tested as a standalone element in order to determine the cascadability effects and the optimum spectral guard bands between SChs.

Regarding the second stage of the FOX-C node (at the SCh level) there are two options to be considered. These are the HSR-WSS and the TIDE schemes for the processing functions (i.e. drop, pass-through and add) of FCh without spectral overlap and with spectral overlap respectively. Each scheme is applicable for a different flexible SCh signal format as discussed in the previous section. The two options in combination with the compatible formats determine in turn the two system cases to be tested.

Finally it is noted that the SCh generation and detection schemes are initially tested separately (i.e. without the presence of the flexible switching node) over a transmission test-bed in order to determine their expected performance.

The targeted testing cases and their functions are listed in the following table. A detailed description of the set-ups, the testing processes and the targeted measurements is provided in section 3 of this deliverable.

TABLE 1. *List of targeted testing cases and functions*

	System elements included	Purpose / Functions
Testing activity 1 Flex signal format performance	Transmission test-bed + eOFDM (main scheme) Transmission test-bed + NFDM (main scheme) Transmission test-bed + O-OFDM (main scheme) Transmission test-bed + e-fOFDM (optional) Transmission test-bed + O-fOFDM (optional)	FCh generation and evaluation SCh generation up to 1Tb/s Comparison of different formats over the same transmission platform
Testing activity 2 1st stage FOX-C node evaluation	Transmission test-bed + eOFDM (or NFDM) + WSS Transmission test-bed + O-OFDM + WSS (optional)	Determine SChs guard bands Test WSS cascadability effects on SChs
Testing activity 3 FOX-C system testing	Transmission test-bed + (WSS + HSR-WSS) + eOFDM Transmission test-bed + (WSS + HSR-WSS) + NFDM	Drop/Add of FCh from/to a SCh Performance evaluation of dropped FCh after SCh transmission Performance evaluation of added FCh after SCh transmission
	Transmission test-bed + (WSS + TIDE) + O-OFDM	Performance evaluation of non-processed FChs after transmission Cascadability effects on neighbouring FChs Determine system metrics like: FCh spectral guard bands, minimum switching granularity

2 The FOX-C transmission system test-bed

This section provides a detailed description of the OrangeLab transmission test-bed that is used for the performance evaluation of the FOX-C developments. Moreover, the available test and measurement capabilities devoted to the testing activities of the project are listed.

2.1 Test-bed description

The experimental test-bed has been designed with the main goal to evaluate the performance the two stage FOX-C node developed in WP4. The test-bed will integrate the multi-carrier transmitter using the various solutions developed in WP3, the transmission line with the sub-wavelength optical switch, and finally the receiver able to perform the bit-error rate (BER) measurements to evaluate the quality of overall system.

Various series of tests will be implemented to evaluate performance of the SCh and FCh optical add/drop multiplexer developed in FOX-C. The first evaluation procedure will consist in verifying if the switch is able add/drop one FCh inside the multi-band SCh signal in the case where it is introduced in the middle of a transmission line constituted of several fibre spans. This is illustrated in Figure 1 below. The performance of the dropped sub-channel will be evaluated after transmission over the first half of the fibre link. A replica of this sub-channel generated in the transmitter will be reintroduced at the place of the dropped sub-band, and will propagate over the second half of the line. The BER performance of the various FChs (the add/drop one and its pass-through neighbours) will be evaluated at the end of the fibre link.

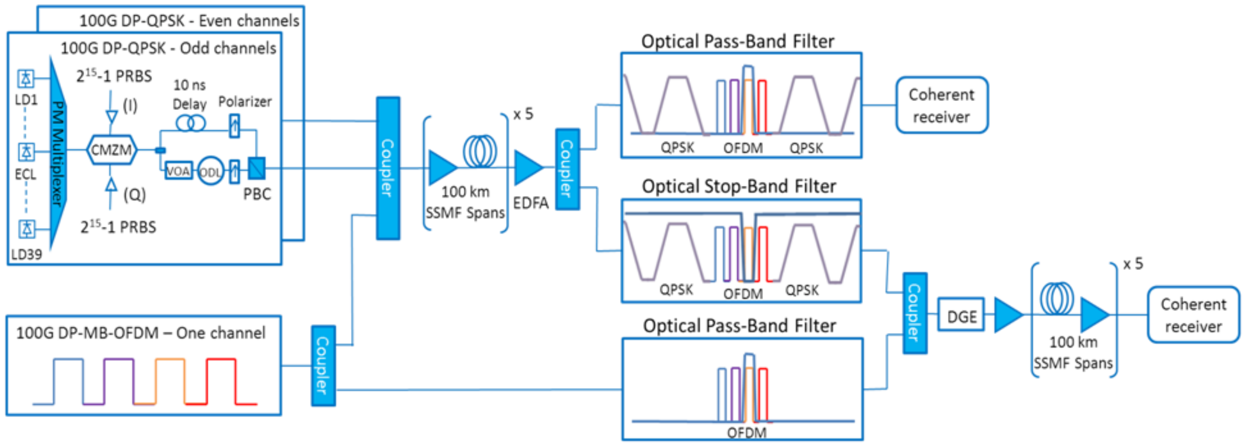

Figure 1. *Set-up of the 10 × 100-km transmission test-bed, with the 124.4 Gbps DP-MB-OFDM channel, the 79 odd and even 112 Gbps DP-QPSK wavelengths, the 10 × 100-km uncompensated G.652 SSMF transmission line with the sub-wavelength optical switch located in its middle.*

Once the proof of concept has been successfully demonstrated, it is essential to show that such sub-wavelength optical switch can be cascaded in order to be introduced in a meshed optical transport network equipped with multiple ROADM. For doing that, a recirculating loop of 100 km or 2x100 km in which the sub-wavelength optical switch is inserted has to be implemented. The experimental test-bed is described over the Figure 2 below. The multi-band signal over which the add/drop has to be carried out is inserted in a WDM multiplex of several tens of channels at 100 Gbps. The WDM channel comb is then inserted into the recirculating loop for several loop roundtrips. In the loop, the sub-wavelength add/drop consists in dropping one sub-wavelength over one arm of a 3-dB coupler and to suppress it over the other arm of the 3-dB coupler. After a decorrelating fibre, the dropped sub-band is reinserted into the multi-band signal at the place of the suppressed band by the means of a second 3-dB coupler, as illustrated in Figure 2. This testing process allows us to control how many add/drop can be cascaded and to measure the crosstalk induced by the add/drop process.

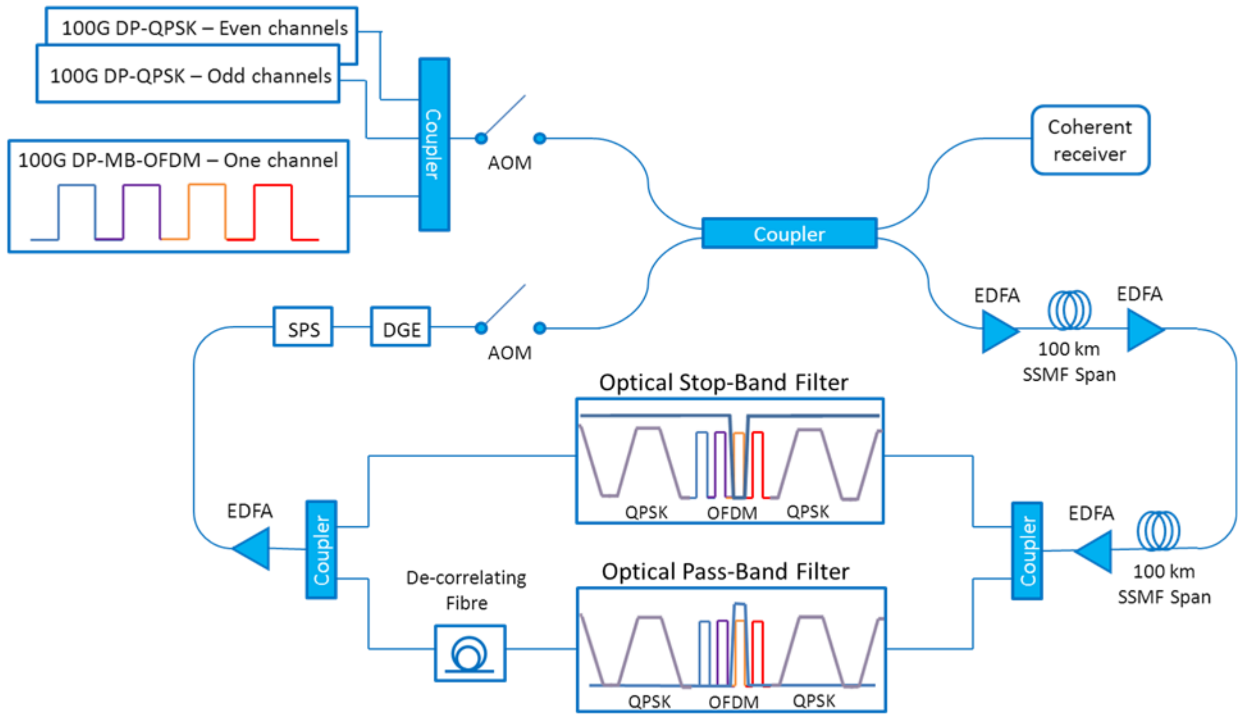

Figure 2. *Set-up of the 2 × 100-km G.652 fiber-based recirculating loop including the OFDM sub-band optical switch. AOM = Acoustic-Optical Modulator, SPS = Synchronous Polarization Scrambler, DGE = Dynamic Gain Equalizer.*

2.2 Available testing resources

The testing resources count all the materials required to build a multi-carrier source, a recirculating loop equipped with the sub-wavelength optical switch under testing, and the coherent detector able to receive the signal and evaluate the BER. Among these resources, we can cite:

- Arbitrary waveform generators with high bandwidth (~20 GHz) and high sampling speed (~64 GSamples/s).
- Linear RF drivers for amplifying the electrical signal before attacking the electro-optical modulator.
- Complex Mach-Zehnder modulators to generate the signals carrying QPSK or high-order QAM.
- Polarization-maintaining (PM) optical couplers, PM optical amplifiers, …
- Acousto-optic modulators (AOM) for controlling the recirculating loop, and associated electrical pulse generators.
- Standard single-mode fibre spans.
- Erbium-doped fibre amplifiers (EDFA).
- Synchronous polarization srambler (SPS) to stabilize the operation of the loop with respect to polarization effects.
- Dynamic gain equalizer (DGE) to control the power of the WDM multiplex components after each loop roundtrip.
- Coherent receiver with two 90° hybrids (one per polarization) and four balanced photoreceivers.
- Real-time oscilloscope with high storage capabilities to memorize the signals over the four channels (I-PolX, Q-PolX, I-PolY, Q-PolY).

This list is non-exhaustive and some additional testing materials could be required to complete the tests.

3 Testing procedures and targeted measurements

This section provides a detailed description of the testing activities including the main targeted measurements to be obtained for each case. Moreover, the initial and tentative work plan for the set-up and evaluation of the FOX-C systems is presented. This is an open process that will be re-evaluated once the different testing activities progresses and according to the integration of the different elements in the test-bed. The final section highlights the key procedures agreed by the partners for the successful completion of the project's testing activities.

3.1 Description of testing activities and targeted measurements

A list of the planned testing activities is shown in Table 1 on page 10. More details for each activity are provided in the following paragraphs

3.1.1 Testing activity 1: Flexible signal format performance evaluation

In this activity the flexible transmitter-receiver schemes developed and studied in WP3 are integrated with the transmission test-bed and characterized. This is the first step towards the implementation of the system test-bed, prior to the integration of the node elements and should include the required number of SChs and FChs for the final system testing. Additionally, it offers the possibility to compare different flexible signal formats over a common transmission test-bed and examine their performance against certain transmission impairments.

Targeted requirements

The main formats to be examined include the cases of eOFDM, NFDM, and O-OFDM. Optionally, the e-fOFDM and the O-FOFDM schemes can be also examined provided that the they are available at the defined testing period.

For each case at least 3 SChs are generated, if possible with different spectral widths by including a different number of optical subcarriers (i.e. number of FChs). A spectral guard band of 12.5GHz should be included between the SChs, with the capability to be reduced to 6.25GHz. The maximum spectral width of a SCh is 200GHz in order to comply with the FOX-C node requirements, in the case of the FSR-based switching node. At least one of the testing cases should include a SChs with an aggregated capacity of 1Tb/s or higher. There should be also at least one FCh in any SCh with a minimum capacity in the order of 10Gb/s.

In the case that only one SCh can be generated (e.g. due to limited number of required resources), then dummy signals should be inserted, emulating the existence of other SChs at the required spectral positions and with similar spectral characteristics as a real SCh. Also in this case several different versions of the SCh should be tested in order to include all different testing scenarios, and in particular the maximum SCh capacity and the inclusion of a FCh with the minimum capacity.

The set-up includes the appropriate amplification elements at the transmitter and receiver side, in order to vary the launch power level and control the additive ASE noise level respectively, required for the performance evaluation measurements.

The default receiver set-up is based on offline processing for the evaluation of all types of received signals. However, for the case of NFDM/NWDM the real time receiver set-up developed in WP3 can also be examined.

Set-up

An abstractive view of the set-up is shown in Figure 3. According to the type of transmitter, FChs are generated and multiplexed into a SCh. Several SChs are then generated (or emulated) before they enter the transmission loop set-up. At the input of the transmission loop an amplifier sets the required launch optical power in the fibre link. The output loop switch controls the appropriate loading of the transmission link and the input loop switch defines the number of circulations in the loop and therefore the transmission distances. At the output of the loop an amplifier controls the ASE noise loading for the OSNR measurements. Finally, before the receiver the examined SCh and/or FCh is extracted and fed to the receiver for the DSP-based evaluation of the transmission performance.

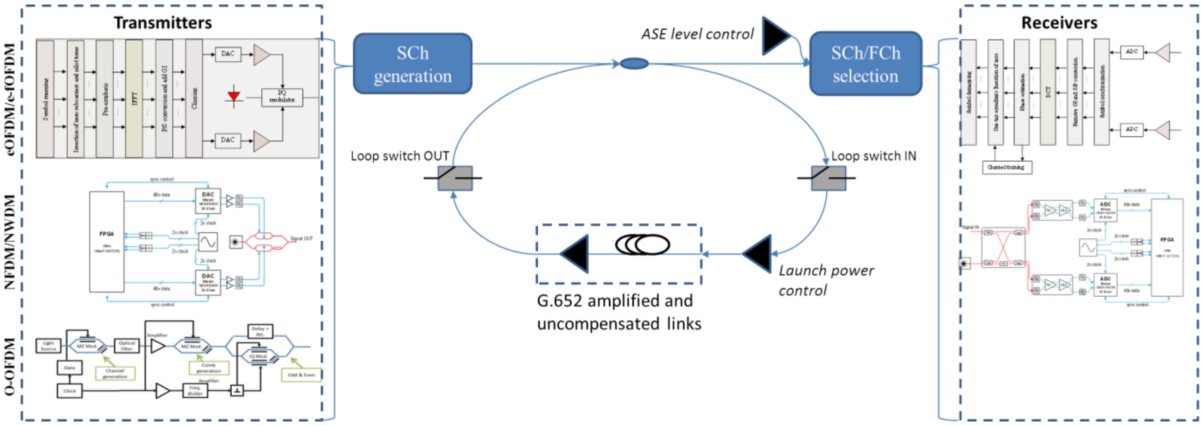

Figure 3. *An abstractive view of the set-up for the testing of different flexible signal formats*

Targeted type of measurements

The transmission performance evaluation of different flexible SCh formats and the extraction of key performance metrics is the key objective of this testing activity.

Before proceeding to the specific measurements, the initial effort should concentrate on the optimization and fine tuning of the recirculating loop based transmission test-bed, including the loop control and the set-up of the appropriate power levels.

The performance measurements should target at least the extraction of the following characteristics:

- The definition of the optimum launch optical power conditions in the fibre links for maximum performance, including the extraction of the performance penalties for different launch power levels and the dependency on the type of the FCh modulation format and the SCh spectral widths.
- The BER versus received OSNR for given transmission distances and for different types of FCh modulation formats.
- The evaluation of the cross-talk penalty with respect to the width of the spectral guard band, primarily between the FChs in the SCh.

Optionally, a set of additional measurements can be performed depending on the availability of certain solutions, their applicability in the test-bed set-up and provided that these can fit within the available time plan of the activity. Such measurement can include:

- The efficiency of different processing algorithms under various received OSNR levels at the receiver.
- The comparison between optimized offline processing and real-time processing results for the case of NFDM/NWDM, under different received OSNR levels and transmission distances

3.1.2 Testing activity 2: 1st stage FOX-C node evaluation

This activity follows the testing activity of the flexible transmitter-receiver schemes and integrates the 7.5GHz resolution WSS switching element from Finisar in the set-up. This element is the first stage of the FOX-C node and is responsible for the add, drop and pass-through of SChs. It is a common element for all the examined cases and FOX-C node solutions and practically it is the first step in the integration of the complete FOX-C node for the system tests that follow.

The reason for providing a separate testing of the first stage of FOX-C node lies on the fact that all spectrally flexible network solutions proposed today consider only the switching of SChs in the nodes performed by such WSS-based flexible elements. Therefore, this testing case complies with current solutions and forms a benchmarking case. Moreover, the specific solution provides a redesigned WSS element with finer resolution than the commercially available WSS elements and its possible added benefits are required to be examined.

Targeted requirements

The FOX-C WSS should demonstrate the functions of SCh select, add and pass-through. The maximum spectral width of a SCh to be selected (i.e. dropped) is 200GHz and the minimum 12.5GHz. The pass-through function covers the entire C-band spectrum.

The 6.25GHz addressability of the module determines the spectral guard band between SChs defined initially at 12.5GHz, but performance test should include also the 6.25GHz case, demonstrating a better spectral efficiency.

Performance results should be extracted at least for the cases of eOFDM, NFDM and O-OFDM.

Set-up

The set-up for the evaluation of the FOX-C WSS is shown in Figure 4 and includes two testing options. The first option can be used for the evaluation of the cascadability effects of the node and is the main option to be implemented. The second option is a more advanced set-up and includes a control loop inside the transmission loop that allows a SCh to be processed at a specific iteration, thus emulating different transmission distances before and after processing. For clarity purposes, in this figure, the recirculating loop set-ups are represented in an abstractive form as system elements. Both set-ups are extensions of the flexible transceiver test-bed shown in the previous sub-section.

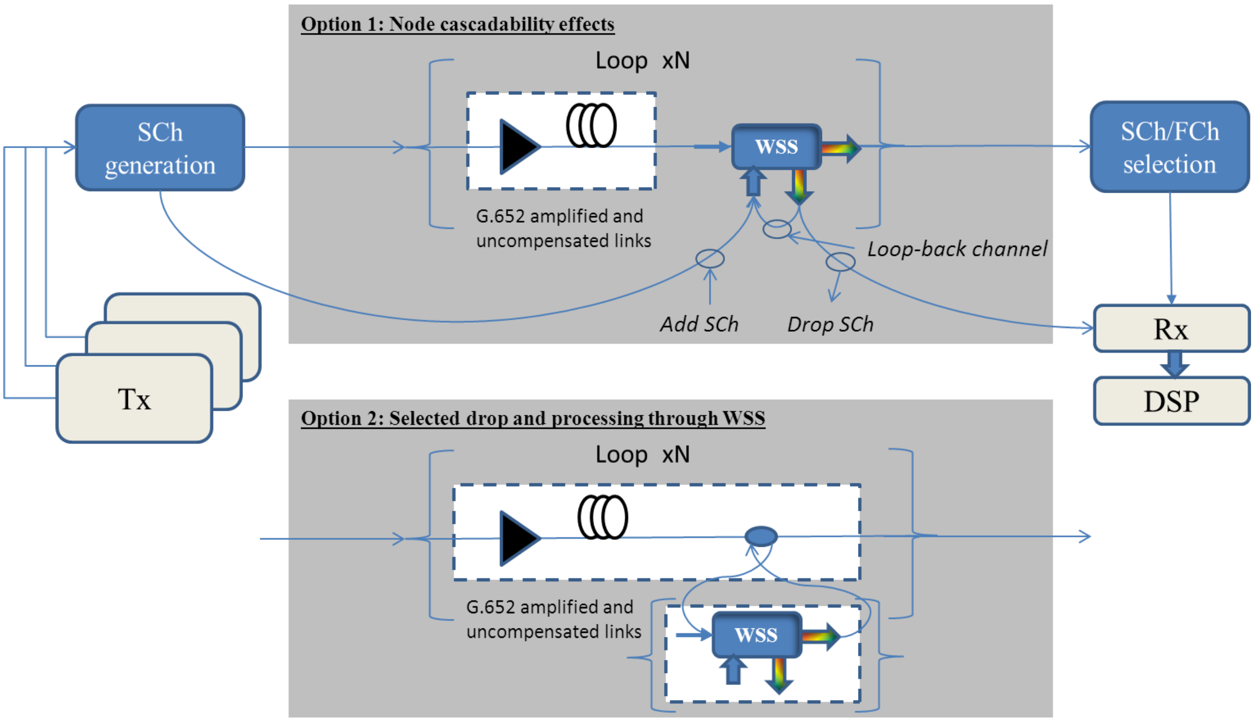

Figure 4. *The extended transmission test-bed set-up with the inclusion of the FOX-C WSS module.*

The first option includes the FOX-C WSS inside the loop arrangement and at the output of the amplified link. In each circulation one SCh is dropped and another one is added in the same spectral position. The added SCh can either be the one dropped or a new one fed by the transmitter. This set-up examines the cascaded filtering effects of the node on the processed SCh and the neighbouring ones, determining in turn the total number of nodes over an optical path that can process a SCh.

The second option can be realised by including inside the transmission loop another recirculation loop, only with the FOX-C WSS element. In this case, the inner loop can be controlled in order to allow a drop and add of a SCh at a specific circulation of the SChs inside the transmission loop. This set-up has an increased complexity in terms of control and requires modifications of the initial loop set-up. However, it can offer a common platform for any related measurement and therefore it will be examined as a solution.

It is noted that the first option complies fully with the already evaluated transmission system set-up at OrangeLabs shown in Figure 2. In case that the second option is not possible to be implemented, then the set-up of Figure 1 can be utilized for the transmission performance evaluation of the dropped and added SCh, restricted though to one node element.

Targeted type of measurements

The goal of this testing activity is to examine the following performance characteristics:

- The performance degradation due to SCh switching on both the dropped SCh and the neighbouring SChs, for different spectral guard bands and by examining the central and the edge FChs inside the processed SChs
- The transmission limits or alternatively the OSNR penalty of the pass-through channels and the added channel, with respect to the results obtained in testing activity 1
- The effect of the guard band between SChs with respect to the transmission distances before and after the FOX-C WSS node.
- The cascadability effects on the added and pass-through SChs, by determining the number of cascaded nodes for a given OSNR penalty at the receiver.

3.1.3 Testing activity 3: System testing with the complete FOX-C node

This last activity is responsible for the complete system test and includes the full FOX-C node set-up. Since there are two solutions identified for the processing of the SCh contents at the second stage of the node, two system set-up are also defined for the system tests. One is based on the use of a HSR-WSS element and applies for SChs that carry FCh with a small spectral guard band between them. The second is based on the use of the TIDE solution for the processing of the FChs and applies for O-OFDM signal formats with spectrum overlapping and no guard bands between FChs.

Targeted requirements

In both cases examined (i.e. the HSR-WSS and TIDE based node), the overall system set-up, the targeted functionalities and the targeted type of measurements are the same. The system set-up follows the set-up of the WSS evaluation from testing activity 2 and extends the node configuration in order to include the second stage. The dropped SCh from the first stage should now be fed into the second stage where its FCh contents are processed. A new Sch should then be generated with modified FCh contents and added.

The basic testing case targets, the ‘drop’ of at least one FCh from the SCh contents, in the second switching stage of the FOX-C node, with a minimum spectral width in the order of 10GHz. In this case, the remaining FChs are passed through the switch and added back in the system together with a new FCh being added at the spectral position of the dropped FCh.

Efforts should be made for evaluating also an additional testing case in which multiple FChs (ideally) with non-contiguous spectra are dropped and added from/to the same SCh. This case can also include the addition of two FChs for one dropped FCh, with at least one of the two added FChs to be located at an empty spectral position next to the original SCh. This last case emulates the dynamic modification of SCh contents at the FOX-C node which is one of the key benefits of the proposed scheme.

Set-up

The set-up for the evaluation of the complete 2-stage FOX-C node is shown in Figure 5 for the two cases of a HSR-WSS and a TIDE based node. The set-up is actually similar to the first option shown in Figure 4, and follows the design illustrated in Figure 2. Additionally, it considers the second stage in the nodes which processes the contents of the selected SCh by the first stage.

In the case of the HSR-WSS node, the dropped SCh is passed to the high spectral resolution switching stage which then selects and drops one or more FChs. At each circulation the FChs are passed to the receiver for evaluation. New FChs are added directly from the transmitters or the dropped FChs are looped back and together with the pass through FChs form the modified SCh that is added back in the system. In the case of the TIDE node a similar process is carried out. However, due the implementation complexity, the TIDE scheme processes one FCh by first selecting a copy of it for evaluation at the receiver and then by reshaping it in order to be all-optically erased from the SCh with the use of the interferometric structure. A synchronised in phase signal can be added at the same spectral position in each circulation.

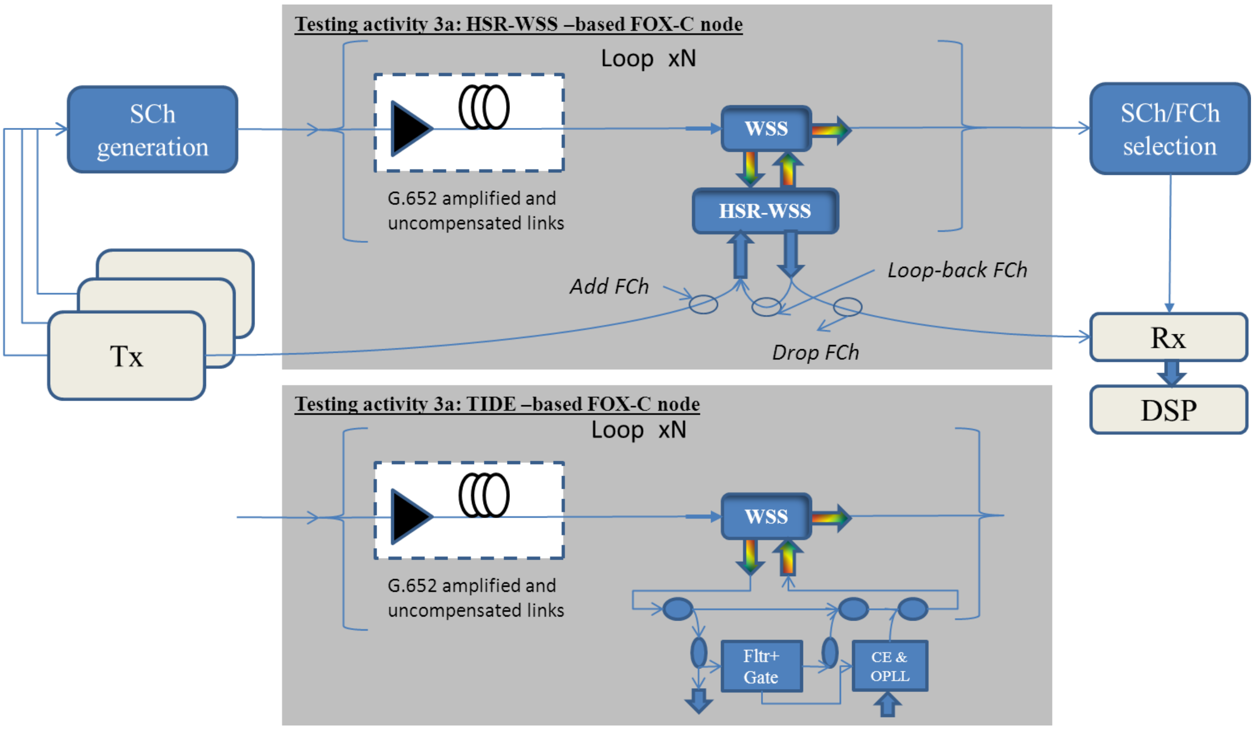

Figure 5. *The FOX-C system set-up for the evaluation of the 2-stage FOX-C node. Two alternatives are presented related to the testing of HSR-WSS (up) and TIDE (down) switching schemes.*

It is noted that the full FOX-C node can be also implemented and tested using the second option proposed in Figure 4. If this scheme is available from the testing activity 2 then it can be extended to accommodate the second switching stage, with no added complexity. If not then the transmission related performance measurements of the dropped and added FCh will be carried out by utilizing the single node transmission set-up presented in Figure 1.

Targeted type of measurements

The goal of this testing activity is to examine the following performance characteristics:

- The performance degradation due to FCh switching on both the dropped FCh and the neighbouring FChs of the processed SCh, in comparison with the direct transmission without the presence of the FOX-C node as well as in comparison with the SCh switching stage only.
- The transmission limits or alternatively the OSNR penalty of the pass-through channels and the added channel, with respect to the results obtained in testing activities 1 and 2.
- The identification of the optimum spectral guard bands between FCh, for the case of HSR-WSS, by evaluating the performance of the neighbouring FChs after transmission.
- The cascadability effects on the added and pass-through FChs, by determining the number of cascaded nodes for a given OSNR penalty at the receiver.

3.2 Test-bed implementation and evaluation work plan

The assigned time for the implementation of the complete system test-bed and the experimental evaluation of the FOX-C concept, modules and techniques is 9 months and spans from M28 to M36 of the project. In this period, the overall implementation and testing activity is divided into two phases:

➔ Phase 1 – Transmission test-bed implementation and evaluation:

Initially, the transmission test-bed provided by OrangeLabs is redesigned according to the FOX-C testing requirements. This includes also the implementation of the eOFDM transmitter and receivers (provided also by OrangeLabs) and the preparation of the test and measurement instrumentation in support of the different formats to be tested.

Next, the NFDM the O-OFDM and if applicable the e-fOFDM and O-fOFDM formats are integrated in the test-bed and examined in back-to-back configuration based on offline processing supported by the measurement equipment provided in the test-bed. The case of real-time processing for the NFDM format is also examined separately during this step for possible inclusion in the final evaluation measurements and in parallel to the offline processing.

Finally, the different formats are evaluated in terms of performance for different transmission distances inside the transmission test-bed and according to the specifications defined under testing activity 1.

➔ Phase 2 – Node integration and FOX-C system evaluation:

The implementation of the final system test-bed is performed in two steps, according to the two stages of the FOX-C node.

Initially, the redesigned WSS by Finisar (first stage of FOX-C node) is included in the transmission set-up, which is modified accordingly. At this point it is decided which of the two options referring to the position of the node in the transmission loop will be followed. The main priority will be the implementation of the second option of the selected drop and processing scheme unless the control complexity of the transmission test-bed does not allow this (see Figure 4). It is noted that the FOX-C switching concept can be successfully demonstrated with both options.

Provided that the testing work plan is executed without delays and technical problems, testing activity 2 will follow and focus on the evaluation of the first stage of the FOX-C node. This process will also assist in the re-optimization of the transmission test-bed in the presence of the FOX-C node if required.

The second implementation step integrates the HSR-WSS and TIDE stage of the FOX-C node. Both set-ups are included in parallel in the transmission test-bed, although the testing activities are performed separately for each case using the compatible signal formats.

Finally, the complete test-bed is used to demonstrate the FOX-C switching concept and to evaluate the performance of the different modules and subsystems according to the specifications defined under testing activity 3.

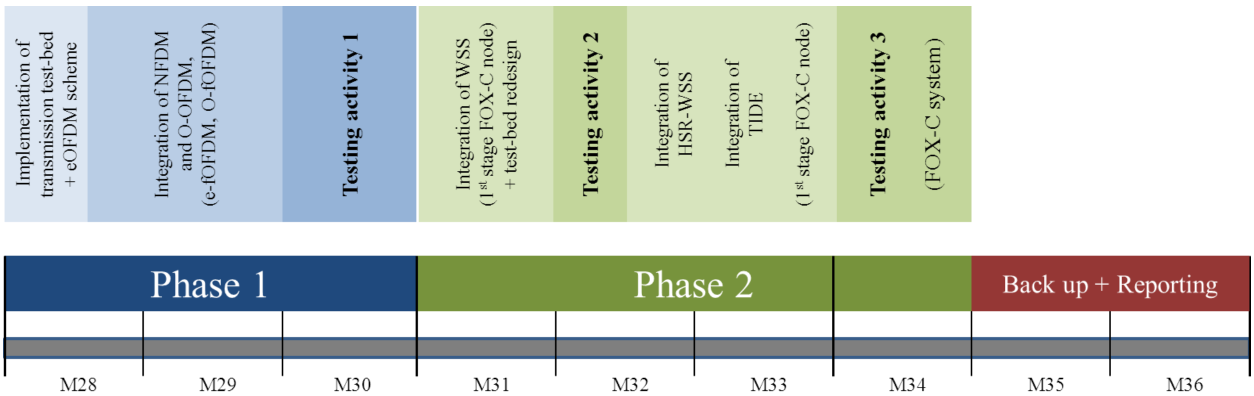

Figure 6. *FOX-C system implementation and testing time plan*

The work plan and the associated time plan are presented in Figure 6. The various activities are split into the two phases presented above, while the two last months are reserved for the final reporting and as a back-up period to resolve any possible delays.

Based on this time plan it is important to notice some key remarks:

- A relatively short implementation period is initially foreseen for the transmission test-bed. This is because a lot of preliminary work has already been carried out by OrangeLabs. This small period is assigned for the case that some small modifications are required in the test-bed in order to meet the testing requirements.
- In case that a separate transmission test-bed is established at ASTON University laboratory for the case of O-OFDM testing (see section 3.3) then this should be completed within M28 and M29 and should also include the full O-OFDM transmitter-receiver set-up. In this case the time plan for the execution of the testing activities at OrangeLabs is relaxed since the O-OFDM case is removed. In both cases, the time period for testing activity 1 is fixed for M30.
- All the flexible signal formats are implemented and tested within WP3 activities. The time assigned in phase 1 is for the integration of these tested schemes in the test-bed.
- The integration of the second stage can shift immediately after that of the first stage in case of implementation delays. In this case testing activity 2 is removed or partially examined together with testing activity 3, which includes both switching stages.

3.3 Remarks, risks and testing alternatives

The objectives of the FOX-C project can be met with the successful implementation of one switching scheme achieving the drop and add functions of FChs from a SCh at ultra-fine resolution. This is required to be demonstrated for one only flexible SCh format. However, the plan in FOX-C project is to evaluate both novel switching schemes (i.e. the HSR-WSS and the TIDE configurations) for different SCh formats. This variety of options and solutions increases the required effort for the implementation and testing activities but minimizes significantly the overall risk for the successful demonstration of the FOX-C concept. Moreover, it offers the opportunity to provide comparative results among different schemes and type of signals, covering a large area of solutions proposed in the field of flexible optical network systems.

According to the initial plan, the testing activities are performed using the transmission test-bed provided by OrangeLabs. This is an advanced transmission test-bed with state-of-the-art test and measurement equipment and includes two different designs as described in sub-section 2.1. The first design considers two separate recirculating loops. The switching node in this case can be placed in between the loops in order to examine the performance of a dropped signal (i.e. one or several FChs or even a complete SCh) after transmission and the performance of the added and neighbouring signals after again transmission. The second design considers the node within the loop and can be used to examine the cascadability effects. Both designs have been set up and used recently for multi-band eOFDM transmission experiments that resemble the required set-up for the testing of FOX-C system. A key modification in the latter design is proposed and relates with the inclusion of a second loop inside the transmission loop in order to provide increased flexibility with respect to the evaluated transmission distances before and after the switching node. In case that this modified design can be implemented then it can be commonly used for the evaluation of both the transmission and cascadability effects. It is noted that similar set-ups with dual recirculating loops have been developed and operated in the past by partners AIT and Finisar who can assist in the required modifications provided that the appropriate control signals can be successfully generated at minimum complexity and given the available time plan. If such modifications are not possible to be implemented on time, then both the available designs at OrangLabs will be implemented for the testing activities related with the node performance.

The developed modules by FOX-C partners in WP3 and WP4 activities are planned to be transferred and integrated in the OrangeLabs transmission test-bed according to the work plan presented in the previous sub-section. These include at least the NFDM transceivers by ETHZ, the e-fOFDM transceiver solution by Tyndall-UCC, the first stage WSS element by Finisar and the HSR-WSS element by HUJI.

The integration of the O-OFDM transceiver and the TIDE switching scheme (offered by ASTON) with the OrangeLabs transmission test-bed will be examined. However, a key issue identified in this case relates with the transfer of the necessary equipment and the additional effort and time required for the reassembly of the TIDE switching subsystem, since this is a bench-top prototype. An alternative that is examined is to set-up a second transmission test-bed at ASTON laboratory for the separate evaluation of the O-OFDM generated SChs and the switching performance of the TIDE scheme. In this case, a commercially available WSS element with typical 12.5GHz resolution will be provided by Finisar for the construction of the first stage of FOX-C node. Also in this case, ASTON's effort in WP6 will be fully allocated in the testing activities related with the O-OFDM transmission performance and the evaluation of the TIDE switching scheme and will include the implementation of the second transmission test-bed. Moreover, the majority of AIT's effort will be transferred in this activity to assist in the development of the second transmission test-bed and the relative performance evaluation experiments, providing if required the necessary elements for the setup of the transmission test-bed. The proposed time plan is the same for both cases. This alternative will be discussed among the partners before M26 of the project and evaluated in terms of risk and required effort, and with the goal to maximise the innovative outcomes and the visibility of the project.

4 References

{no references}

A. Addendum to testing activities and related work plan

An addendum to the testing activities and the related work plan as these were defined in version 5 of D5.1 is included in this section. The purpose of this addendum is to describe in detail the updated work plan for the final testing activities as this was agreed by all partners with effect from 1/1/2015. The addendum follows the recommendations of the EC project office received after the 2nd annual project review on the 21st of November 2014 and is pending approval by the EC project office.

The updated work plan considers a 3-month extension to the project duration, in order to complete safely and accurately all the planned testing activities, demonstrating experimentally the full potentials of the developed elements and subsystems. It is noted that the original plan as this is presented in section 3 of this deliverable is still valid for the fulfilment of the project objectives, and the extra 3 months are proposed for testing all the different solutions developed until now in the project. The purpose of this extension is to provide a more complete investigation of the project's findings and increase the scientific impact of the project.

In the following sub-sections, first a detailed description of the testing activities is provided as these were agreed by the partners of the FOX-C consortium. The addendum concludes with the updated work plan and the plan on the use of resources by the partners in order to carry out successfully the proposed activities.

A.1 Detailed description of testing activities

Testing phases

The testing activities will be implemented in two phases as these were defined in section 3.2.

Phase 1 – Transmission test-bed implementation and evaluation:
Phase 2 – Node integration and FOX-C system evaluation:

The duration of the two phases and the related work plan are defined in section 5.3.

Implementation Test-beds

Two separate test-beds will be developed to support the testing activities. The activities to be carried out by each test-bed are included in the following paragraphs.

1. The Orange Labs test bed located at partner's FT premises.
    - In phase 1, the Orange Labs test-bed will use its recirculating loop based transmission set-up (as this is defined by partner FT in section 2) and evaluate the multi-band transmission schemes of eOFDM and NFDM formats provided by partners FT and ETHZ respectively. Initially, the already established set-up will be modified accordingly in order to achieve the targeted testing requirements defined in section 3.1. Given the availability in time and human resources, the e-fOFDM case by partner UCC will be also considered for evaluation. The decision will be taken once the two main schemes are implemented and start being evaluated
    - In phase 2, the recirculating loop set-up will be upgraded and include the 1st stage WSS element from Finisar and the 2nd stage HSR-WSS element (i.e. the AWG-based filtering element) from HUJI. The set-up will be used then for the evaluation of the switching performance of the HSR-WSS-based FOX-C node for both the eOFDM and NFDM multi-band transmission schemes and the transmission performance of the processed channels.
2. The ASTON Lab test-bed located at partner's ASTON premises.

  - Remark: The ASTON Lab test-bed was not planned originally by the project to carry out any system level testing activities. However, it is implemented with the goal to evaluate the TIDE switching scheme with the O-OFDM transmission format in addition to the switching scheme and the related formats that are tested by the Orange Labs test-bed, providing a complete study of all the development in FOX-C project.
  - In phase 1, the ASTON Lab will implement a recirculating loop transmission set-up based on its own hardware resources and assisted if required by hardware resources provided by partner AIT. This test-bed will not have necessary the same characteristics (e.g. loop length, number of amplified spans etc.) as the Orange Labs test bed since it will be created based on the available hardware elements. The ASTON Lab test-bed will evaluate the transmission performance of the O-OFDM format provided by partner ASTON. Given the availability in time and human resources, the O-fOFDM case by partner ASTON will be also considered for evaluation.
  - In phase 2 the recirculating loop based set-up will be upgraded in order to include the TIDE switching subsystem. Moreover, the fine resolution WSS element (i.e. the bulk grating dual WSS solution) from HUJI will be integrated with the TIDE subsystem. The use of a commercially available WSS element will be considered if possible to emulate the functions of the 1st stage of the node. The switching performance for the TIDE-based FOX-C node will be evaluated demonstrating primarily the Flex-Ch drop/erase and add functions of the node for the O-OFDM scheme and the transmission performance of the processed channels.

Types of testing activities

The following types of testing activities are defined:

- Transmission performance evaluation of the eOFDM and NFDM multi-band schemes at Orange Labs test bed
  - Full performance characterization of all channels.
  - Optimization in terms of launch power, guard bands, DSP etc. (for both schemes)
  - Comparisons between eOFDM and NFDM performances
    - optionally including e-fOFDM if relative measurements are available

- Transmission performance evaluation of O-OFDM at ASTON Lab test bed
  - Full performance characterization (all channels)
  - Optimization in terms of launch power and DSP

- 1st stage WSS switching performance characterization at Orange Labs test bed
  - Single SCh add/drop/through performance characterization: a) w/o transmission, b) after transmission, c) followed by transmission
    - To be carried out for at least one format including basic channel performance tests and be compared against the transmission performance results
  - Cascadability effects on the add/drop SCh and the neighbouring SChs
    - Include Evaluation of the FCh at the edges of the processed SCh.

- 2nd stage HSR-WSS switching performance characterization at Orange Labs test bed
  - FCh add/drop/through performance characterization a) w/o transmission, b) after transmission, c) followed by transmission
  - Cascadability effects on the add/drop FCh and the neighbouring FChs
    - Include full performance characterization of all processed FChs and valid comparisons with the cases of 1st stage WSS switching and without switching

- 2nd stage TIDE switching performance characterization at ASTON Labs test bed

  - FCh add/drop/through performance characterization a) w/o transmission, b) after transmission, c) followed by transmission
  - Cascadability effects on the add/drop FCh and the neighbouring FChs
    - Include full performance characterization of all processed FChs and valid comparisons with the cases of 1st stage WSS switching and without switching

A.2 Updated work plan

The updated work plan considers a small extension to the project duration by 3 months. This extension is proposed due to the increased effort required in order to implement both set-ups and evaluate the different flexible channel transceivers and switching schemes fully and accurately. This will allow the FOX-C consortium to produce high quality results which are effectively expected to significantly increase the final impact of the FOX-C research activities.

The work plan presented in section 3.2 is updated and extended to M39 of the project. Two separate work plans are created, reflecting the planned testing activities at Orang Labs and ASTON Lab and are presented in Figure 7 and Figure 8 respectively. Both work plans include the two phases defined above and coincide in terms of the overall phase durations. A back up period is also reserved at the end of each phase to accommodate any unforeseen delays during the execution of the activities.

Work plan associated with the testing activities at Orange Lab test bed (Figure 7)

The first 3 months in phase 1 are assigned for the preparation of the test-bed, the integration and required modifications with respect to the e-OFDM scheme and the detailed evaluation of the e-OFDM transmission performance. The activities during the first 3-month period (M28-M30) will be carried out by partner FT at Orange Labs premises.

The following 2 month period (M31-M32) is assigned for the integration and testing of the NFDM scheme. In this period, researchers from ETHZ will be hosted at Orange Labs and will deliver the NFDM transceiver to be integrated in the transmission test-bed. They will then carry out the required testing activities in collaboration with the FT researchers and according to the standards defined for the e-OFDM scheme with the goal to produce comparable measurements between the two cases.

It is noted that by M31, partners FT and ETHZ in collaboration with UCC will evaluate if the e-fOFDM scheme could also be implemented and evaluated at Orange Labs test bed, defining the exact time frame for this extra testing activity. In case that this is agreed, a researcher from UCC will join the Orange Labs research team, provide the e-fOFDM transceiver modules and assist in the evaluation of the scheme.

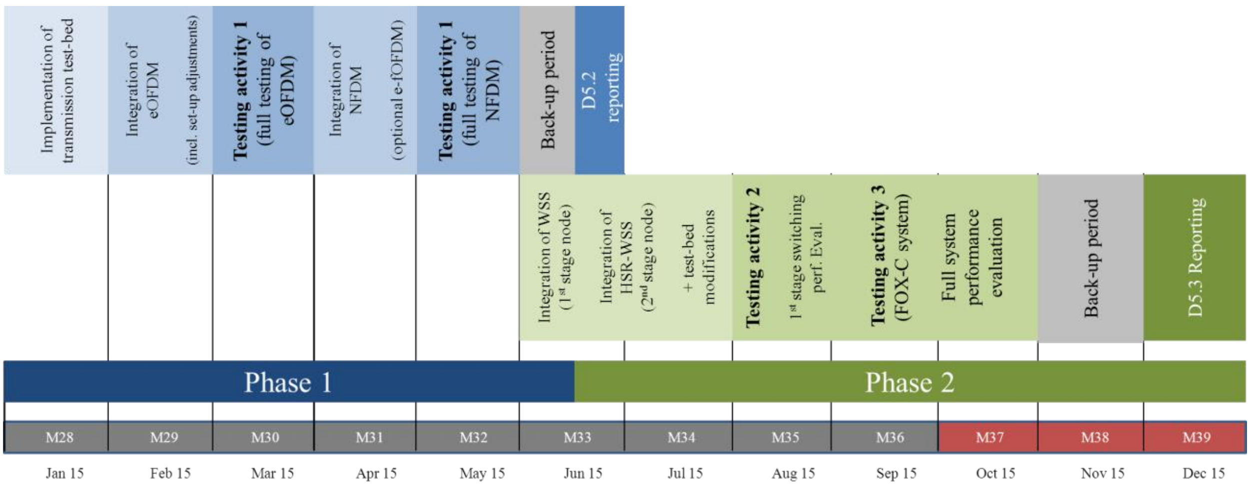

Figure 7. *Updated work plan for the testing activities at Orange Labs*

The last month in phase 1 (M33) is reserved for the editing of D5.2 and includes a back-up period in case of unforeseen delays.

Phase 2 starts immediately after the end of testing activity 1 and can only overlap with the reporting period of phase 1. The first 2-month period in phase 2 (M33-M34) is devoted to the integration of the 1st stage WSS element and the 2nd stage HSR-WSS element in Orange Labs test-bed. Partners Finisar and HUJI will deliver the two elements to the test-bed at the beginning of this period and will also assist FT in the integration of the modules in the test-bed. Researchers from partner HUJI will be hosted in this period at Orange Labs.

Following the successful integration of the switching node, a 3-month period (M35-M37) is assigned for the completion of testing activities 2 and 3. This includes a range of measurements for both switching stages (as defined in the previous subsection and the related paragraphs in 3.1). During this period researchers from HUJI, WONE and Finisar will assist the FT research team in the successful completion of the defined measurements. The measurements will include first the use of the e-OFDM scheme. Next the real-time NFDM scheme will be evaluated by the ETHZ research team who will be hosted again at Orange labs to join these final testing activities.

The last two months (M38-M39) are reserved for back-up purposes and for the editing of the final results reported in D5.3.

Work plan associated with the testing activities at ASTON Lab test bed (Figure 8)

The first 3 months in phase 1 (M28-M30) are assigned for the implementation of the test-bed and the integration of the O-OFDM scheme. The following 2-month period (M31-M32) is used for the detailed transmission performance evaluation of the O-OFDM scheme, providing a full performance characterization of all channels. The activities during this period will be carried out by partner ASTON at their premises and will be assisted if required by partner AIT. It is noted that by M31, partner ASTON will evaluate if the O-fOFDM scheme could also be implemented and evaluated in their test bed.

The last month in phase 1 (M33) is reserved for the editing of D5.2 and includes a back-up period in case of unforeseen delays.

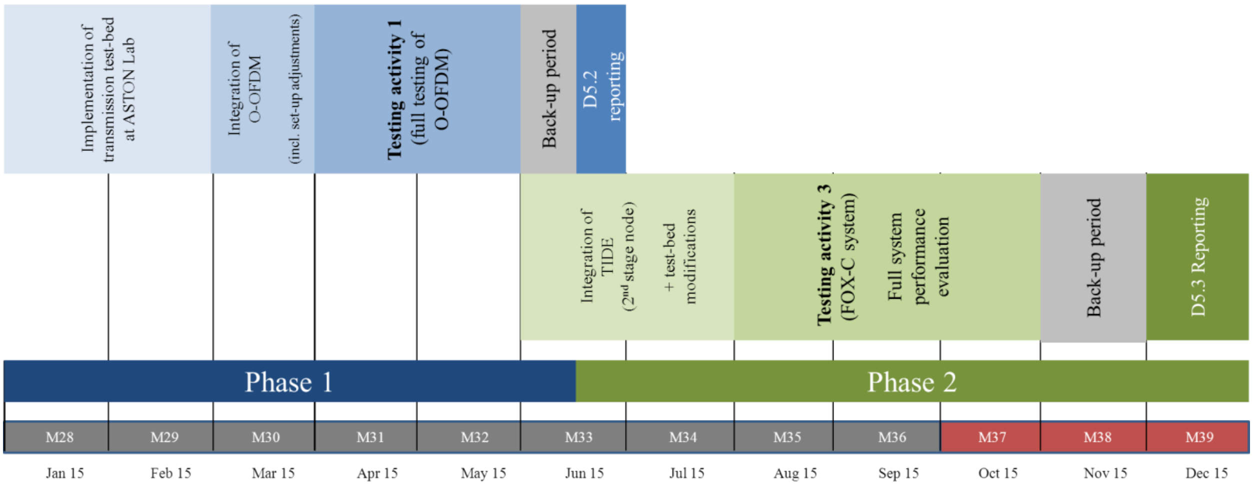

Figure 8. *Updated work plan for the testing activities at ASTON Lab*

The first 2-month period in phase 2 (M33-M34) is devoted to the integration of the TIDE switching sub-system in ASTON Lab test-bed. This includes any modifications and adjustments required in the recirculating loop transmission set-up, which will be also backed up by hardware modules provided by partner AIT. Also the fine resolution WSS element will be delivered by HUJI to ASTON Lab and integrated with the TIDE subsystem. Researchers from partner HUJI will be hosted in this period at ASTON lab. Following the successful integration of the TIDE node, a 3-month period (M35-M37) is assigned for the completion of testing activity 3, including a detailed set of measurements, as defined in the previous subsection and the related paragraphs in 3.1. All measurements will be carried out by partner ASTON and will be assisted by partner AIT.

The last two months (M38-M39) are reserved for back-up purposes and for the editing of the final results reported in D5.3.

A.3 Plan on the use of resources

FOX-C partners will allocate their planned resources for the testing activities in the two test-beds according to the following:

Orange Lab test bed will be supported by partners: FT, ETH, HUJI, Finisar, WONE and UCC.

ASTON Lab test bed will be supported by partners: ASTON, AIT and Finisar.

The following table summarizes the currently available effort and the planned effort for the testing activities in WP5 after the proposed redistribution of effort as explained in the next paragraphs.

TABLE 2. *Currently available and planned effort per partner for the testing activities*

	FT	ASTON	ETHZ	HUJI	Finisar	WONE	AIT	UCC
Remaining effort for WP5 testing activities	5.9	8.0	9.0	5.0	4.4	10.0	12.0	0
Planned effort for WP5 testing activities (after proposed redistribution)	7.9 (+2)	10.6 (+2.6)	12.4 (+3.4)	5.0	4.4	6.0	9.0	2.5

Remarks on the proposed effort redistribution:

- AIT proposes the transfer of 9PMs (partially from WP5 and WP4 activities and including the unclaimed effort in WP3) to partners ASTON, ETHZ and FT.
- WONE proposes the transfer of 2PMs to WP4 activities and 2 PMs to partner FT supporting further the final test-bed
  Note: The 9PMs from AIT and the 2PMs from WONE correspond to additional 2PMs for FT, 2.6PMs for ASTON and 3.4PMs for ETHZ considering the average PM rate of these partners declared at the beginning of the project. (More details are included in the document “Response to the second annual project review”)
- The effort from partner Finisar will be split between both test-beds providing around 70% of its effort (3PMs) to the Orange Labs test bed
- The effort from partner HUJI will also be split between both test-beds providing around 66.6% of its effort (3PMs) to the Orange Labs test bed and the remainder (2PM) to ASTON test bed.

The overall effort in WP5 is increased from 54.3 PMs to 57.8PMs. This increase in effort follows the proposed 3-month extension and is required in order to successfully implement the additional test-bed and the detailed measurements defined in this deliverable, maximizing the overall impact of the project.

The total effort allocated for the testing activities at Orange Labs test-bed is 34.9PMs and for the testing activities at ASTON lab test-bed is 22.9PMs.

The testing activities at Orange Labs test-bed concentrate a larger effort, which is attributed to the increased number of measurements on two (and possibly three) flexible channel formats and the detailed evaluation of the two stages of the flexible node. Partner FT has a major role in this activity by implementing and providing the test-bed infrastructure and all necessary modifications. FT’s effort is proposed to be increased according to the reallocation of effort from AIT and WONE. It is noted that there is an official commitment by the FT management to fully support the testing activities at their premises allocating extra effort from their own resources if required. Additionally, partner ETHZ is one of the main contributors in these testing activities at Orang Labs, providing the NFDM transceivers and being actively involved in the performance evaluation measurements in both phases of the project. ETHZ will also collect and process the results providing the comparison studies. For these reasons the ETHZ effort is increased by 3PMs (with effort transferred by partner AIT). Partners HUJI and Finisar will participate in the second phase of the testing activity and will deliver and implement the switching node. Also partner WONE will assist during phase 2 in the final measurements and the overall system evaluation. Finally, adequate effort from partner UCC is available to support the additional evaluation of the e-fOFDM scheme if applicable.

The testing activities at ASTON Lab test-bed are led by partner ASTON and primarily assisted by partner AIT and HUJI. ASTON's effort is increased by 5PMs, in order to support the implementation of the additional transmission test-bed and perform the extra measurement required for the evaluation of the TIDE node solution. AIT will assist in the development of the recirculating loop test-bed and support the necessary modifications for the inclusion of the node in the loop. Moreover, AIT will contribute in the final measurements. HUJI will perform the integration of the fine resolution WSS element in TIDE. A small contribution is foreseen for partner Finisar supporting mainly the node integration and the relative measurements.