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| **Projet ANR-N-GREEN**  **Convention ANR-15-CE25-0009-0x** |

**Deliverable D1.2**

**N-GREEN network architecture description**

Partners of the project

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# Summary

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| A REVOIR  This deliverable aims at describing the N-GREEN network architecture. N-GREENs aims at capitalizing on the rather mature technologies (mostly derived from developments realized for next-generation optical access networks). The proposed approach will be based on WDM optical packets that allow taking the best benefit from the wide bandwidth of optical gates and switches which becomes cost-effective thanks to the progresses of optoelectronic integration. These concepts will be applied in the key features of the future nodes, namely a WDM by-pass of a packet node and a WDM backplane of a high capacity (100 Tbit/s) router. The considered use cases include core and metro/core networks and also new fronthaul network architectures. |

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# List of Acronyms

|  |  |
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| BBU | BroadBand Unit |
| CN | Concentration Node |
| CO | Central Office (at the border of access and metro/access networks) |
| Core CO | Core Central Office (at the border of metro/core and core networks) |
| CPRI | Common Public Radio Interface |
| EN | Edge Node |
| Main CO | Main Central Office (at the border of metro/access and metro/core networks) |
| MBS | Macro Base Station |
| NFV | Network Function Virtualisation |
| OLT | Optical Line Termination |
| RAN | Radio Access Network |
| ROADM | Reconfigurable Optical Add-and-Drop Multiplexer |
| R-SOA | Reflective Semiconductor Optical Amplifier |
| SDN | Software Defined Network |
| SOA | Semiconductor Optical Amplifier |
| RRU | Remote Radio Unit |
| WDM | Wavelength Division Multiplexer |
| WSADM | WDM Slotted Add/Drop Multiplexer |
| WSS | Wavelength Selective Switch |

# Introduction

In this part, we describe the objectives of the deliverable. It is necessary to identify:

1. the network models that shall be studied in the second year of the project
2. the scenarios to be evaluated in terms of network physical and virtual topologies, of traffic types and demands, and of typical use cases
3. the features to be implemented in network nodes in order to support these network models
4. the KPIs to be computed in order to assess the proposed network models

We explain that the main challenge of N–GREEN is to reduce the cost and the energy consumption of Ethernet based equipment and the same time, maintain or improve the network performance.

# General context

*Synthétiser ce qu’il y a dans le D1.1*

## General context

The main evolution trends of telecom networks have been recalled in deliverable D1.1. They include a growth of the global traffic, where video contents play a major role, an increase of the proportion of the traffic issued from mobile terminals (particularly in the context of 5G introduction) and the deployment of small size data centres at the edge of regional networks. Another major change, which concerns the control plane, is the emergence of networks operated “as a service” due to the introduction of SDN and NFV paradigms. Finally, energy efficiency has become a major criteria, in order to limit the CO2 footprint of these future networks.

The introduction of optical switching technologies present a great potential for improving the energy efficiency of the switching nodes of these future regional (or metropolitan) networks. In spite of several impressive laboratory demonstrations of optical packet switches, optical switching is only performed at the wavelength channel level, e.g. in ROADMs in present operational networks. N-GREENs aims at capitalizing on the rather mature technologies (mostly derived from developments realized for next-generation optical access networks). The proposed approach will be based on WDM optical packets that allow taking the best benefit from the wide bandwidth of optical gates and switches, which becomes cost-effective thanks to the progresses of optoelectronic integration.

The introduction of a new networking technology, like the one proposed by N-GREEN, will be possible only if it is able to satisfy key challenges in terms of cost and performances. A preliminary list of targeted characteristics was shown in D1.1. for different network segments.

Regarding the cost issues, it is clear that, at least for metro networks, where Ethernet is the dominant technology, N-GREEN solution needs to be cheaper than Ethernet one. Some technical characteristics may be defined by introducing KPI (that may depend on the use cases), which can be evalued by suitable performance evaluation techniques, as described in section IV.2. These KPI include latency and jitter (end-to-end of for a given network segment) and also network availability.

Other expectations that have to be fullfiled include energy efficiency, scalability and future safeness. The later points are linked. It is clear that a disruptive technique like N-GREEN will only be introduced if it is expected to satisfy the network requirement during a sufficiently large time window. Probably around 10 years, that roughly corresponds (assuming ~30% yearly traffic growth) to the ability to support at least a 10 times traffic increase.

## Use cases

N-GREEN targets three uses cases that were recalled in D1.1:

Use case 1: A low cost solution, competitive with Ethernet technologies, based on a physical ring topology for the metro area. The network segments targeted are: the metro access/aggregation for the wireline part, the fronthaul and the backhaul links for the wireless part.

Use case 2: New solution for the metro core and the backbone, supporting mesh topologies, to implement high capacity dynamic bypasses, in order to offer an efficient interconnection layer for inter-data centre communications.

Use case 3: Modular high capacity backplane for the interconnection of line cards inside a switch/router.

However, the third use case is not related to networking issues but to node issues and thus shall not be addressed in the present deliverable.

Use cases 1 is illustrated in Figure 1. There are two types of nodes: those on the ring (described as “bridge nodes” in the next section) and the node that “closes” the ring by an electrical bridge (described as an optical switch node in the next section).



Figure 1: N-GREEN bus in a physical ring topology

Use cases 2 is illustrated in Figure 2. There are two types of nodes: those inside the bus (described as “bridge nodes” in the next section) and the node that “terminates” a bus and possibly interconnects different buses (described as an optical switch node in the next section).



Figure 2: N-GREEN buses in a meshed topology

# Description of the N-GREEN solution

## Specificities of the network solutions

### N-GREEN for metro networks

The first two use cases present the following features:

* connection oriented
* unicast and multicast support
* multiservice support (different traffic classes with different QoS requirements)
* data plane support (10 wavelengths sub-bands, fixed duration slots, payload spread over the 10 wavelengths),
* control plane support (1 control channel carried over a separate wavelength)

These characteristics can be offered either on ring or on bus physical topologies. However, in all cases the network is structured into transparent buses (“transparent” means here that traffic transiting from one bus extremity to the other does not experience opto-electronic conversion).

### N-GREEN for access networks

*This is currently not identified in the N-GREEN use cases from D1.1*

### Requirements on N-GREEN nodes

There are two types of N-GREEN nodes:

* optical bridge nodes, with 2 bi-directional interfaces that are synchronized at the time-slot level, and with add-drop capabilities (typical nodes on a ring, or on a bus)
* optical switch nodes with 2 or more bi-directional interfaces, and electrical transit between the multiple interfaces; a hub that “closes” a ring is an optical switch node with 2 bi-directional interfaces, a node interconnecting 2 rings is an optical switch node with 4 bi-directional interfaces, a node in a mesh network may present even more bi-directional interfaces

## NGREEN data plane protocols and mechanisms

### Introducing labels to support a connection oriented mode

*(from POADM publication* Sadeghioon et al. VOL. 7, NO. 2/FEBRUARY 2015/J. OPT. COMMUN. NETW. A237*)*

N-GREEN technology is able to carry different client protocols (IP, MPLS, Ethernet, SONET/SDH, etc.) in a connection-oriented mode. Each of these protocols present different encapsulation frame formats and may request different transport modes. An adaptation sublayer encapsulates all client data in a holistic manner, while supporting the various requirements. The operation of the MAC adaptation layer is illustrated in Figure 3.



Figure : MAC Layer structure and Packet encapsulation

Client data units are first encapsulated, adding network specific information. Client flows are then multiplexed, using possibly segmentation or padding, in order to obtain fixed size bursts, which shall be handled by the transport sublayer. Control information is to be carried in the control channel.

Relevant control information carried in the client header such as addressing, transport type, and QoS class, is extracted and analyzed to identify the appropriate client flow, consisting in a a forwarding equivalence class (FEC). This flow shall be identified by a service data unit (SDU) level label carried in a header associated with the client data. The SDU header also carries segmentation and reassembly (SAR) information if necessary and SDU length in order to enable burst demultiplexing at reception. The SDU-level label can be used to implicitly identify the client layer, or, e.g. the virtual private network (VPN), or the multicast flow to which the client packet belongs; this is used for correctly and efficiently addressing demultiplexed bursts at reception.

SDU-level labels can also used to identify how client flows are to be demultiplexed; priority mechanisms can be used, e.g. to speed up the transport of client flows with stringent latency requirements. At ring or bus interconnection nodes SDU flows can be groomed into new bursts without accessing the client layers.

Fixed size PDUs are created by adding specific information regarding the physical layer, framing, synchronizing, error correction, and padding. PDUs can be considered as containers that group multiple SDUs with the same characteristics. Scheduling rules are used to select which PDU, if any, is inserted in each time slot.

Since all the nodes can potentially receive all the traffic, a node needs a means to recognize each flow, per time slot (and per wavelength band if there are multiple bands).

This is done thanks to packet-level information carried by the control packet. Control packets are electronically processed at each node, in order to identify which optical packets need to be received and whether a new packet can be inserted. A node identifies which PDUs to receive and extract

using PDU-level labels in the control packet characterizing each PDU carried in a given time slot.

### Insertion/extraction processes

When the node is allowed to insert an optical packet, the electronic PDU to be transmitted is split into 10 pieces which are sent simultaneously on the 10 data channels of the wavelength band, and the control packet is correspondingly updated.

Introduce figure

The process deciding that the node is allowed, or not, to insert an optical packet may differ depending on how the network is operated:

* Opportunistic insertion: whenever a slot is empty, a node can use it to transmit an optical packet; the node may decide not to use it if it considers that none of the PDUs currently being build is ready for transmission;
* Reservation mode: a slot may be empty but reserved for another node, or another class of service.

A node decides to receive a packet when the PDU-level label carried by the control channel indicates that this packet belongs to a flow sent to the node.

* The node may receive the packet and free the corresponding slot by erasing the packet; this is typical for the unicast support;
* It may also receive only the packet, without erasing it; this is typical for the multicast support;
* In the multicast case on a ring, a node may be responsible to erase a packet without receiving it.

### Scheduling

Scheduling is internal to each node. It consists in selecting the packet to be transmitted when multiple packets are ready to be transmitted.

The scheduling decision can be destination based and/or CoS based; CoS covers both data plane performance, protection level and type of traffic (unicast vs multicast).

### Fast control by the control channel

The control channel carries information that characterizes the data which is currently carried in the slot. The node relies on this information to assess whether the packet is to be received and/or erased; this is done by matching the PDU-level label with an entry in the switching information table.

A node either inserting or erasing a packet carried in a slot has to update the corresponding information carried in the control packet.

### Requirements on the network nodes

A classical label-based operation is implemented in each N-GREEN node thanks to multiple local tables shown in Figure 4.

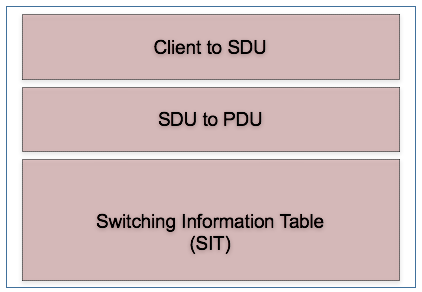


Figure 4: Forwarding Information Base for an N-GREEN node

* The client to SDU (CTS) table binds a client flow to a given SDU label
* The SDU to PDU (STP) table binds SDU labels to a PDU label (and thus to a flow within the N-GREEN network).
* The switching information table (SIT) maps PDU-level label to the action (i.e., operation) that the node takes on the PDU (receive, insert, erase).

At each time slot, the node processes the control packet in order to identify which action(s) to take, based on the PDU-level label characterizing each PDU. If the label is not listed in the SIT, the PDU is passed transparently. Otherwise, the SIT identifies which of the four following actions is to be taken:

1) Receive-erase: the node receives the PDU and strip it off.

2) Receive-pass: the node receives the PDU but does not erase it from the ring.

3) Erase: the node erases the PDU without receiving it.

4) Receive-insert: the node extracts the PDU and modifies the label stack   
(e.g., pops the outer label), and retransmits the PDU into the network.

The first three actions occur when the node is either a source or a destination for the flow within a single ring. The last one occurs in a hub with POADM interfaces on two or more nodes. Inter-ring or inter-bus traffic corresponds to optical PDUs that a hub receives on one ring/bus and inserts on the other.

The local tables only contain information regarding the labeled flows that are handled in the electronic layer by the N-GREEN node. When a PDU label does not figure in the SIT, the flow passes transparently through the optical layer. This is very positive in terms of configuration and complexity[[1]](#footnote-1).

The CTS, STP, and FIT tables shall be downloaded by the SDN controller. They are updated if there is a new entry or a change within the network (e.g. a failure, as part of protection policy) .

## NGREEN control plane protocols and mechanisms

### Splitting the control between the node and the SDN controller

There is a fast control realized thanks to the control channel, and a slower, although dynamical, control realized thanks to the SDN controller.

The SDN controller is in charge of matching client flows to SDU level labels and to match SDU level labels to PDU levels. Information relevant to each node is downloaded by the SDN controller within the forwarding tables to be used by the node. Only the SDN controller has a global view of all the flows carried inside the network.

*Which protocol is used to download the forwarding information?Could it be an extension of OpenFlow?*

*Do not forget configuration issues and monitoring issues;*

*in particular, how is a failure reported to the SDN controller?Is the reaction to a failure to be distributed within the nodes or to be centralized by the SDN controller?*

### Local Control with the control channel

* We present the opportunistic control plane that enables a competition between nodes to access to the channel and reserve slots.
* Reservation mode : a node can only use for a given flow specific slots which are reserved for the flow

Any alternative?

### Control by the SDN controller

The SDN enables the control of the different components of the nodes to improve the reactivity of the network facing traffic profile changes, network upgrade or a failure issue.

## NGREEN protocols and mechanisms for protection

This section aims at presenting the different protection protocols that we have proposed to N-GREEN.

To be discussed: in the POADM proposal, we considered that the reaction to failures was directly distributed within the nodes, which presents the following requirements

* Complexify the nodes, because they have to know the path taken by each flow they are either inserting or receiving
* Increased recovery delay, as the reaction is very fast, due to the implicit failure indication carried by the control channel

In N-GREEN, we could either consider the same distribution, or we could decide to deport the intelligence within the SDN controller which would thus download new tables every time a failure occurs.

# Approaches for Performance and techno-economic evaluation

## Specification of the KPIs, the target scenariosand selected benchmark

### KPIs

The performance parameters include: the end-to-end packet delay, packets jitter, packet loss ratio, etc.

### Target scenarios

For performance evaluation, for dimensioning and for techno-economic evaluation

### Benchmarks

The first benchmark is the current electronic packet network based on Ethernet carried over an optical transport network (ROADM). This can be referred as “packet optical” in the literature (?).

Other benchmarks can be considered: optical circuits based on ROADM, optical packets with either ECOFRAME or TWIN architectures

## Performance evaluation approaches

In this section we show the methodology adopted to assess the performance of the network. In order to avoid distorting the results, the extra-resources allocated for protection are not considered in the performance study.

### Mathematical models

The access to the medium is mathematically modeled using the queuing theory.

### Simulation platforms

Describe the simulation tools hat are taken into consideration. The scenario contains the physical and the logical topology, the traffic matrix, the QoS of flows.

### Simulation scenarios

The following texts seems to be very detailed. To be simplified?

#### Buffer dimensioning

#### Insertion delay

Insertion delay refers to the time for which client traffic must wait before it is aggregated in the optical packet. Two processes may have impact on the insertion delay. The first one is the waiting time in the electronic buffers (known as buffering time). Although we assume that electronic buffers have infinite sizes, buffering time may vary depending on whether classes of service are considered or not and also thanks to statistical multiplexing. The second one is the waiting time for container full (or partial) filling (container construction). For instance, best effort traffic can be taken off from the optical packet if high priority traffic arrives before sending the container. In addition, the waiting time for packet insertion can be as small as 1µs if the ring is busy when the container is constructed. This is specific to N-GREEN node whereas this time is at least equal to 10µs for other optical slot switching technologies like POADM.

The insertion delay should be less than 250µs at each terminal taking into account 5G requirements. Some already obtained results from node-level simulations show that this delay is mostly less than 20 µs whatever the load. Furthermore, the insertion delay could be further minimized taking benefit from the N-GREEN over-dimensioned nodes in low load cases. To this end, we will evaluate two different scenarios. In the first scenario, the non-used wavelengths assigned to given time slot might be used by another node provided that the corresponding fixed lasers are free (resource sharing in spectral domain). This last constraint may reduce the efficiency in resource utilization. The second scenario shares resources instead in the time domain. In other words, it considers a very small time granularity (e.g., 100 ns) in order to better use the partially used resources and therefore improve latency. However, additional time guard bands should be considered in the last scenario.

Two methods of packets emission will be proposed. By analogy with switch modes, the first emission method is called “cut-through emission”: WDM packets are constructed from waiting electronics packets in the buffer and sent immediately on the available slots of ring, while these electronic packets are not expected to have enough client traffic to build full WDM packets. This method may reduce the latency but the resources’ use may be not optimum. In the second method, called “store and forward emission”, incoming electronic packets are buffered inside a filling buffer and constructed WDM packets are sent after a threshold is reached. The threshold could be a certain percentage of capacity (electronic packets remain memorized until sufficient information is collected for the optical packet creation for example after each constructed 7 μs instead of 10 μs, i.e. 70 %), or using a timer based mechanism.

#### Periodic latency guarantee

The current mobile network architecture consists in distributed radio access networks. The evolutions proposed in next generations aim to build centralized radio network architectures (C-RAN) to reduce consumption costs and power at the base stations. These C-RAN architectures include simplified base stations at each antenna (Remote Radio Heads: RRH) and central processing units (baseband unit: BBU) located in the cloud. Thus, this type of architecture confronts the problem of controlling the latency in the transfer process. Low latency is considered critical for the 5G, in particular for the deployment of the C-RAN approach (allowing time constraints like HARQ to be fulfilled over non dedicated networks), or to reach E2E expected latency from 1 to 10ms (depending on targeted services). One specificity in the C-RAN context is not only the latency constraint, but also the periodicity of the data transfer between RRH and BBU. New scheduling and routing paradigms and new technologies have to be considered to guarantee delay constrained periodic data transfers. Dynamical optical bypass and dynamical management of the emission should be considered to guarantee latency constraints.

In this context, the requirement is to make progress optical networks towards high capacities and low latencies at reasonable cost. In particular, considering the CPRI standards, in case of multi-antenna deployment, the set of antenna links may advantageously be multiplexed onto different optical wavelengths, considering Wavelength Division Multiplexing (WDM), Coarse WDM and/or Dense WDM. The introduction of DWDM in fixed optical access networks (standard NG-PON2) is consistent with this approach in the DWDM optical fronthaul and participates in the fixed-mobile convergence.

These periodic communications will thus bring requirements for latency, availability and security of transmissions that the node and network architectures have to ensure. New scheduling and routing paradigms have to be implemented at the control plane level to solve this periodic and delay constrained data transfer. Indeed, one of the most promising approaches relies on the concept of Deterministic Networking (DN) such that one gets rid of statistical multiplexing. The traditional queue managements are replaced by time based forwarding. Solutions for Deterministic Networking are under standardization in IEEE 802.1 TSN group, as well at IETF DetNet working group. To make DN working over an optical WDM network composed of several nodes, it is required to manage the time at which the slots of deterministic paths are crossing each node, and all the nodes through the network have to be sufficiently synchronized to avoid contention.

#### Mono vs multiclass of service

We will consider the mono-class approach in which all clients traffic is gathered in the same queue without CoS distinction. The approach treats all types of electronic packets in the same way. We will consider also multi-class approach, in which electronic packets will be classified according to its CoS. However, we will provide better QoS (lower latency and PLR) for higher-priority CoS. In order to obtain the best performance, different methods of packets’ emission will be tested namely cut-through mode or upgrading from lower to higher priority classes, store and forward mode with different threshold for each CoS, pre-emption in the favor of the higher-priority classes. These CoS policies can also be applied at the transit level. For instance, low priority transit traffic might be buffered at intermediate nodes if high priority traffic containers are constructed and are still waiting for free time slots.

#### Mechanisms of slot transmission in both rings

The performance of N-GREEN node will be investigated within different mechanisms of slot transmission, in particular in double rings architecture, as it is common for metro aggregation networks. Here, we propose that the two rings are used for transmission and protection targets. Each ring has a different direction of transmission.

The 1st scenario, called “double bidirectional transmission”, consists of sending the same packets on the two rings simultaneously. Each destination receives its packets twice via the two directions, so the resources’ use is not optimum. However, this scenario guarantees the protection: in case of path failure through one ring, packets will arrive to their destinations through the second ring. A second advantage of this scenario is the control simplicity.

The 2nd scenario, called “shortest path unidirectional transmission”, consists of sending packets to their destinations through the ring which its direction corresponds to the shortest path. The shortest path may be determined by the transmission distance, for example the path with less intermediate nodes, or by the load. In case of path failure through one ring, packets will be reemitted via the second ring. The use of the resources is optimum but at the expense of the control complexity (determination of the shortest path, informing the SDN orchestrator in case of failure, reemission via the second ring). Moreover, in case of path failure, the latencies may be higher than those of the 1st scenario, since the packets must be re-emitted via the second direction (ring).

The 3rd scenario, called “distributed unidirectional transmission”, consists of sending a certain percentage x% of the traffic via a first ring and the rest y% via the second ring. The resources’ use is not optimum as in the 2nd scenario but could better than the 1st scenario. In case of path failure via one ring, just one part of the traffic (x or y%) will be re-emitted through the second ring. Each scenario of slots transmission and each emission method results in a different energy consumption state that we will estimate in order to determine which scenario/emission method leads to the best compromise between the performance (in terms of latency and PLR) and the energy consumption.

## N-GREEN networks dimensioning

This section describes of the dimensioning methodology adopted to dimension N-GREEN and the reference technologies.

## Techno-economic assessments

In this section, we describe the techno-economic method adopted in computing the CAPEX and the OPEX. The target is to compare the total cost for various technologies over a 10 year period

## Energy consumption evaluation

In the second year of the project, we shall compare the energy consumption of the different technologies. The tool to be used is GWATT.NET.

# Physical aspects

## NGREEN physical limits

We give the expected physical limits of N-GREEN of the optical layer in each network segments. The technologies expected to be available in the near future (and previously described in D1.1) are those that shall be used to implement N-GREEN networks.

## Upgradability and scalability issues

This section describes of the potential of the N-GREEN solution in terms of upgradability and scalability.

How different is this from physical limits in the previous sub-section and techno-economic analysis in the previous section

# Conclusion

After a brief reminder of the most important points realized in the first year, we describe the studies for the second year of the project, especially the PoC.

# Requirements for performance studies (5 pages) (input for WP3)

## Buffer dimensioning (Annie ?)

## Insertion delay (Tulin, Amira, Wiem, Djamel, Dominique Barth ?)

## Periodic latency guarantee

## Mono vs multiclass of service (Djamel, Amira, Wiem)

## Mechanisms of slot transmission in both rings (Tulin, Amira, Wiem)

1. If a label is errored, no node would then ever erase the PDU. This can be solved by a simple time-to-live (TTL) field to be updated every time a PDU passes a node, even if it is passed transparently, as the control information for each data PDU is electronically handled in every node. [↑](#footnote-ref-1)