STRONGEST Fundamentals

"Scalable, Tunable and Resilient Optical Networks Guaranteeing Extremely-high Speed Transport"

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(Adapted from Annex I, Part B of the Project Proposal)

Abstract

STRONGEST ("Scalable, Tunable and Resilient Optical Networks Guaranteeing Extremely-high Speed Transport") is an Integrated Project that was approved within the fourth Call of the Seventh Framework Programme of the European Commission (Theme 2009.1.1 "The Network of the Future") and started its activity on January 1st, 2010. The consortium brings together 17 partners, chosen among major European industrial players,leading Telecom operators, Universities and Research Centres.

The present text describes in a plain way the rationale standing behind the Project, evidencing the limitations of existing transport networks (scalability, power consumption, quality of service, cost), delineating the expected evolutionary scenarios for the next ten years and presenting the proposed network solutions that will be investigated in details and demonstrated during the Project lifetime.

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Introduction

Internet traffic has been growing quickly for many years, despite changing economic conditions, and this growth will continue in the future, requiring transport networks with a capacity larger by at least an order of magnitude than currently. To cope with this evolution, the cost of today's network solutions is still too high. In addition, in line with the EC goal of reducing the overall emissions, energy efficiency should be widely improved, using whenever possible optics instead of electronics where only transport is required. Moreover, due to the unpredictable traffic increase, flexible bandwidth management has to be used instead of fixed allocated bandwidth. Finally, end-to-end QoS must be ensured through different network domains.

For these reasons, the key requirements of innovative ultra-high bandwidth networks refer to scalability, energy efficiency, flexibility and assurance of end-to-end quality of service, beside reduction of total cost of ownership.

In the data plane, current equipment and network architectures still provide limited scalability, are not cost-effective and do not properly guarantee end-to-end quality of service. In the control plane, the open issue is to define an end-to-end control structure that allows different technologies and domains to inter-work efficiently, incorporating virtualization of network resources.

Based on these rationales and aimed at coping with the related issues, the Project proposal STRONGEST (*"Scalable, Tunable and Resilient Optical Networks Guaranteeing Extremely-high Speed Transport")*, was presented by a consortium of 17 European partners for the 4th call of the EC 7th Framework Programme (Theme: "The Network of the Future") and was approved.

STRONGEST is operating since January 1st, 2010; its main objective is to design and demonstrate an evolutionary ultra-high capacity multilayer transport network, compatible with Gbit/s access rates, based on optimized integration of Optical and Packet nodes, and equipped with a multi-domain, multi-technology control plane. This network will offer high scalability and flexibility, guaranteed end-to-end performance and survivability, increased energy efficiency and reduced total cost of ownership. Beside the identification of the optimized network architecture, feasibility studies and experimental implementation and demonstration of prototypes will be key activities, as well.

In the following sections the rationale standing behind STRONGEST and the main Project objectives will be described, evidencing the limitations of existing transport networks (scalability, power consumption, quality of service, cost), delineating the expected evolutionary scenarios for the next ten years and presenting the proposed network solutions that will be investigated in details and demonstrated during the Project lifetime.

Will present transport networks survive until 2020?

New applications, an increased number of users and a higher bandwidth usage per user will lead to massive core bandwidth growth. How can that amount of information be transported? In addressing this fundamental question, we are concerned with four issues: (i) the future bandwidth required will be at least an order of magnitude higher than currently, (ii) despite this, transport network equipment must use less electrical power than today, (iii) end-to-end quality of service must be ensured throughout heterogeneous network domains that use different technologies and belong to different operators, (iv) the transport network cost will have to rise sub-linearly with bandwidth to allow users to afford it. The following sections expand on these basic issues.

Huge bandwidth growth

The throughput of the Internet has been growing exponentially for more than 20 years, independent of economic boundary conditions like the burst of the internet bubble in the year 2001. It is expected that this growth will continue for the coming years, again independent of the momentary economic conditions. Moreover, in an attempt to overcome the current (2010), dramatic slowing down of economy, many countries are significantly supporting the expansion of public information infrastructure, that will lead to even higher growth. This growth is driven partly by the evolution of existing solutions to higher bandwidths, and also an increase in user base.

Also, new, potentially disruptive services will appear; in the residential market we will see triple-play with ultra-high definition video, 3D Internet, 3D-multimedia, and multimedia supported social networking. Additionally business services and other demanding applications such as Tele-Medicine or applications which we cannot imagine today will eventually gain huge momentum. Table 1 shows the large bandwidth requirements from some of these services, showing that access rates of between 100Mbit/s and 1Gbit/s will be required.

Table 1 - Intensive bandwidth consuming applications

Some applications requiring low latency and intensive bandwidth consumption		Bandwidth
Business services	Optical VPN	1-100 Gbit/s
	SAN	1 Gbit/s
Tele-Surgery	Decoded HD video	1 Gbit/s
Ultra High Definition Real Time Contents	Ultra HDTV (UHDTV)	400 Mbit/s
Residential Services	2D High definition TV/ Videoconference	10-15 Mbit/s / per channel
	3D High definition TV/videoconference	100 Mbit/s per channel

An example for the traffic growth is shown in Figure 1. The figure shows the average and peak traffic through the German internet exchange node DeCIX from January 2007 to February 2009 (800 days). It can be seen that the average traffic increased by a factor of about 5 in this time and the peak traffic even more by a factor of about 7.

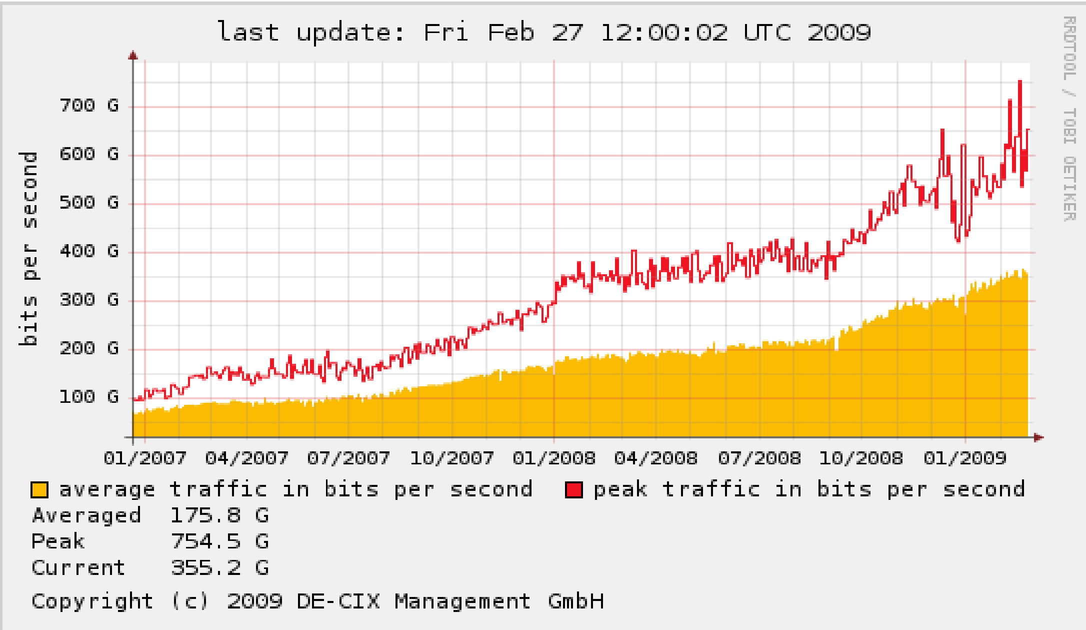

Figure 1- average and peak traffic at the German internet exchange node DeCIX since Jan. 2007

Existing broadband access in Europe is typically multi Mbit/s. To meet the access requirements for services mentioned above, optical fibre in the access network will be installed. Indeed, utilising soon to be available WDM PON technology [ROHDE], this will increase to 1Gbit/s per customer by 2020.

Current networks are heavily contended: if all consumers demanded bandwidth simultaneously they would only receive a small fraction of their maximum rate. The networks rely on statistical multiplexing gains. In the future, the growth of new, bandwidth hungry services will create a heavy demand on the core network. Services based on video will inevitably have long hold times, implying that high statistical multiplexing gains will not be available and contention will need to be reduced to maintain acceptable service.

A simple calculation reveals the magnitude of the problem. If we consider a country with about 20 million residential customers and with 1.000 access nodes, such as Great Britain, Germany, France or, then the average number of customers per node is 20,000. If they each demand 1Gbit/s, then assuming a 10:1 contention, the average net demand on each access node will be about 2Tbit/s. Variations on this model

reveal demands of anything between 1 and 10Tbit/s – which in any case is close to the maximum capacity on an optical fibre, using current technology. The core network will be required to deliver this bandwidth from each of the 1000 access nodes to Service Provider's content servers. The result will be multiple, parallel optical transmission systems, carrying multiple Tbit/s of aggregated traffic.
Clearly this raises issues related to high capacity transmission, but it also implies that future transport will require multiple fibre pairs, very large capacity optical switching at wavelength and fibre level, and very different architectures to handle these traffic volumes. Apart from the physical layer issues, such huge traffic will cause problems at the higher layers, when needing to be content aware, and providing quality of service. Thus the design of large scale, intelligent metro/access nodes becomes a significant challenge.

Customers expect more bandwidth at the same price

Consumers are currently paying roughly the same for Broadband as they were originally for dial-up access, which offered several orders of magnitude less bandwidth. This was economically viable for operators because the original core networks already had sufficient capacity to accommodate the relatively low internet volumes. However, in the future, as access bandwidth increases by yet further orders of magnitude, the core will have to be upgraded by the same factor. It is unlikely that consumers will be willing to pay equivalent orders of magnitude more, and therefore network operators will not have an economic incentive to build core networks requiring significant capacity upgrades. So the upgrade must come at a significantly lower cost than today.
Network costs of current all IP network architectures strongly depend on traffic growth. As we can see in Figure 2, such a cost increase will impact on the ISP's margins. Therefore, new architectural solutions able to face with the expected traffic increase in a cost effective way are needed in order to assure a low cost broadband Internet access in Europe.

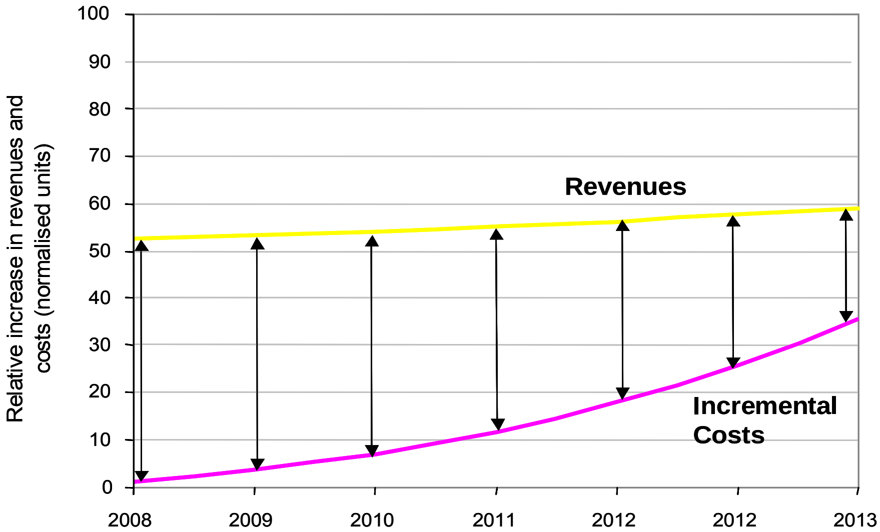

Figure 2 - Reducing margins vs. bandwidth growth for existing network architectures

The addition of thousands of wavelengths will demand an automated control plane to perform realistic management as well as limit the potentially enormous Operational Expenditure. A multi-layer control plane will give additional OPEX reduction and other benefits.

Electrical power efficiency

Two main questions arise.
How can a large bandwidth be supported in a cost efficient and power efficient way? How can an economic, low power edge node be designed to cope with such huge traffic?
Currently the power consumption of ICT is estimated to account for approximately 2% of the global greenhouse gas emissions. About 14% of these emissions is attributed to the telecommunication networks. Note that this does not include the data centres (16%) or the user premises devices such as modems and PCs (18%) [PICKAVET]. According to the university of Minnesota the current (year-end 2008) annual traffic growth rate worldwide is about 50-60%. The monthly Internet traffic rate (year-end 2008) was between 5 and

8 EB (ExaByte = 10^{18} bytes). In Western Europe the monthly Internet traffic per capita is about 3.2 GB. It is safe to say that these figures demonstrate a paradigm shift is required in the network in order to sustain the growing traffic rates while limiting and even decreasing the power consumption.

In the current telecommunications networks the vast majority of the power consumption can be attributed to mobile and fixed line access networks. Fixed line access networks consume twice as much power as the mobile access networks but due to a higher growth rate the share of mobile access networks will increase. Currently access networks are mainly implemented with copper based technologies such as ADSL and VDSL. This is mainly for historical reasons. The backhaul networks are implemented in optical fibre. The current trend is to replace the copper based technologies by fibre. This is mainly due to the significantly higher bandwidth, lower power consumption of fiber technologies and the reduced sensitivity of the power consumption to increased bit rates.

Additionally, with increasing bit rates the power consumption for routers is becoming a bottleneck as well. Access network power consumption is typically connection-driven. This means that the power consumption mainly depends on the number of active connections. Especially with fibre technology being rolled out it is to be expected that the access network power consumption will remain constant over the coming years (while heavily increasing the capacity). Routers, on the other hand, have exponentially increasing power consumption as a function of the bit-rate. This is demonstrated in Figure 3 [PICKAVET]. Note that on the left hand side the smaller routers used in access networks are displayed. If this trend is continued the share of the core and aggregation networks will largely increase compared to access networks. In Japan for example it is to be expected that by 2015 routers will consume 9% of the nation's electricity.

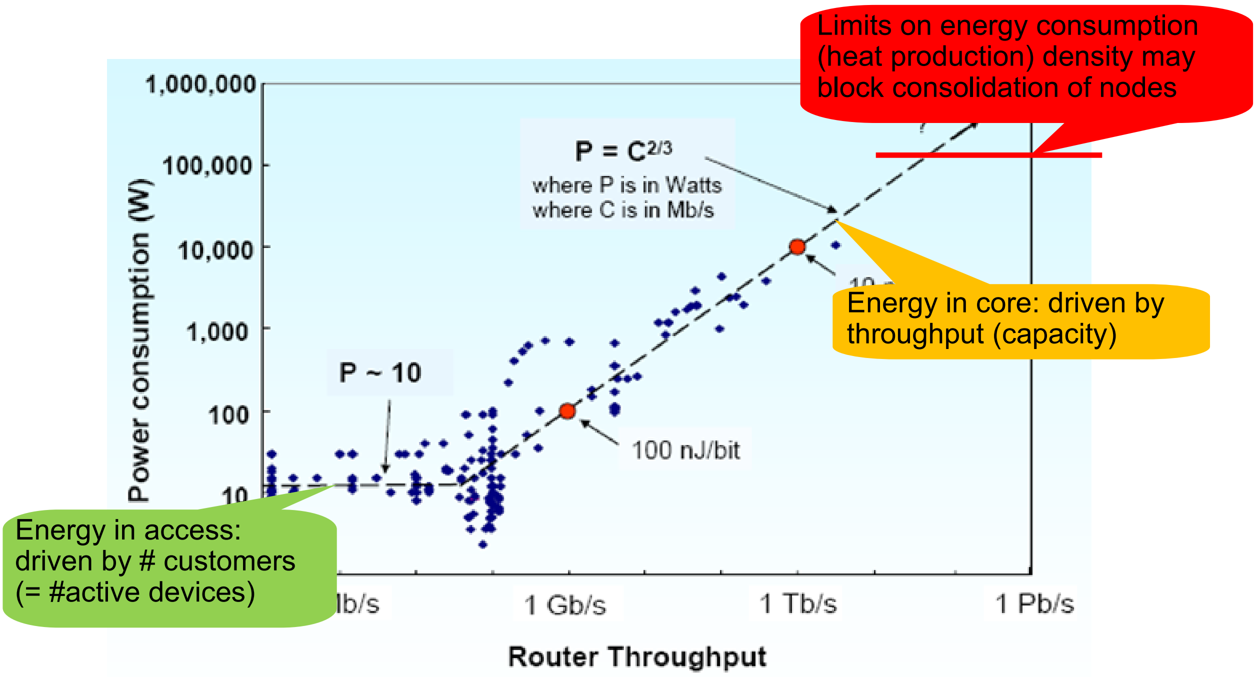

Figure 3- Power consumption of routers related to throughput [PICKAVET]

Currently, the access network is dominating overall energy consumption, but in the future the core will become increasingly important and feasibility limits may be reached (due to growing traffic volumes and more node consolidation). For these reasons innovation needs to stay well below these limits, even to avoid further growth of energy demand.

Worldwide the energy consumption for ICT is really huge (more than 150 GW in 2007) and is growing with traffic demand. STRONGEST is addressing metro/core transport networks where the main components of power consumption are routers and data centers.

With increasing traffic throughput, routers and data centers will have to face with scalability and energy limitations.

Since the router energy consumption increases with throughput, STRONGEST leverages on new architectures to reduce the number of routers, assuming that traffic switching will be preformed as far as possible in the optical domain. The Project also addresses the optimum placement of content servers and novel content distribution schemes, to avoid unnecessary multiplication of traffic and related energy consumption

End-to-end quality of service

Present networks only guarantee intra-domain QoS, but do not assure end-to-end QoS, with technical and commercial implications.
If, in the future, more sophisticated transport technologies is used, including for instance virtualization of resources, monitoring and assurance of end-to-end quality will become mandatory. This will also facilitate quick and low-cost introduction of new services.

The network we have today

Although it is hard to identify a unique network architecture generalising those that are used at present in different countries by different operators, nevertheless we can outline some typical, common characteristics of existing networks, with the help of Figure 4. (Roughly speaking, architectures are identified by network topology, number of nodes in the different segments, and layer 1, 2 and 3 technologies connecting them.)

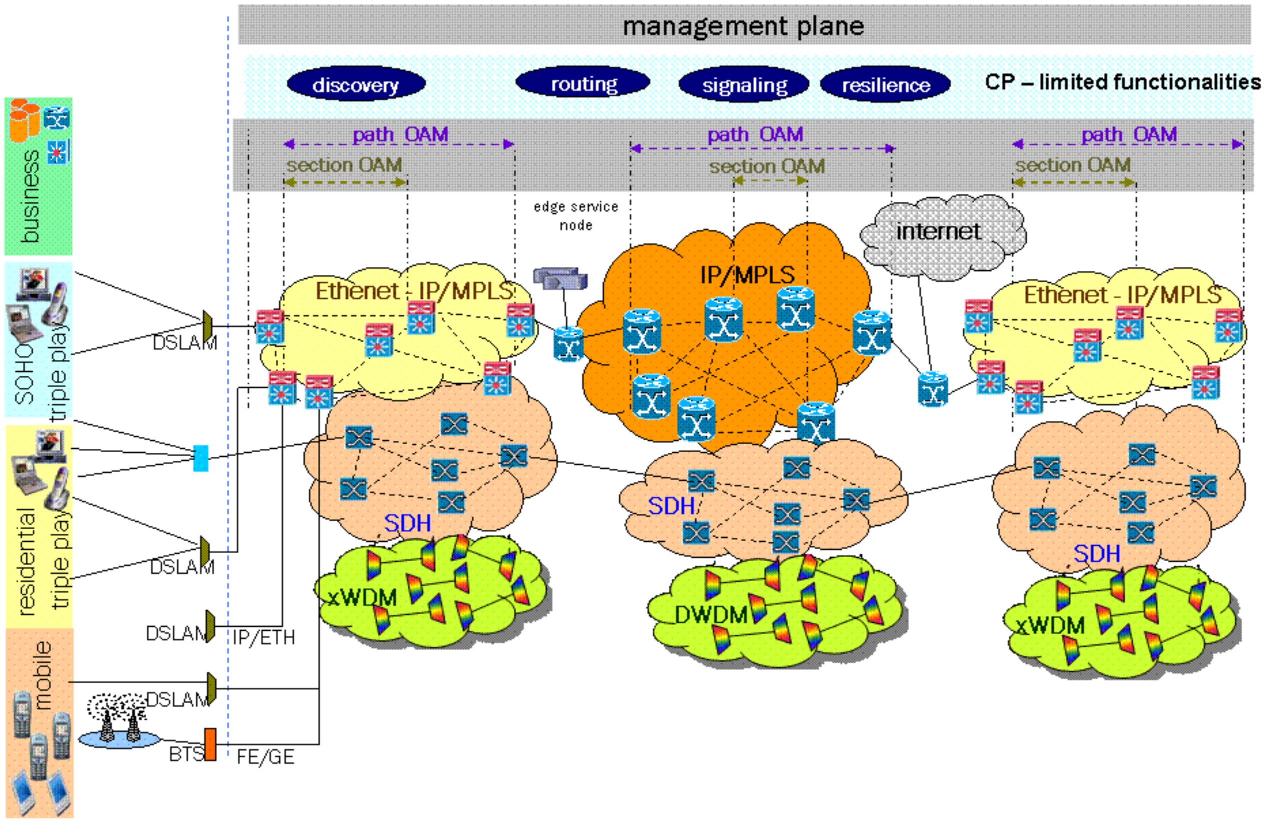

Figure 4- state-of-the art architecture

In the peripheral segment, access networks convey traffic generated by customers into access nodes; in most countries these nodes are in the number of many 1000s.

Moving away from periphery, metropolitan area networks, that consist of many transport chains, carry traffic from access to metro nodes. Many types of client traffic are carried (including IP, Ethernet, ATM, SDH, ESCON and Fiber Channel), being characterized by a low-level of aggregation and grooming; this problem is exacerbated by the coexistence of unicast (Video on Demand, High-Speed Internet and Voice services) and multicast traffic (i.e., mainly IPTV). In the metro area common transport technologies are SDH, Ethernet and WDM (dense and coarse); different traffic requirements are usually satisfied adopting separate networks, thus allowing the coexistence of circuit (e.g. SDH) and packet (e.g. Ethernet or IP/MPLS) transport. Metro (or "edge") nodes, consisting of IP routers, aggregate the traffic generated in a metro area and, when needed, transfer it to the core network. The number of such edge nodes is typically in the order of 100.

Finally the core network interconnects the edge routers, offering backbone connectivity. Packets (mainly IP/MPLS and Ethernet) and circuits (SDH, OTN and WDM) co-exist, with low-level significant functionality duplication. Today's core networks make use of IP routers for aggregation of multiple provider edge (PE) traffic demands; the transport function is typically ensured by 10Gbit/s DWDM transmission systems in the form of chains, with some use of optical add-drop multiplexers, fixed or reconfigurable (ROADMs).

Current network architectures have been designed and sized to handle current traffic demands; yet, they are inadequate for the future volumes, due a number of drawbacks, hindering them from the point of view of scalability, energy efficiency, end-to-end quality of service and cost.

Firstly, there are too many network tiers with electronic interfaces between them. Networks typically have access, backhaul, metro, outer core and inner core tiers.

Secondly, there are too many IP routers. All router electronic interfaces are costly, and consume power; among them, the most energy hungry are those that perform the so called “deep packet inspection” on data.

Finally, there are too many network nodes. The present number of nodes is the result of legacy technologies; in the future, longer reach transmission systems will allow large size node consolidation.

With existing network architectures a bandwidth increase by 10 times would require huge investments in all tiers, routers and nodes described above. Actually, much of the electronics in today’s networks is there to aggregate small traffic demands into bigger ones, such that the transport pipes are well utilised.

In the future, long reach optical access networks and, consistently, consolidated access nodes will be a key driver to significantly reduce the number of required equipment. The design of next generation metro and core transport networks must include this assumption.

The STRONGEST approach to network evolution

It is the view of STRONGEST partners that a future scalable network will need a complete change of architecture. STRONGEST is exploring a number of alternative transport architectures, to identify the optimum one. In this process it is addressing key issues such as – how many separate network tiers are required? How can the number of IP routers be minimised? How can we best utilise optics to eliminate cost and power in the network? How can we optimise the demarcation between access, metro and core nodes? How can such a network be controlled? What optical layer technologies will fulfil the requirements of the overall architecture?

From a technology point of view, although the scalability requirement seems to be satisfied in the shorter term for a limited number of network elements (e.g. 100 Gbit/s Ethernet interfaces, in the process of being standardized by IEEE, and a 100Gbit/s OTN container, just defined by ITU-T), the scalability of current architectures is not future-proof. In a 10 years scenario, today architectures are not cost-effective either, and do not guarantee enough end-to-end quality of service.

During the last years a lot of effort has been dedicated to define and implement an efficient control plane for resource optimization in case of single network domains, for both packet and circuit technology. The open issue is to define an end-to-end control plane that allows different technologies and domains to inter-work efficiently and according to a consistent approach. Such a control plane is essential for the efficient management of the future ultra-high bandwidth network.

This automatic control plane can incorporate such advanced features as virtualization of network resources that allows a complete decoupling of service level (client) with respect to the transport level (server). Such a feature leads to a simplification of connection requests, because the service layer can require an “abstract” network service from the transport one, independently of adopted technology, architecture, interface types, protection mechanisms and other detail characteristics of the transport platform.

STRONGEST is exploring medium term and long term architectures to solve the issues discussed above. A clear methodology will be followed to achieve this, in a systematic way, starting from the current scenario and considering two evolutionary steps, i.e. a mid-term (say, 5 years) and a long term (say, 10 years) scenario.

Medium term architectures

One of the main STRONGEST objectives is the development of a pre-commercial network architecture that will offer high scalability and survivability for any kind of service, while minimizing the total network costs (CAPEX, OPEX including power consumption, etc.). A few assumptions and requirements have been identified for medium term applications, together with transport solutions that deserve consideration in that time frame.

The basic assumption for the access network evolution (that is assumed as a given condition, since it will not be the subject of direct STRONGEST activity) is a significant reduction of the access node number, due to access node consolidation and longer reach fibre access technology.

For metro and core networks (the segments where the Project is mainly focused) some basic requirements have been identified for medium term evolution.

The metro network, transporting traffic from the access nodes to the metro nodes, should be designed to minimize cost and power consumption, and to maximize traffic efficiency and quality of service as well. Under this point of view, there are a number of interesting transport solutions in the medium term ranging from simple point to point fibre, to fixed filter chains, cheap ROADM chains, CWDM and DWDM. The number of metro nodes, in the medium term, probably will not change very much, and will still have edge routers inside.

The core network shall be designed as cheap and power efficient as possible; therefore routers will be bypassed wherever feasible. A likely way to do this will be a multi-layer GMPLS-controlled transport network based on a combination of hybrid wavelength switched optical networks (WSON) and new transport-oriented packet transport networks (e.g. MPLS-TP) for Ethernet service delivery; alternatively. Besides, the control plane architecture will be based on a path computation element (PCE) approach, for efficient inter-domain and inter-carrier path computation.

In such medium term scenario, IP routers will be exclusively used in those nodes where IP header processing is mandatory, i.e. for access and metro edge (BRAS), for service platforms and network border edge, and for interconnection between ISPs. On the other hand, pure transport functionalities (switching, restoration, etc.) will be done by more cost effective technologies such as layer 2 or lambda switching. IP offloading over WSON and MPLS-TP are shown schematically in Figure 5, wavelength bypass through ROADMs being more appropriate for bandwidths of around 5Gbit/s and above.

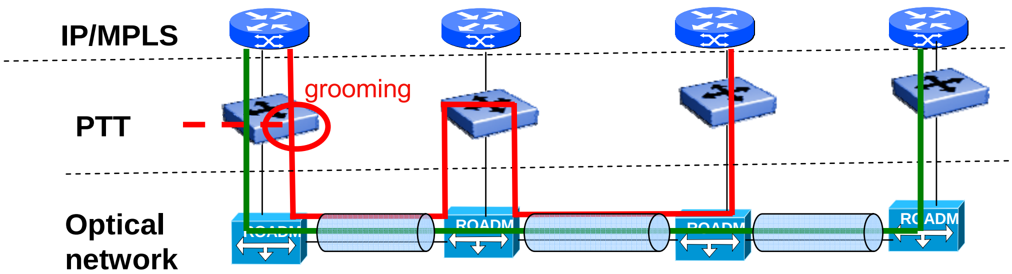

Figure 5 - IP offloading over WDM and MPLS-TP bypass

As shown in Figure 6 [LORD], IP off-loading over WSON will reduce the size of the required routers. This reduction will be particularly significant in the network core, where a higher amount of transit traffic is carried.

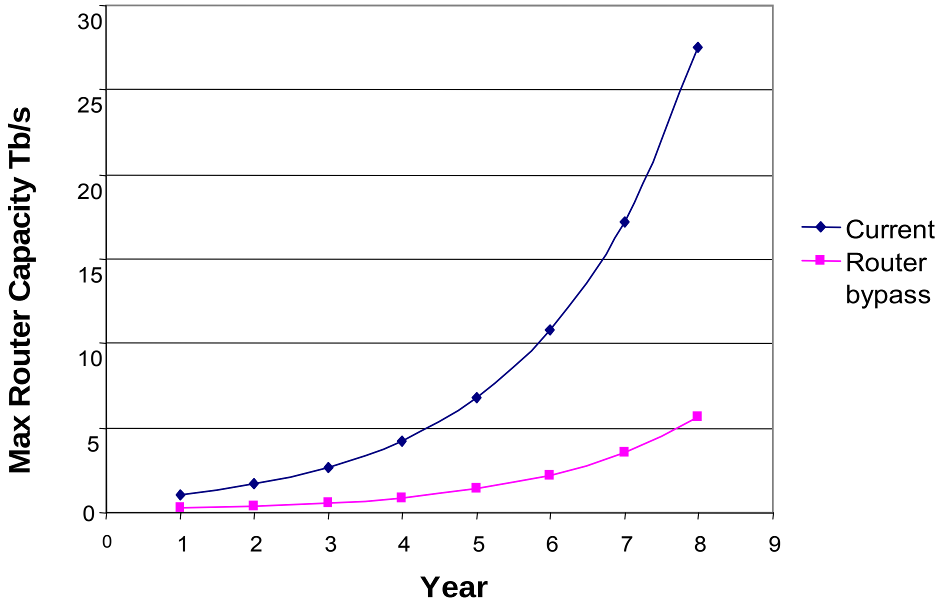

Figure 6 - Router capacity required for current and router-bypass architectures

Modelling results from the same author have shown significant power savings too, given by the following table.

Table 2- Worst node power and total power consumed (unit: kW)

	1st year Worst node	All nodes	3rd year Worst node	All nodes	5th year Worst node	All nodes	7th year Worst node	All nodes
Current	24	300	60	740	150	1900	380	4700
Router bypass	7	240	13	430	31	900	78	2100

We can conclude that the introduction of WSON in the core is expected to significantly reduce OPEX (space and power consumption, maintenance costs, etc.). Based on the previous assumptions, the trend will be the progressive spread of optical switching nodes towards the edge.
If the traffic growth in parts of the network is too small to utilise a complete wavelength bypass, then other technologies can be used for sub-wavelength multiplexing, still avoiding Layer 3, such as MPLS-TP, PBB-TE and also OTN. The Project is evaluating and comparing these approaches.

Long term architectures

As node consolidation, resulting from deep reach access, takes place, we will be left with a few hundred nodes in our networks. It is likely that a separate metro and core tier will still be required, as with the medium term options. However there are some major differences with respect to the previous case.

In the longer term we can assume that the traffic demands will result in multi Tbit/s links and switches. A multitude of solutions then becomes possible; here we draw attention to the key issues, and indicate the main architectural alternatives that the Project is exploring. In particular, some characteristics of the network in this time frame will further change

Due to wider diffusion of longer reach fibre access technologies and further consolidation of access nodes, the number of these nodes will be reduced drastically, well below 1000. Also, the architecture of metro nodes will be similar to the medium term one, but their capacity will now be approaching 100Tbit/s.

The core network will still be designed bypassing routers wherever possible. Yet, the whole network will now consist of parts with different flexibility, because a fully flexible network in both the core and metro/access domains would result in unnecessary complexity and cost. Hence, the ideal network will lie somewhere within two extremes: static core and flexible metro/access, opposed to flexible core and static metro/access. In all cases, the merit of the new architecture is the potential to minimise the number of routers needed.

Figure 7 shows one possible solution, where the dynamic core network is made of large L1/L2 switches, while the metro networks are only formed by static transport chains. The large core switch, which will be prototyped as part of STRONGEST, will feature as much optics and lower layer aggregation as needed to limit the need for routers.

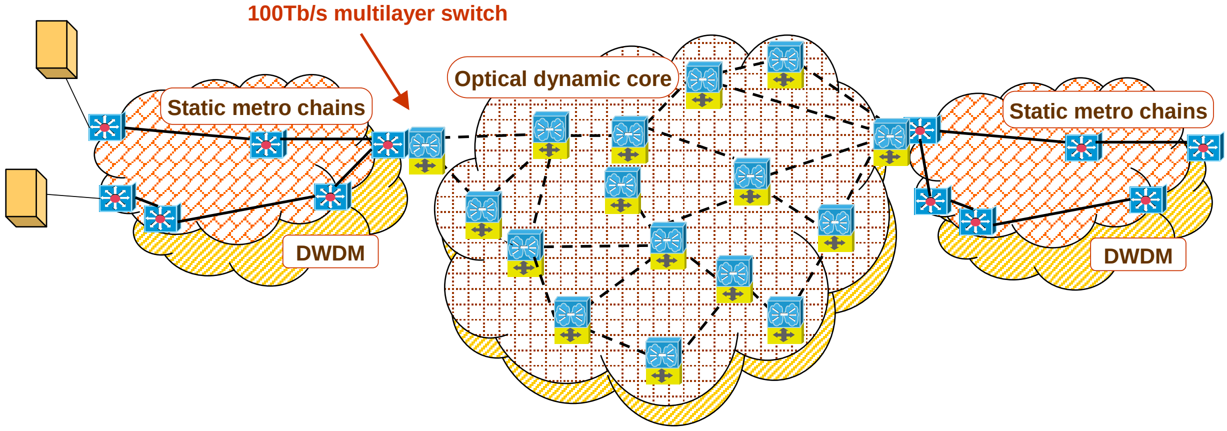

Figure 7 - Static Metro plus dynamic Core

The key characteristic of this solution is a large, dynamic optical core (e.g. 100 nodes) using optical circuit switching, that is fed by short, static metro chains carrying capacity to core nodes as cheaply as possible; in this case all the dynamics is handled in the large core. This approach would allow a large and cost effective core network, with mesh restoration and fast response to dynamic traffic changes.

Alternatively we might envisage the opposite solution, given below in Figure 8, that is characterized by large dynamic optical metro networks (based on optical burst switching, OBS, or optical circuit switching, OCS, or both) and a small core with very few nodes, allowing point to point fibre connectivity with huge DWDM. The small number of core nodes would make this feasible from a cost perspective. In this case all the dynamics are handled in the metro, which means over shorter distances, where physical effects are not as great and transmission can be kept simpler. This approach would allow operators to manage different metro regions, and even purchase from different vendors.

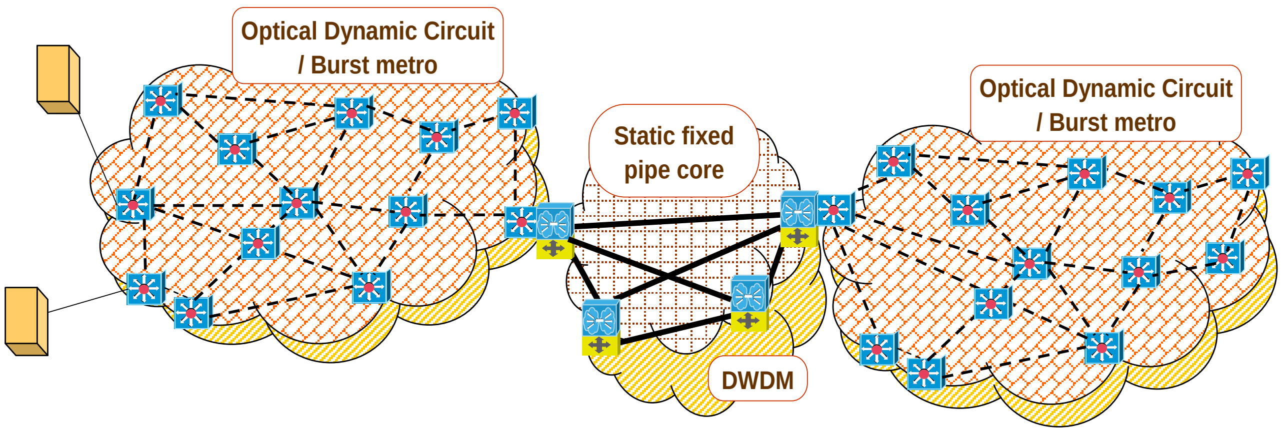

Figure 8 - Dynamic Metro + Small Static Core

These two solutions imply very different technologies, and a completely different partition between metro and core nodes. This also depends on the origin of the dynamics. For example, traffic dynamics might arise from varying service demands, time of day usage, service Provider churn, unpredictable traffic growth and network restoration. Traffic studies in STRONGEST are going to clarify the level of dynamics in each part of the network, until the Project will be able to perform in-depth network designs based on the above architectures.

Finally, it could be possible that both the metro and core of the network require dynamic traffic, for different reasons. In this case we can consider combining the dynamic solutions above to give a further alternative. This solution is achievable using separate dynamic solutions for metro and core with a large router in between. Alternatively we may consider integrating the metro and core solutions optically to remove the requirement for a router in this part of the network.

There are many open questions to be resolved for the long term architectures and STRONGEST will address all of these issues. Where in the network will the traffic dynamics appear? How big will the traffic be? Is there a cost/power benefit in using a dynamic technology (e.g. OCS, OBS) to handle the dynamics, or is simple bandwidth overprovisioning by static pipes better? In each architecture, what is the optimum size of the metro and core networks? In each architecture, what are the most appropriate transport technologies? (For example do OBS and OCS have roles and if so, where?)

Mid-term to Long-term architectures transition and motivation

Assuming that a new network requires from 5 to 10 years to be fully developed, it is reasonable to envisage a two-step network evolution.

In 5 years (mid-term) from now, the mid-term architecture will take the advantage of full optimization of existing technologies (packet transport, wavelength transport) with some key impacts. Firstly, IP routers will be eliminated from the core network; IP routers will mainly survive at the network edge, ensuring the traffic grooming and the service distribution at the boundary of the transport network. Secondly, packet transport equipment (e.g. MPLS-TP) will be widely used in the transport network for grooming and low bit-rate connectivity, adopting innovative control plane and admission control features. Finally, advanced DWDM equipment (mainly ROADM) with innovative control plane (WSON) also enabling resource virtualization will allow highly efficient wavelength connectivity.

In 10 years (long-term) from now it is likely that there will be both a further increase of bandwidth requirements (in the order of 1Gbit/s for retail customers as well) and the reasonable development of Optical Burst Switching (OBS) technology. This will produce a deep impact on the network structure, allowing further reduction, or even elimination, of electrical switching in the transport and enabling dynamic sub-lambda switching at optical level.

Finally, the Project is going to study a specific strategy, to ensure a graceful migration from the mid-term to the long term architecture(s), preserving as far as possible the investments that will be necessary in the former phases.

Experimental activities

Beside architecture studies, experimental activity is the second pillar of STRONGEST commitment, and will be carried out in different locations and with different purposes, but under strict coordination of an ad-hoc work package.

For medium-term networking solutions, both data and control plane experiments have been planned over the *ADRENALINE* test-bed, run by CTTC in Barcelona, Spain.

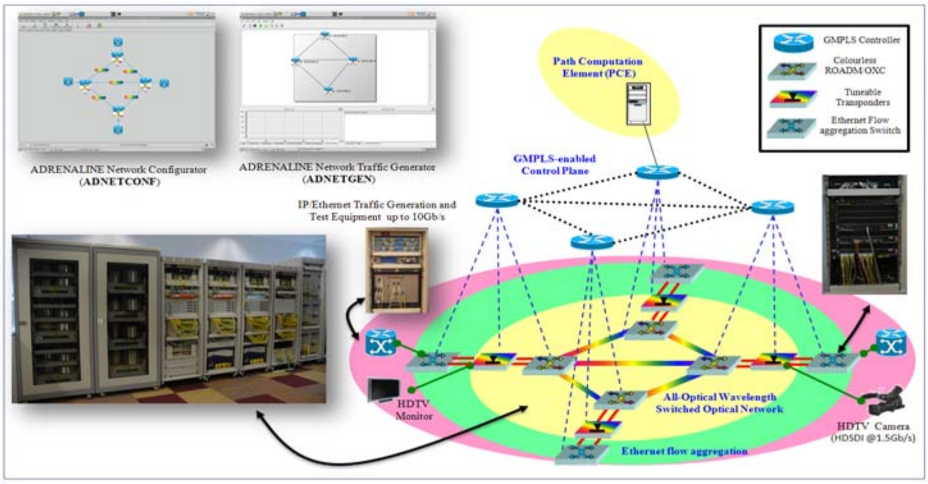

Fig. x – The CTTC *ADRENALINE* test-bed

These experimental activities are aimed at demonstrating the feasibility of multi-layer routing, restoration and grooming mechanism for PCE based GMPLS control plane, with WSON and multi-layer PCE based architectures, paying special attention to scalability, speed and reconfigurability.

For long-term networking solutions, both data and control plane experiments have been planned over a test-bed that is run by Alcatel-Lucent in Stuttgart, Germany, to validate ultra-high capacity L2/L1 nodes. In particular the feasibility of scalable hybrid photonic/electronic network architectures for Petabit transport networks and L2 gateways enabling end-to-end quality of service will be demonstrated.

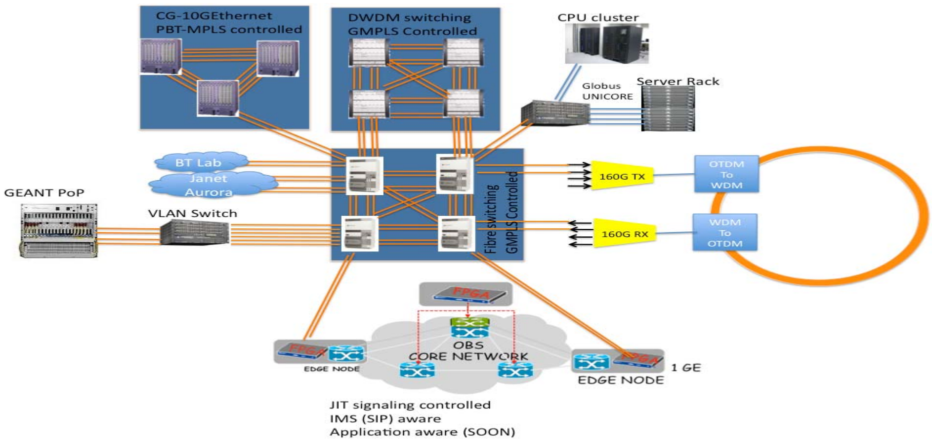

Fig. y – The distributed test-bed between University of Essex and BT Labs

Furthermore, experiments combining both medium and long term functionalities for data and control plane are planned in a distributed test-bed between University of Essex and BT Labs in UK. The two locations are connected through a dark fibre link. This test-bed will allow the feasibility demonstration of sub-lambda granular optical nodes; routing, restoration and grooming mechanisms for sub-lambda granular optical networks; interworking between medium term and long term solutions.

Finally, pure control plane demonstration activities will be carried out over distributed test-beds interconnected by means of IPSec tunnels. These activities will include experimental analysis of multi-domain PCE based control plane architectures, control plane interoperability tests, CAC and PCE interworking tests, end-to-end OAM interoperability tests

The four test-beds are intend to validate experimentally the data plane and control plane solutions devised by other work packages of the Project, with respect to mid-term and long term scenarios.

What is STRONGEST aiming at?

STRONGEST is designed to contribute significantly to the objectives of the ICT fourth call that are aimed at major goals such as "Overcoming technology roadblocks and reinforcing Europe's industrial strengths".

To this purpose STRONGEST leverages on the definition of innovative architectures for developing a scalable, resilient and cost-effective transport network, offering ultra-high capacity to the end users in the broadband society of the future. The new architectures will take into account the evolution of the access network technologies, but the studies carried out by the project will focus mainly on the metro and core areas, because these are the part of the network where the main scalability issues are foreseen in the next years.

Hence, the main objective of STRONGEST is to design and demonstrate an evolutionary ultra-high (Petabit) capacity multilayer transport network, compatible with Gbit/s access rates, based on optimized integration of Optical and Packet nodes, and equipped with a multi-domain, multi-technology control plane. This network will be able to offer high scalability and flexibility, guaranteed end-to-end performance and survivability, increased energy efficiency and reduced total cost of ownership.

From this general statement, detailed objectives can be elaborated, such as: study of novel architectures, identification of effective solutions to reduce energy consumption, combination of the best of transport technologies, definition of a control plane for end-to-end service delivery, enabling of virtualization of resources, experimental validation, and contribution to standard bodies and fora.

At the end of STRONGEST there will be something new!

Several European projects, in the last few years, have investigated on improving throughput and dynamic traffic control in specific network segments (NOBEL, NOBEL Phase 2, MUSE), or have worked on fundamental research and realization of research infrastructures (MUPBED, GEANT, PHOSPHORUS), or, again, have explored the problems of service support in production networks (FEDERICA), and, finally, have tried to capitalize these efforts in a comprehensive architectural view from the point of view of service provisioning by exerting a transversal coordination action (BREAD).

Furthermore, Networks of excellence such as the e-Photon/ONE initiatives and the on-going BONE for the optical area as well as NEWCOM initiatives for the wireless area have created solid foundations for cross-dissemination of expertise in networking technologies among the European Countries.

In spite of the recent significant technological advances, the European telecommunication market, pressed by and the international economic turn-down and by the competition of low cost countries, puts in front of the European industry a new set of challenges. In fact, the new scenario calls for going beyond present state-of-the-art for facing the rapidly changing market, as regards cost of network architectures (in terms of both CAPEX and OPEX) and the acquisition of new market segments by offering end-to-end connectivity services with hard QoS (assurance of bandwidth, maximum delay and reliability).

So, the fundamental question rises: what will be the really new outcomes from STRONGEST, helping European industry to compete successfully in an increasingly harsh environment, and European operators to provide their networks with effective and future-proof solutions?

Basically, STRONGEST exerts leverage on the definition of an innovative architecture for developing a scalable, resilient and cost-effective transport network that, at the end of the project, will offer ultra-high capacity to the end users, either citizen or enterprise in both private and public sectors.

In details, STRONGEST is committed to conceiving and demonstrating: new hybrid photonic/electronic nodes for Petabit/s data transport, featuring low power consumption and low footprint; new transport network architectures, offering high scalability and survivability for any kind of service; and new multi-layer control planes, enabling the dynamic reconfiguration of wavelengths and providing advanced virtualization mechanisms that will make resource allocation independent of the actual transport technology. Also, the Project will investigate the most appropriate transport technologies for 100 Gbit/s and above, and, at the same time, will explore the feasibility of sub-wavelength multiplexing in the optical domain based, for instance, on optical burst switching (OBS).

Detailing again, the dynamic behavior of transport networks will be pushed definitely forward by providing advanced multi-layer routing and traffic engineering strategies for optimized, efficient utilization of resources, including grooming strategies to support L1 and L2 switching and bypassing. With respect to present, simple traffic engineering functions, the Project will enrich the network control plane with advanced features, like coordinated L1-L2 service aggregation, switching and transport capabilities, as well as the support of anycast and multicast functions, and the support of the new multi-granular multi-layer node architectures. The adoption of PCE-based solutions in multi-layer and multi-domain scenarios is expected to significantly improve the effectiveness of path computation.

Finally, any solution that will be technically conceived and demonstrated by the Project, beside technical novelty, shall have to meet stringent cost requirements, to ensure successful deployment in the even more challenging market conditions that will occur in 5 to 10 years from now. This calls for a clear confirmation, through techno-economic studies, of the expenditure advantages and energy savings produced by the STRONGEST architecture, and requires the definition of an effective and cost-minimized migration strategy, leading from existing router-intensive networks to the long-term optimized STRONGEST solution.

How does STRONGEST work?

In order to reach the desired objectives, the scientific and technical activities of the project have been organised into 3 main (technical) Work Packages:

WP2 – Network efficiency and optimization
WP3 – End-to-end solution for efficient networks
WP4 – Network prototypes implementation and demonstration

The WP2 main goal is to design an efficient and optimized network architecture for new transport solutions. It includes all the architectural studies carried out in the project, from the identification of the requirements to the definition of target architecture.
At the same time, WP3 aims to provide efficient solutions to support end-to-end services delivery across domains that are heterogeneous in terms of technologies. It includes studies related to OAM, control plane, network virtualization and traffic admittance solutions.
In parallel, WP4 focuses on the implementation, integration and experimental validation of the STRONGEST's reference architecture.

An additional WP has been introduced to guarantee a strong coordination of all the technical activities in the project, including dissemination and standardization:

WP5 – Technical coordination, dissemination and standardization

Finally, all the activities related to the management of the project are included in WP1:

WP1 – Project Management

The relationships among the four technical work packages are shown in Figure 9.

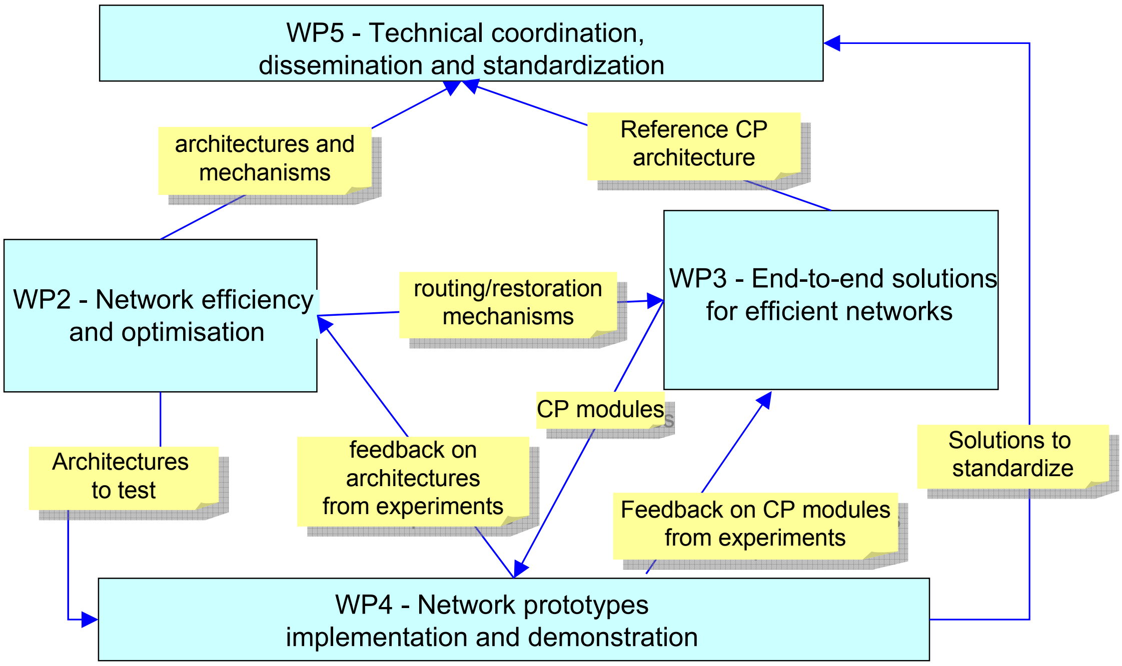

Figure 9 – Relationships among STRONGEST work packages

From the previous sections, it is clear that STRONGEST positions itself as the producer of a new optical network architecture for the next-generation converged Network of the Future. Targeting the same success as obtained by other standards that were born in European research labs (like GSM), the consortium aims at a new multi-layer network concept, including an efficient migration scenario.

In order to achieve the expected impact the Project will use a work methodology based on a well balanced consortium cooperation, focusing the target of the Call through the development of: innovative architectures, whose specifications comply with medium and long term scenarios; low cost technical solutions, reducing required investments and future operational costs (including the energy related ones); focused education and training activities, that will create the basic knowledge and will prepare human resources; and strong involvement in standardization activities, to foster world wide acceptance of STRONGEST views and solutions.

STRONGEST is not an island...

A significant project impact can be achieved only if there is a large consensus among the scientific and industrial communities about the concepts, architectures and systems investigated and proposed by the Project.

Even though the consortium is already composed be highly qualified partners, a strong interaction is desirable at the European and world level to reach significant acceptance and deployment of the proposed solutions. To foster scientific collaborations with other relevant scientific projects and organizations, STRONGEST is getting in touch with such projects as:

FEDERICA (EC – Research and experiments on new Internet architectures and protocols),

BONE (EC – Network of Excellence serving to the European optical networking community),

ETICS (EC FP7 – Economics and Technologies for Inter-Carrier Services),

MAINS (EC FP7– Metro Architectures enablINg Subwavelengths),

GEYSERS (EC FP7– Generalised architEcture for dYnamic infraStructure sERvices), AKARI (Japan – Implementation of a new generation network by 2015),

GENI (US – Experimental suite of infrastructure supporting Network Science and Engineering experiments)

From the beginning, STRONGEST is establishing contacts, particularly with other complementary FP7 projects, in view of formal cooperation. This synergy is particularly desirable to achieve a heavier impact on standardisation, and to facilitate, later on, successful industrial deployment.

The promotion of newly elaborated concepts and solutions in standardization bodies is of the utmost importance for the success of STRONGEST ideas. Therefore the significant Project findings will be transformed into proposals for standards, in order to reinforce the European position in the key standardization bodies and fora. These proposals will be submitted where and when appropriate to the pertinent working groups, mainly in ITU-T, IETF, OIF and ETSI, by leveraging the corresponding involvement of STRONGEST Partners.

The main technical areas where significant contributions to standardisation can be foreseen are: packet transport technology (e.g.: MPLS-TP), optical transport technology (e.g.: WDM, WSON, OBS), multilayer transport networks, and integration of packet and optical nodes.

Exploitation of results

The consortium includes participants from major European telecommunications players, thus exploitation by and within each partner's organization is an obvious outcome for the results obtained by STRONGEST. Furthermore, the major partners are also involved in standardization bodies (ITU-T, IETF, OIF, ETSI, etc.), and are committed to foster international standards in the advanced optical networking area. The partners will therefore be highly dedicated to push the STRONGEST architecture in ongoing standards discussions.

The STRONGEST consortium consists of contributors who clearly represent the main actors in the networking field. It is composed by telecommunications operators (TI, BT, DT, TID and PrimeTel), who understand the end user requirements that drive innovation of new networking concepts, and the resulting deployment issues. Also, system vendors (ALUD, TEI and NSN) are present, that have a vast know how in developing deployable systems, and have therefore the ability to transform project outcomes in actual end products. Of course, academic partners (UST, UPC, UEssex and UoP) and research centres (CTTC, IBBT, CNIT) are also there, being in charge of generating new ideas, which can be then instantiated by the industrial ones.

Bringing together partners that understand and participate in all aspects of the research process will maximise the chances of successful exploitation of the project output and turn into economic benefits. Telecommunications operators can exploit the project outcomes to realize lower cost, ultra-high capacity network infrastructure for the benefit of end-users; system vendors can realize revenues from developing standards compliant systems, fit for deployment by operator networks; research institutes and universities can take advantage of the intellectual property generated through the project by exploitation of know-how in commercial ventures (e.g licensing) or future research projects.

Fig. 10 summarizes the route that will lead to the deployment of mid-term and long-term STRONGEST transport solutions and evidences the major impacts on network features, cost reduction and sustainability

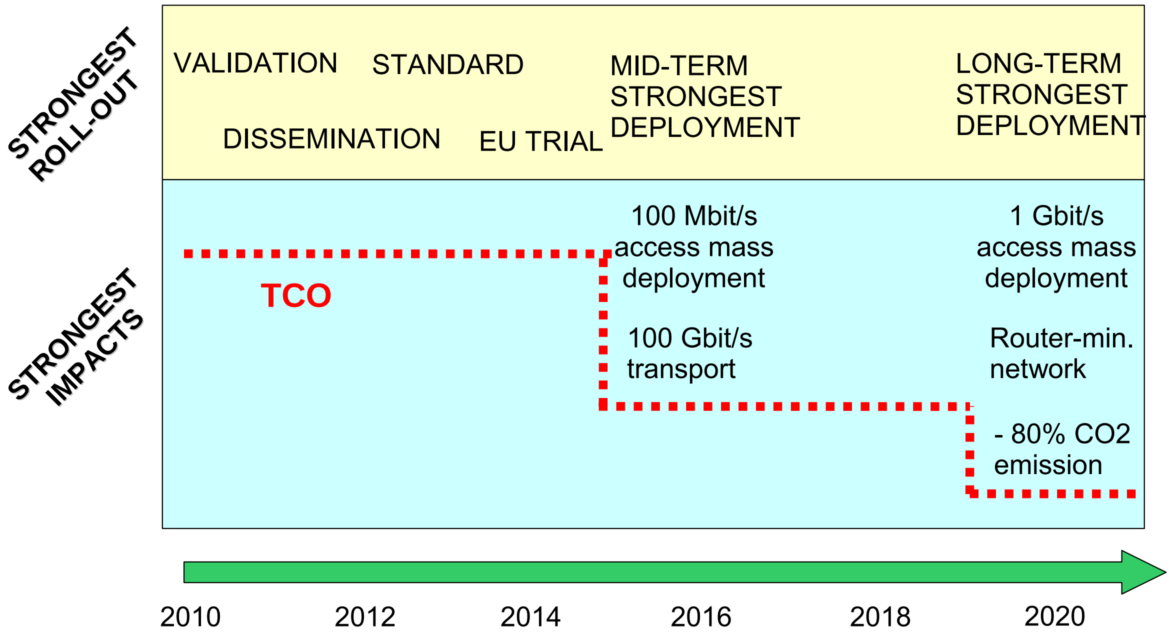

Figure 10 – Route towards the deployment of STRONGEST network solutions

Conclusions

The FP7 project STRONGEST has started its activity on January 1st, 2010. The Consortium is working hard, having an ambitious objective in mind: to overcome the limitations of today transport networks by designing and demonstrating an evolutionary ultra-high capacity multi-layer transport solution, compatible with Gbit/s access, based on optimized integration of optical and packet nodes, and equipped with a multi-domain and multi-technology control plane, that shall offer:

- high scalability and flexibility
- guaranteed end-to-end quality
- increased energy efficiency
- reduced total cost of ownership

By the valuable contribution of all partners, by an efficient organization of activities and by developing consensus around ideas and results, we believe that this goal will be successfully reached by the end of the three years Project lifetime.

The novel solutions that will be produced by STRONGEST will support the European industry in competing successfully within an increasingly harsh global market, and will help the European operators to provide their networks with effective and future-proof solutions. And, at the end of the chain, but on top of EC priorities, will favour the offering of ultra-high capacity services to the end users, either citizen or enterprise, in both private and public sectors.

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Acronyms

ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BM	Burst Mode
BRAS	Broadband Remote Access Server
CAPEX	Capital Expenditures
CV	Curriculum Vitae
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
E-NNI	External Network-to-Network Interface
E2E	End-to-end
ETSI	European Telecommunication Standardisation Institute.
FMC	Fixed and Mobile Convergence
GMPLS	Generalized Multi-Protocol Label Switching
GPON	Gigabit PON (refer to IEEE 802.ah)
IETF	Internet Engineering Task Force
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IPTV	Internet Protocol Television
ITU	International Telecommunications Union
LSC	Lambda Switching Capability
L2SC	Layer 2 Switching Capability
L2TF	Layer 2 Termination Function
LSP	Label Switched Path
MAN	Metropolitan Area Network
MEF	Metro Ethernet Forum
MPLS	Multiprotocol Label Switching
MPLS-TP	Multiprotocol Label Switching Transport Profile
NGN	Next Generation Networks
NNI	Network-to-Network Interface
OAM	Operations, Administration, and Maintenance
OBS	Optical Burst Switching
OCS	Optical Circuit Switching
OPEX	Operational Expenditures
OPM	Optical Performance Monitoring

OTN	Optical Transport Network
PCE	Path Computation Element
PON	Passive Optical Network
PE	Provider Edge
PoP	Point-of-Presence
PTN	Packet Transport Network
PTT	Packet Transport Technology
QoS	Quality of Service
R&D	Research and Development
RACS	Resource Admission Control Subsystem.
SDH	Synchronous Digital Hierarchy
TCO	Total Cost of Ownership
TE	Traffic Engineering
TISPAN	Telecoms & Internet converged Services & Protocols for Advanced Networks
UMTS	Universal Mobile Telecommunication System
UNI	User-to-Network Interface
VoIP	Voice over IP
VPN	Virtual Private Network
WCDMA	Wideband Code Division Multiple Access
WDM	Wavelength Division Multiplexing
WP	Work Package
WSON	Wavelength Switched Optical Networks