2009

OPTICAL NETWORKING REQUIREMENTS FOR EUROPEAN NRENs

White Paper

CONTENTS

1. INTRODUCTION

Over the past decade, the changing regulatory environment, competition and imaginative implementation of new business models has led to major changes within the telecommunications sector. Instead of monopolistic operators, we now have multiple networks and network providers, including National Research and Educational Networks (NRENs), and a huge range of devices, services and service providers to choose from. Virtually most of these networks and services depend heavily on underlying optical fibre technologies within the core transport network.

In this environment, network and services convergence is becoming a normal way to maximise the market size of individual products. The need for ICT businesses to maximise their market size and the continually changing regulations lead to an expectation for increased flexibility and a growing need to interoperate networks. This will have an impact on all levels of the network. Locations where different types of network interface to each other can sometimes benefit from simplified interfacing at the physical level. This in turn presents new requirements for optical component and systems technology.

For the network operator and service providers there is a growing interest in providing customers with control over their services to give improved customer experience (customer control over their own services/networks). In response to this, both the network and the way services are delivered must fundamentally change. Increasing levels of control over services and networks will be required in order to facilitate network and service operations and to improve customer experience. Determining how this control should be implemented is a major issue currently being addressed by both the research community and industry and is a subject for standardisation.

This report tracks the trends and developments taking place in this complex and changing environment and seeks to extrapolate those trends together with the research work that is being carried out within the PHOSPHORUS consortium to distil the final Roadmap which will identify the European NRENs requirements and trends for deploying optical network technologies. This report briefly describes research directions, concepts and future evolutions relevant to PHOSPHORUS and within the European FP6 and FP7 programs. It also discusses how these technologies can be deployed by European NRENs.

2. RATIONALE

Fibre networks and related technologies provide the underlying infrastructure for all modern telecommunications core networks and high capacity computing networks. Given the very high investment that has been made into the infrastructure and the investment made in related research, it is important to summarise, from time to time, the progress that has been made in research and to set this in the context of the industry developments. As a Test-bed project, driven by European NRENs, PHOSPORUS is well placed to capture and analyse the developing requirements of the European research network infrastructure for photonics technologies.

The synergy developed between PHOSPHORUS partners and the wider EU NREN and photonics research community will help to develop a consensus in the vision.

The WP7 (Dissemination Workpackage) has taken over the responsibility to capture this vision and deliver it in a way that it can be useful to all interested parties.

3. SCOPE

In this document, “Optical Transport Network Technologies” refer to all computing and communications networks which employ optical fibre as a transmission medium and include the optical component technologies: the technologies for physical, data link and network layers and the related control layers. The most advanced network concepts explore the use of optics beyond transmission, to implement switching and simple resource allocation functions.

This report lists the drivers for further development and analyses the current status and trends in both components and networks. In addition it examines ongoing photonics related research in the Framework Programmes, with emphasis on the work that has been carried out within PHOSPHORUS. Furthermore it shows how NREN network capabilities are enhanced by this. The vision of this exercise is to see how the network layer can enable end-to-end network service delivery in an application specific manner and specifically what is the role of optical network technologies to support and enable such a vision.

This report also identifies any gaps in the research programmes with emphasis on views on how optical network technology, in a broad sense, impacts on each part of the end-to-end network service delivery and on the interoperability of public networks.

3.1 AIMS

The aims of this white paper are

- To assemble a broad cross-section of views about the trends and directions in optical transport network technologies and to build consensus about the areas which will have the greatest potential impact on future NREN networks.
- To identify techniques based on optical communications technology that can improve NREN network operations and help to reduce costs as well as to improve the service delivering capability of their networks.
- To set out the issues and solutions in a way that will provide options and guidance to those people who have the responsibility to develop and implement future NREN networks, the technologies and the required areas for further research and development activity.
- To introduce a selected number of research directives and concepts within and relevant to PHOSPHORUS and some future developments.

3.2 AUDIENCE

The audience for the *Road Map* is those people who have the responsibility to develop and implement future NREN networks, the technologies and the required areas for further research activity. This includes three main groups of people: those with the responsibility to develop and implement the hardware and software technologies (component and equipment vendors), those with the responsibility to develop, implement and operate the NREN networks and services and those with the responsibility to direct the future research programme (funding bodies). These people will be referred to as *stakeholders*. It is understood that members of the PHOSPHORUS consortium are among the stakeholders but, since this report only reports on the trends and developments, they can rely on this document as a future reference other than specific guideline on their research.

While the *stakeholders* have extensive understanding and experience in this area, feedback has shown they see value in the Guide as a reference. For others involved in the field, the document will provide a broad appreciation of the wider developments taking place.

3.3 STRUCTURE OF THE WHITE PAPER AND HOW TO USE IT

The structure of the white paper has been created in consultation with the consortium and leading visionaries in the field, including equipment vendors, network operators and funding bodies. It sets out the trends and drivers for change relating to optical networks and discusses the underlying component and systems technology developments as well as the major transport network and control layer developments. Research project references are provided for those interested in helping to exploit the technology. As a way to help provide insight into changes and trends associated with optical networks, Annex 1 provides a “Road Map to Today”, summarising how optical fibre technology has developed over the years since its first commercial use in 1980.

4. METHODOLOGY

The methodology for the preparation of the report is outlined below:

- Capturing key messages at conferences, workshops and seminars.

  Specific effort was put into defining workshops that help to develop the picture of market and research at international level. These workshops have been very helpful in assembling the regional visions and research trends. OFC and ECOC are unanimously considered to be the most relevant conferences for the field of optical communications. We give a brief description of the workshops below. In Annex 3 a summary of the workshops that took place in conjunction with OFC2007 is presented with the key messages that have been conveyed.

  - *OFC2009: Workshop on "Grid vs. Cloud Computing and Why This Should Concern the Optical Networking Community*

    The workshop on "Grid vs. Cloud Computing and Why This Should Concern the Optical Networking Community" acted as a platform for discussions on the challenges faced by optical network researchers in delivering the necessary technologies essential for Cloud and Grid computing services which require high speed optical networks to provide advanced and flexibly reconfigurable infrastructure.

  - *ECOC2008: Workshop on Optical Grids, Drivers and applications for High Performance Optical Networks*

    The main objective of the workshop on "Optical Grids, Drivers and applications for High Performance Optical Networks" was to discuss the work on the emerging aspects related to advanced techniques, platforms, paradigms and models for the design, deployment and usage of high performance optical networks with a particular focus on Grid networks and applications. The workshop covered a broad scope of research questions in the optical Grid networking realm ranging from applications that require Grid Infrastructure, the control plane that enables these applications to the optical network infrastructure that supports these applications.

  - *ECOC2007: Networks for IT: A New Opportunity for Optical Network Technologies*

    The workshop, "Networks for IT: A new opportunity for optical network technologies" built on the realization that networks increasingly deal with managing and adapting distributed computing and associated data management resources (PCs, servers, supercomputers, clusters) and storage systems. Its aim was to address a paradigm shift in the optical network architecture that may be needed to enable dynamic and distributed IT services at large scale. This workshop offered a unique opportunity for optical network researchers and practitioners to give their views on the impact of the optical network architecture on each part of the end to end service delivery and on the interoperability of public and service provider networks of all kinds. In addition to invited paper presentations, the workshop provided an intimate setting for discussion and debate.

    - *OFC2007: International Workshop of Future Optical Networks*

      This workshop focussed on visions of future optical networking architectures, technologies, and their roles and applications. It featured invited talks in the areas of (1) optical networking architectures 5-10 years from now, (2), how do we get there, i.e., what technological challenges lie ahead and (3) what are the major roles and applications of these future networks.

- The scope and first content of the white paper were discussed firstly among the WP7 Roadmap

- Reviewing the progress developments in standards bodies and industry fora working on topics related to optical networks. These include in particular the ITU-T, the IETF and the IEEE. In Annex 2 a brief summary of the IPShpere vision is given as example of this interaction.

- Consulting experts working within the European Framework Programmes. Special effort was given in reviewing the work of project active in the area of optical networking with emphasis on resolving interoperability and end-to-end service delivery issues, in order to understand the role of optical networking (Annex 4).

- Holding a meeting at ECOC 2007, with experts invited from Europe, USA and Asia providing their views on future directions. (A report on this meeting is to be found in Annex 5)

- Requesting input from consortium partners, and specifically from the NRENs participating in PHOSPHORUS.

- Requesting input from non participating European NRENs.

5. NEXT GENERATION NETWORKS

Next Generation Networks (NGN) represents the telecommunications industry's co-ordinated response to the changing environment. NGN introduces the concept of a packet convergence layer which clearly separates services operations from network transport operations. The broad assumption is that any and all services map into the convergence layer and that all converged services traffic can be carried by any suitable transport infrastructure.

NGN tends to focus on services that can be readily mapped into an IP infrastructure because of the pressing need to deliver these services more efficiently than can be achieved using 64 kb/s network legacy infrastructure. However, while this may be attractive for many popular lower bandwidth multimedia services, this is not the complete picture. There are many services that cannot efficiently be carried by IP, and by TCP over IP, particularly the high bandwidth/high security services such as leased lines, Ethernet connections and low latency VPNs. This list can be extended to TV inter-studio networks, cable TV, higher quality video transmissions and high performance data connections for storage area networks and the like. For example, in some situations InfiniBand is likely to be a more suitable convergence layer for data networking protocols than IP.

Today these services are carried at either network layer 1 or layer 2 and are mainly provided for business use. In the future there will be additional high bandwidth services for residential customers. In the case of these higher bandwidth services, the developments currently taking place at network layers 1 and 2 are of great significance and these are described in section 9 ("Communications and computing technology").

The transition to NGN will take a number of years. There are several reasons behind this:

- Industry and standards will focus first on the things that will bring early cost benefits and provide new features that will be particularly attractive to customers
- While high level principles have been widely discussed, the detailed solutions are still being developed in various standards bodies
- While NGN is able to cater for different network types (e.g. customer network, public network, service provider network) it makes no assumptions about which layer functions are carried out in each network type and there is substantial capacity to incorporate new ideas generated through research activity.

5.1 NEXT GENERATION SERVICES

A key feature of the NGN initiative is the emphasis now being placed on service creation and operation. Service related functionality is being clearly separated from development and provision of the transport network and new architectures are being created with this in mind (as an example, see Annex 2). Unlike traditional telecom networks that were designed for a specific type of service, or range of services, future networks are expected to carry all types of traffic together over the same transport infrastructure which will be packet based. Open interfaces for services definition and provision will facilitate open competition in the services domain, while open interfaces in the transport network domain will increase supplier choice to the operators and facilitate network interconnection.

6. DRIVERS FOR FURTHER DEVELOPMENTS

6.1 COST REDUCTION FOR NETWORK AND BUSINESS OPERATIONS

A good proportion of components and sub-systems research is devoted to reducing the costs and improving the manufacturability of key components such as transmitters, amplifiers and switches. Devices with enhanced performance such as higher speed transmitters can also lead to fewer components being needed and help reduce capital costs.

More efficient network utilisation is possible by radically simplifying the network structure, by making it mesh and cross-connect based rather than ring based. Improved design methods will allow a capex reduction through more efficient utilisation. This can be achieved for example through improved shared restoration schemes and through flexible designs that avoid sterilized capacity arising.

Today, payment transactions between the numerous players that are involved in providing a particular service to a particular customer are very manually intensive. Automation of the settlement systems will not only reduce costs, but will also provide accurate traceability and enable more precise allocation of charges. Also manual steps in OAM&P limit the opportunity to reduce operational costs. There are substantial benefits to be gained by eliminating these.

Each of the above steps will require a new network control layer to allow service providers and operators to more effectively control the network and services configuration, customers to exercise better control of the connections and services they need and comprehensive network data to be gathered.

The telecom market is a global one and new global standards are needed for this control layer. Work in this area is already progressing well. In turn, the existence of global standards will assist open procurement and will help to reduce capital expenditure on equipment.

A recent driver for new developments is a growing demand for power aware network devices and networks. The global need of energy is growing, and the percentage of energy used by information system and telecom infrastructures grows at a faster pace. Several projects are addressing the issue of power consumption reduction in networks, and optical technologies have interesting potentialities in this area.

6.2 NEW REVENUE OPPORTUNITIES

New revenue opportunities arise when new services are identified and a demand for them grows. Video and multimedia based services are expected to lead to rising demands from consumers while increasing use of Ethernet based services are expected to lead to increased communications demands from industry and businesses. For example, growing awareness of the need to cut down unnecessary travel gives a stimulus to tools for collaborative working.

There are many ways to categorize applications and services. A possible one proposed in Eurescom study P1551 "Applications and services for ADSL2+ and beyond" and discussed in the BReATH project deliverable D4.1 "Sustainable strategies and service evolution scenarios for broadband access – Part 2: Service evolution scenarios" is given below:

- Information services (www browsing, interactive shopping, on-line newspaper, on-line translation, location-based broadcasting services, intelligent search- and filtering facilities)
- Communication services (telephony, video telephony, videoconferencing, voice response and voice recognition, personal location)
- Entertainment (audio on demand, games, video clips, virtual sightseeing)
- Business services (mobile office, narrowcast business TV, virtual workgroups, virtualization of computing and networking resources in general)
- Finance services (virtual banking, on-line billing, universal SIM card and credit card)
- Education (virtual schools, on-line science lab, on-line library, on-line language labs, training)
- Community services (emergency call, administration services, democratic procedures)
- Telematics (road transport logistics, remote control)
- Special services (telemedicine, security monitoring services, instant help line, expertise on tap, personal administration).

Further consideration of services is beyond the scope of this *Road Map,* but more detailed discussion can be found in the references.

Today, the need to quickly set up soft permanent connections is the primary driver for the control plane. But there is a growing call for increased levels of customer control, particularly for Ethernet connections that are widely used by businesses and service providers and in the future could be provided for consumers wishing to gain access to multimedia material. The ability to adjust bandwidth according to changing network traffic requirements is seen as a likely growth area in the medium term, with customer control becoming available slightly later.

These changes will increase the complexity of service delivery. As a way to manage this additional complexity it is likely that automated settlement schemes operating in the service plane will eventually be deployed.

To achieve all of the above would require a higher capacity network, a network control layer and development of new applications to handle automated ordering.

6.3 HIGHER SECURITY

Good security is wanted by virtually all network users, for some it is 'business-critical'. Layers 1 and 2 are seen as providing better security options than layer 3. At present these services are primarily used by business rather than by residential users, in particular to provide Ethernet and layer 2 VPN services, though with the advent of high definition video services it seems likely that some new services will be best delivered at layer 2. Where a business needs a high security layer 3 service, one option is for them to use a layer 2 network service and to provide their own layer 3 private network.

7. PHOTONIC SYSTEMS TECHNOLOGY

7.1 TRENDS TOWARDS HIGHER CAPACITY TRANSMISSION

The capacity of fibre systems has grown relentlessly since their first operational introduction in 1980. A short description of the developments up to recent times is given in Annex 1. In this it can be seen that capacity growth was entirely by faster TDM line speeds up to 1995. By 1995 it was becoming increasingly difficult and expensive to increase capacity further by TDM and rising demand led to the rapid development of WDM systems, boosted by the introduction of Erbium-doped fiber amplifiers (EDFAs). While maximum TDM speeds remained constant over the next few years, fibre capacities increased through increasing the number of WDM channels, each of which could carry 10 Gb/s. Then, as transmission capacity supply outstripped demand, the take up of WDM channels slowed and many WDM systems have been installed yet are only used to a fraction of their capacity.

Now, with the current trend towards packet networking and higher speed Ethernet services, there is once again a demand for increased system speeds up to 100 Gb/s (rather than through the use of many WDM channels). Electronic TDM components supporting 40 Gb/s transmission are now available and have been deployed in a few locations and interest is turning once again to higher speed transmission. The barrier here has not been that high speed components have not been available. Rather it is because these systems have been dependent on 'optical TDM' (OTDM) components that have not yet proved to be economically viable. Delivery of higher speed systems for the foreseeable future appears to depend on new line coding systems and the ability to economically manufacture high speed electrical TDM components.

As time goes by, and particularly as video based services are developed, both the service and the line interface speeds will increase. The present day systems have substantial capacity to absorb additional demand. For example, available network and technology capability will allow service providers currently using 100 MbE to migrate to 1 GbE. Those currently using 1 GbE may want to move up to 10 GbE. This is already driving calls for 100 GbE transmission and demonstration of inter-working at this speed. Indeed, a small number of 40 Gb/s systems have already been in operation for over 3 years, but have not yet been widely adopted.

In this migration, today's photonic systems are in a position to meet demands up to 10 GbE. System speeds at 10 Gb/s are 'normal production' and, if many new 10 Gb/s systems are needed, then available WDM systems (in some cases already installed) will have the capacity to absorb this growth. Available 40 Gb/s technology can even go some way to supporting 100 GbE services. However once operators make heavier demands for system speeds exceeding 10 Gb/s, and certainly for 100 Gb/s, then new technologies and new line infrastructure will be needed, placing new demands on interworking.

7.2 ROLE OF OPTICAL CIRCUIT SWITCHING (OADM AND OXC)

The extension of multiplexing into the optical wavelength domain has vastly increased the capacity of fibre and been a major factor in holding down the cost of digital transmission. In telecommunications applications WDM has been closely tied to the

SONET/SDH layers, while in computing it has supported the datacomms formats. Now, with the digital wrapper approach, both can be supported together. The digital wrapper uses a 2.5 Gb/s or 10 Gb/s SDH frame and any signal format can be mapped into the frame using for example the Generic Framing Protocol. WDM can therefore conveniently carry a broad mix of client signal formats and also allows operators to offer 'wavelength services'.

The capacity carried across individual routes in a network can vary considerably according to time of day, special events and so on. As an extension of this multi-protocol capability, multi-layer network strategies are being researched in which the traffic trends are sensed and the link capacities adjusted according to the demand. Such schemes might be applied to individual customer services or to the traffic on a route as a whole. At the lower end, traffic capacity might be adjusted digitally from low packet rates up to the maximum digital rate allowed by the transport channel (typically 10 Gb/s). If capacity steps higher than this are needed then WDM channels may need to be added or removed. In this case components offering wavelength flexibility such as ROADM or OXC will be essential. Before these components can be deployed however, a control and signalling mechanisms is needed. Current standards activity and supporting research explores GMPLS as a suitable control mechanism. The GMPLS signals can be carried over the DCC channels of the SDH frame.

- Fixed OADMs have been available for some time and used in some systems, but not widely, perhaps because of their inflexibility and because network capacities have not been sufficiently high to warrant an OADM strategy.
- It will be logical to include optical switching components as network capacities grow and as multi-layer network strategies are developed.
- But multi-layer strategies will need a control network, for example to sense network conditions and adjust link capacities automatically.
- Application of optical circuit switching to individual customer circuits may arise later when costs have fallen sharply and switches that are scalable can be manufactured economically. This in turn will depend on the rate at which higher bandwidth services are developed.

7.3 OPTICAL BACKPLANES

Convergence and the need to integrate a variety of functions into a single equipment are leading to new approaches in backplane technology and new standards for constructing modular equipment. Advanced TCA (ATCA) is an open standard that evolved from the PCI Industrial Computer Manufacturers Group (PICMG) to serve the telecommunications industry. It is being developed for carrier-class systems where high reliability is required and it promises to vastly improve the way networks are built and maintained with shortened product development cycles, a faster time-to-market for new products and with less risk.

ATCA provides a construction platform for Carrier class applications employing standard fabric solutions as well as for use in data centres. A key feature relevant to network interoperability is that the backplane is designed to support inter-operable multi-vendor modules. It incorporates advanced software infrastructure providing APIs which are able to handle conversion of signal and protocol formats and which can perform processing at call, signal or packet levels.

The ATCA standard aims to provide:

- Scalable shelf capacity up to 2.5Tb/s
- A scalable architecture that can support availability to 99.999%
- Multi-protocol support for interfaces up to 40Gb/s
- Robust power infrastructure and large cooling capacity
- High levels of modularity and configurability
- The ability to integrate multiple functions and new features
- Convergence of telecom access, core, optical, and data centre functions

8. COMMUNICATIONS AND COMPUTING NETWORK TECHNOLOGY

8.1 THE EVOLUTION OF SDH TECHNOLOGY TO NEXT GENERATION-SDH AND BEYOND

Next Generation SDH (NG-SDH) not only provides high bandwidth connections, it has the ability with Virtual Concatenation (VCAT) and the Link Capacity Adjustment Scheme (LCAS) to dynamically adjust bandwidth in 2 Mb/s increments, allowing system bandwidth to be efficiently matched to any required data services speed. Operators generally recognise that the installed SONET/SDH resource is just too huge to simply throw away for the sake of replacing it by a new packet infrastructure and they are particularly interested in ways to efficiently adapt legacy SONET/SDH capacity to meet new services requirements.

A key advantage of NG-SDH then is that it can provide bandwidth in 2 Mb/s (or greater) steps up to very high bandwidths and this can be dynamically adjusted without affecting carried services. This is a valuable feature that enables efficient use of system bandwidth when providing data services such as Ethernet. A further required feature, currently under development, is to allow the client network to dynamically select the required bandwidth according to the clients own criteria via the user Network Interface (UNI). For this, a suitable signalling and control network is needed. The OIF have prepared draft external NNI Implementation Agreements that have the wanted features. In them, VCAT is treated as a separate network layer with its own signalling so that virtual concatenation groups can be individually controlled. This means that different network layers can operate in different control plane instances. The importance of this is that, in practice, the different network layers may be under the control of different business concerns (see Annex: IPSphere). The draft agreements also include other features such as addressing methods, ways to ensure resilience of the signalling (essential for carrier class networks) and path and neighbourhood discovery (needed to allow automatic configuration as network conditions change). In July 2007 the OIF began interoperability tests using these draft agreements.

Call control actions are coordinated between call controllers at each of three layers: Ethernet, VCAT and SDH/SONET as shown in Figure 1. Although applied to Ethernet and NG-SDH, the OIF point out that the techniques can be applied to other layering strategies.

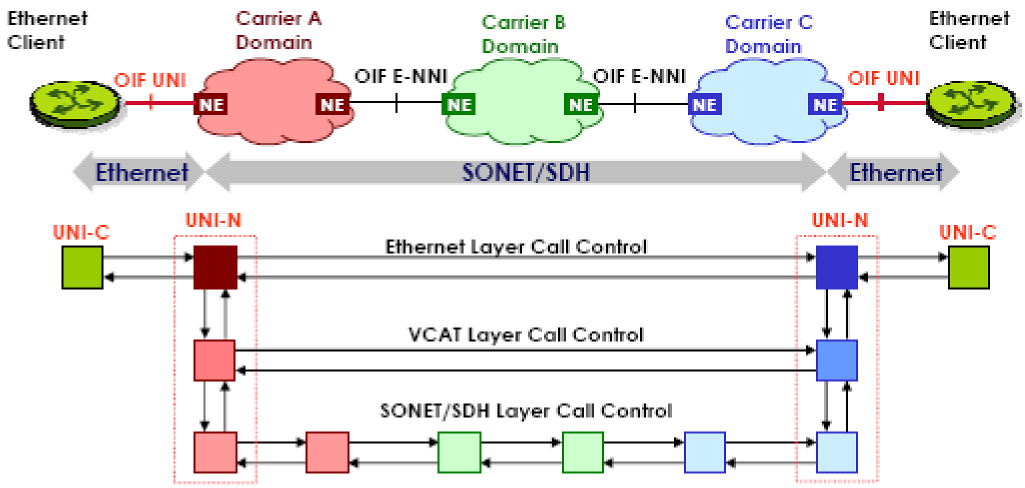


FIGURE 1 OIF MULTI-LAYER CALL CONTROL

8.2 THE PROSPECTS FOR CARRIER CLASS ETHERNET

Ethernet has been the dominant data link protocol in local area networks (LAN) for many years and it is widely offered as a customer service, but it was not designed for large carrier-scale transport networks. However because of its suitability for data and multimedia applications, its flexibility and its widespread use, many carriers now consider Ethernet as a potential convergence solution for Next Generation Networks.

However a number of issues need to be addressed before there can be widespread deployment of Ethernet carrier transport protocol. In particular Ethernet suffers from scalability limitations due to the combination of a flat addressing scheme, broadcast and multicast auto-discovery mechanisms and the limited ability to utilise the full network connectivity (since no loops are permitted in a switched Ethernet network topology). Network management methods are also insufficient for a carrier environment and need to be developed as well as mechanisms to signal the occurrence of a network failure. As conventional Ethernet has very few Operation Administration and Maintenance (OAM) functions and for the technology to be used in a carrier-class environment, it is essential for these to be developed. Rather than develop these features from scratch, recent standardization drafts propose to borrow from other standards to add key transport functionality allowing Ethernet solutions to operate in a similar way to SDH.

Because many of the limitations of Ethernet arise from its connectionless operation, a technique termed Provider Backbone Transport (PBT) based on connection-oriented methods is being developed. The Ethernet addressing scheme has been extended by including an additional 24-bit service tag which enables 16 million services to be supported which allows the customer and the operator to use separate addressing schemes that are independent of each other. The flooding and broadcasting techniques used by Ethernet and the Spanning Tree protocols also restrict scalability. PBT therefore turns these functions off and instead, uses a control/management plane to populate the switch forwarding tables. This effectively converts Ethernet into a connection-oriented packet-switched network technology that can operate with any network topology (linear, ring, mesh).

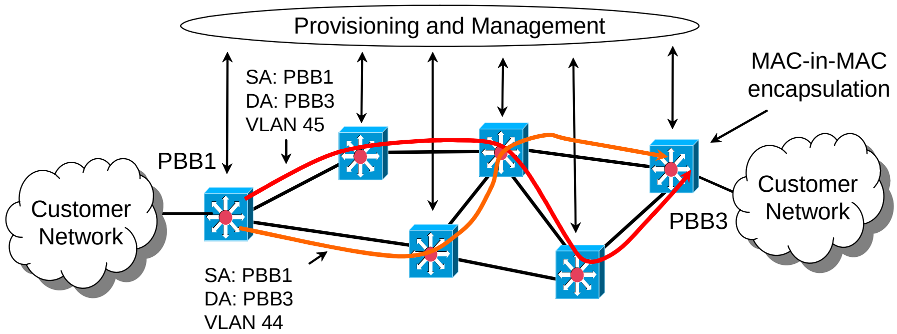


Figure 2 Carrier class Ethernet: Provider Backbone Transport.

8.3 GRID NETWORK RESEARCH APPLICATIONS

Research grid networks link distributed computing resources to perform highly demanding computations needing vast processing capability. To make optimum use of the computing resources, high capacity, low latency connections are needed, and complex optimisation algorithms are run that calculate the best usage of the computing resources, taking account of factors such as the data rate offered by the connecting links and their latency.

The key difference between telecom control planes and the grid application is that, to achieve optimum performance, the grid application needs control systems that are topology aware. This means that the optimisation programme requires knowledge of the detailed topology and the performance of each link. Where the research network is owned by the researchers, this is not a problem. But where it is owned by a commercial third party it may be because an operator's network topology is treated as commercially confidential and may be viewed as a security risk.

Network 'abstraction' provides a useful compromise. If an operator does not wish to divulge the topology of their network, they can provide a summary of the available connectivity between research centres and computing resources. Such a summary could represent the network simply as a pseudo node or as a set of virtual links. Any optimisation programme using the network summary details would not necessarily give the global optimum, but could give a good approximation depending on the degree of summarisation used.

8.4 NETWORK INTEROPERABILITY

Regulatory rules set requirements for public telecommunications networks to inter-operate. For advanced services, this means that not only must client signals traverse successfully from one network to another, but that relevant control and management information must also be exchanged. In a future network, delivery of a typical service will normally traverse several network domains. Depending on the connection more than one access network may be used and multiple transport networks (for example with mobile or global services). Also depending on the service, there may be separate service provider networks, content provider networks or a digital rights management service. The question of interoperability arises between the many possible combinations of these network elements. The main network to network interface types may be summarised as follows:

- Access network to core network
- Core network to core network
- Core network to content provider network

In the future regulatory rules will dictate that these different network facilities be interconnected. The new architectures will need increased levels of control over the network resources to provide flexibility and to gather network usage data. Several standards bodies are developing new 'control layers', placed between the element management system and the elements themselves, to perform this function. When networks are interconnected, these control systems will also need to exchange information over the interface. The NNI and UNI specifications being developed in the OIF, for example, address this requirement.

Optical interconnection techniques can impact the way in which transport networks can inter-operate. First is the access-core interface, providing for extended reach access. As network providers introduce their NGNs they are likely to consolidate edge nodes wherever possible so that they have fewer physical locations where aggregation of traffic takes place. This is one of the means they will use to reduce operational costs. The corollary is that the average length of access links will increase and access systems that can operate efficiently over longer distances before the traffic is aggregated with other services will be an attractive proposition.

Second is core to core interconnection, where higher speed transmission above 40 Gb/s or transparent optical network technology may be appropriate. Already there are calls from the OIF for demonstrations of 100 Gb/s interworking. Also the ITU is developing recommendations for Automatic Switched Optical Networks (ASON) and although a switched optical network is still well into the future, systems with optical add-drop multiplexers have been implemented. It is therefore appropriate to consider the implications for interworking between these systems.

9. RESEARCH DIRECTIONS AND CONCEPTS RELEVANT TO PHOSPHORUS AND FUTURE EVOLUTIONS

9.1 HARMONY

The Harmony system is a multi-domain, multi-vendor, and multi-technology network resource broker with advance reservation features developed within the framework of PHOSPHORUS and detailed in the PHOSPHORUS deliverable, D7.1.2 – "Plan for Using and Exploiting the Knowledge". The main objective of the Harmony System is to provide Users or Grid applications/middleware with the ability to create point-to-point connections using network resources from several domains in a transparent way. The solution proposed by Harmony speeds up the creation of complex resource reservations with advance booking features, involving several Network Resource Provisioning Systems (NRPS) or GMPLS control plane. Harmony defines a common Network Service Plane (NSP) for all of them; hence, interoperability between NRPS (DRAC, UCLP/Argia, and ARGON), GMPLS and Grid applications/middleware is seamlessly achieved. The definition, design and implementation of the Harmony system has been demonstrated in several international events, proving its feasibility to provide services across multi-domain and multi-vendor research network test-beds.

The Harmony system, apart from controlling multi-domain scenarios, enables the Network Resources in the Grid by means of the Harmony Service Interface. This interface has allowed the integration of the Grid middleware and the transport networks, since it is the component of the Harmony system responsible for offering the network resources to the applications in a seamless way. The Harmony system also implements a resource co-allocation and scheduling capability (reservation service), able to reduce the probability of resource blocking, and providing inter-domain topology awareness services (topology service).

Harmony's test-bed has involved up to ten independent domains, proving the multi-domain capabilities of the system and the NRPS utilized. Each domain involved in the test-bed was composed of different physical equipment. Due to the valid tests/demonstrations performed so far, some of the work of the HIS (Harmony Service Interface) is being taken into consideration within the NSI (Network Service Interface) Working Group of the OGF (Open Grid Forum).

The main features of the Harmony system are:

- Network Service Plane implementation with flexible, configurable operating modes (centralised, hierarchical, distributed, among others)
- Inter-Domain Brokers and path computing elements for optical network resources
- Advance reservations for Grid applications.

- Grid Middleware integration with the NRPS or GMPLS.
- Topology abstraction and sharing among (administrative) domains.
- Secure intra-domain topology hiding, using resource abstraction techniques.
- Authentication and authorisation infrastructure integration with NRPS and GMPLS.
- WSDL description (OASIS WSRF v1.2 compliant) of the HSI for flexibility, portability and easy adaptation to new systems and/or applications.

An open source tool is available to the Grid Community that allows Grid applications to request on demand and in advance network reservations services, with specific connectivity bandwidth across different heterogeneous domains.

The main impact it has had on the state of the art is:

- An open source system to request e2e connections to different heterogeneous NRPS
- A system that offers advance reservation functionalities
- A system integrated with the Grid middleware that allows automatic request of connectivity service from the application
- A Service interface that is being proposed within standardization groups (OGF)
- A real system which is being currently operative on the Phosphorus testbed

Harmony is a system that is ready to support the Grid research community and can facilitate their access to network resources that nowadays is provided in manual basis. National Research and Education Networks (NRENs) represent the most potential group of users of the Harmony system, since NREN are the ones which are using multi-technology, multi-vendor and heterogeneous local test-beds.

9.2 G2MPLS

Grid-GMPLS (G2MPLS) is an enhancement to the GMPLS Control Plane that was developed and implemented within the PHOSPHORUS framework. The Grid-GMPLS architecture is detailed in the PHOSPHORUS deliverable D2.1 “The Grid-GMPLS Control Plane Architecture”. It defines the specification and development of mechanisms and procedures to implement the G^2MPLS enhanced services, the Grid Network Services (GNS). The GNS is a service that allows the provisioning of network and Grid resources in a single-step, though a set of seamlessly integrated procedures. G2MPLS extends the ASON/GMPLS Control Plane architecture to provide part of the functionalities related to the joint selection, co-allocation and maintenance of both Grid and network resources. In addition, it integrates and complements the standard ASON/GMPLS network services, i.e. automatic setup and resiliency of network connections across the Transport Plane.

The architecture, including protocol extensions and network interfaces specifications, relevant software components, their integration into prototypes and consolidation for testbed activities for the G2MPLS control plane was developed within the PHOSPHORUS project. The G2MPLS architecture is defined as two Control Plane models: the Phosphorus Overlay and the Phosphorus Integrated. These models concerned the layering of Grid and network resources and had a different meaning and scope with respect to the IETF definitions for Overlay, Augmented and Peer/Integrated models. The G2MPLS control plane solution has been deployed and assessed over the PHOSPHORUS testbed.

G2MPLS is turning into a platform for the easy take-up by Grid-users and NRENs willing to deploy Grid Network Services. There are plans in NXW for reusing the G2MPLS stack as a training platform for NRENs or commercial operators on G(2)MPLS features and issues.

9.3 GN3 VIRTUALISATION

GN3 specifically selected its joint research activities (JRA) to address areas of the existing service that are known to be missing, or new services that have been specifically requested by the users (as derived from a survey of NREN requirements that took place in early 2008). One of these areas of research is the activity on virtualisation as detailed in the JRA1 technical annex.

Virtualisation is a classic technology in computer systems and networking. It has been employed in many areas, ranging from full virtualisation of computer servers to virtual private networks. The introduction of hardware support reduces the overhead and complexity of management with the added advantage of better utilization of hardware resources, increased flexibility and resiliency of the architecture.

Virtualisation can be applied to various network layers and addressed in different ways:

- Virtualisation of node resources within the network, i.e. virtualisation of L1, L2 and L3 devices, thereby creating multiservice virtual nodes.
- Virtualisation seen from the operation and support systems (virtualisation of servers).
- Multi-domain Aggregation of virtualised services and elements, thereby creating a single virtual network spanning multiple physical and control domains.

The work covered by GN3 virtualization task will investigate the advantages of virtualization of the architecture from a network operations, and user perspective. The work will also include a business analysis addressing strategic, tactical, operational, and risk issues.

9.4 GEYSER

GEYSER is an FP7 project that aims to qualify optical infrastructure providers and network operators to enhance and complement their traditional set of business models. The technological enablers for this are the latest advances in physical resource partitioning, logical infrastructure composition and network control plane architectures, which allow network operators (service providers) to operate highly specific, cost-efficient, dynamic, and application demand driven networks. The GEYSER project further enhances the position of infrastructure providers by providing a mechanism for seamless integration and provisioning of network and IT resources. Such Future Photonic Network that can support an IT-services oriented Future Internet architecture will enable and foster the emergence of novel domains of distributed applications which ultimately bring in a whole new and powerful market opportunity for infrastructure providers and network operators.

GEYSER will define and implement a novel photonic network architecture, capable of provisioning optical network and IT resources to network operators for end-to-end service delivery. GEYSER proposes a revolutionary vision under an evolutionary approach that follows a network centric and bottom up strategy. This vision is based on partitioning the photonic network infrastructure to create specific logical infrastructures, composed by optical network and IT resources. This composition will overcome the limitations of networks and domain segmentation. Each logical infrastructure will be controlled by an enhanced Network Control Plane capable of provisioning Optical Network Services bundled with IT resources in an on demand basis. Furthermore, the logical composition of photonic networks will enable the GMPLS/PCE control plane to dynamically scale infrastructure resources based on the network operator needs.

The GEYSER architecture aims to facilitate the emergence of new business models in the future telecom market, where current carrier roles can be split and extended into physical infrastructure provider and (overlay/customized) network operators. Thus, current carriers can also make profits from their infrastructure by carefully/better planning resource allocation to limit unused cycles or bandwidth, and improving the energy efficiency by optimizing their resource usage. The flexibility of the GEYSER logical infrastructure composition mechanism will allow network operators to lease and operate multiple instances of application-specific networks, each with its own specific IT and network requirements.

The following PHOSPHORUS partners are contributing the GEYSER project PSNC, NXW, UEssex, IBBT, UvA, i2CAT, AIT.

10. HARDWARE AND COMPONENTS

10.1 GEANT3 HARDWARE CONSIDERATIONS

Within the Geant3 (GN3) project, a number of hardware considerations will be made. These include:

- Photonic technologies :
    - ROADM technologies such as
        - Wavelength Blocker (WB),
        - Wavelength Selective Switches (WSS),
        - Small Switch Array (SSA)
    - Photonic Integrated Circuit (PIC) based solutions.

- Transmission capacity and granularity:
    - Investigation of issues related to higher capacities per wavelength (i.e. 100Gbps), wavelength count, multicast and compensation techniques

ANNEX 1: PHOTONIC ROAD MAP TO TODAY

The initial driver for optical fibre technology was the opportunity to reduce costs: fibre was made from silica, which was a much cheaper material than copper, fibre cable was lighter, easier and therefore cheaper to handle, buried repeaters could be either eliminated or dramatically reduced in number and system capacities could be increased substantially compared to copper cables.

Initial systems introduced from 1980 used multimode fibre at 850 nm wavelength. The choice of wavelengths was dictated by

1. Ability to manufacture and joint fibre with a small core
2. A 'low loss' fibre window existed at 850nm
3. The ability to produce semiconductor sources and detectors at this wavelength, and couple the light into the fibre

Material systems for LED and laser sources at this wavelength were reasonably well understood as they were close to visible wavelengths and LEDs and Fabry-Perot lasers were produced. Si and Ge materials were suitable for photo detection. These technologies were developed and, as expertise grew, plesiochronous systems development gathered pace and bit rates increased rapidly.

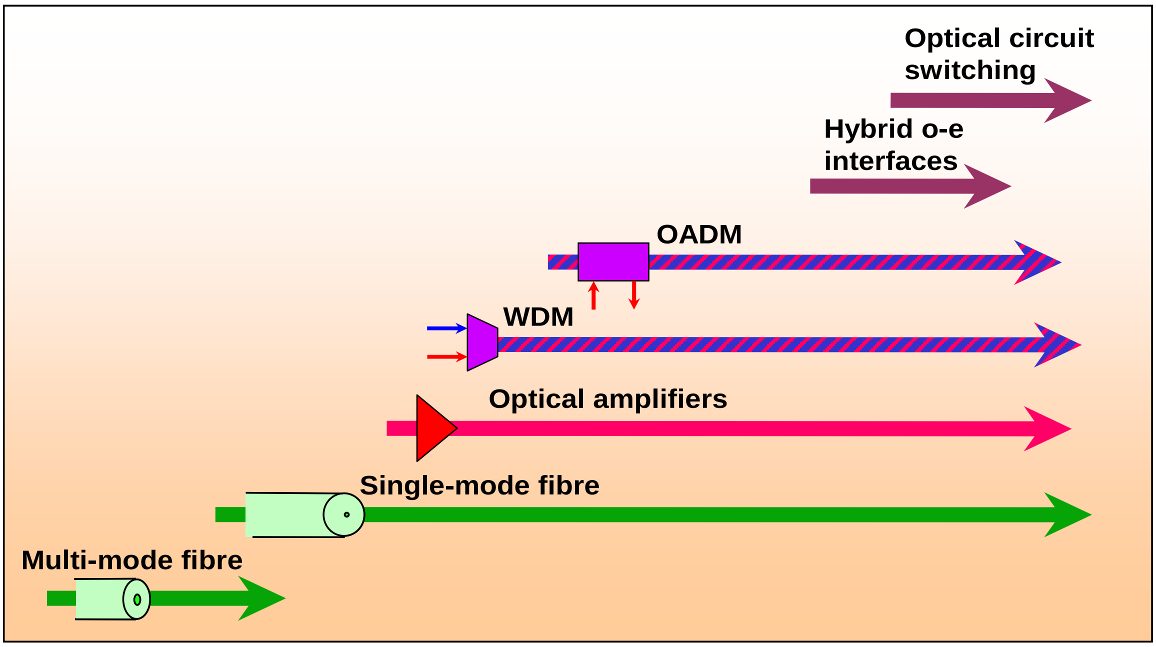
By the time the first multimode systems were introduced, scientists had recognised the improved capability offered by single mode operation at longer wavelengths and research interest turned to methods of manufacturing and handling single mode fibre and the material systems that would be needed, first at around 1300 nm, where it was possible to manufacture fibre with zero dispersion, and later around 1550 nm where additional techniques would be needed to overcome the effects of dispersion.

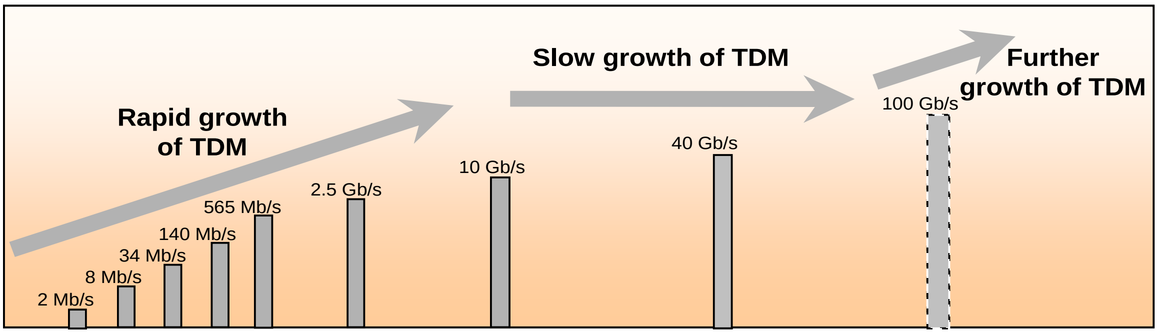
High performance operation demanded improved device architectures and new systems techniques. Distributed FeedBack (DFB) lasers producing a single longitudinal mode proved to be highly successful and could be designed to produce definable wavelengths over a wide range. Specialist fibres were designed with 'negative dispersion' properties and methods to compensate for dispersion were developed, enabling a further increase in bit rate and distance to be achieved.

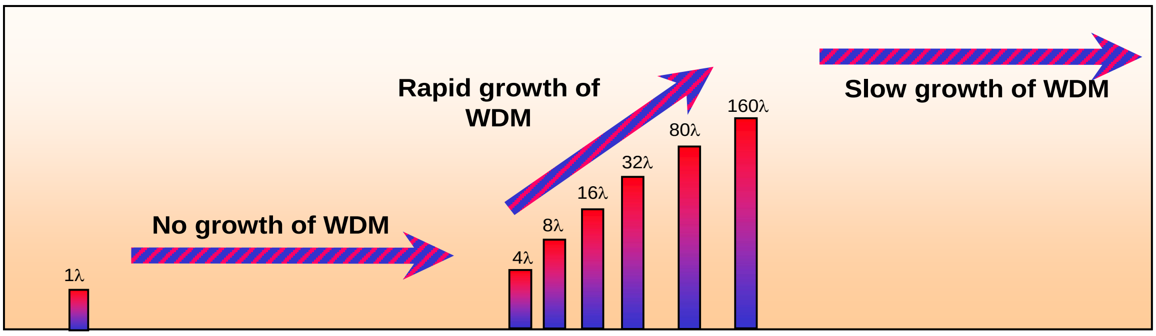
As capacities increased operators needed more flexible and more manageable transport systems and SDH systems were introduced from 1990. The plesiochronous systems continued to be used for many years in parallel with SDH but, by now, most administrations have replaced them.

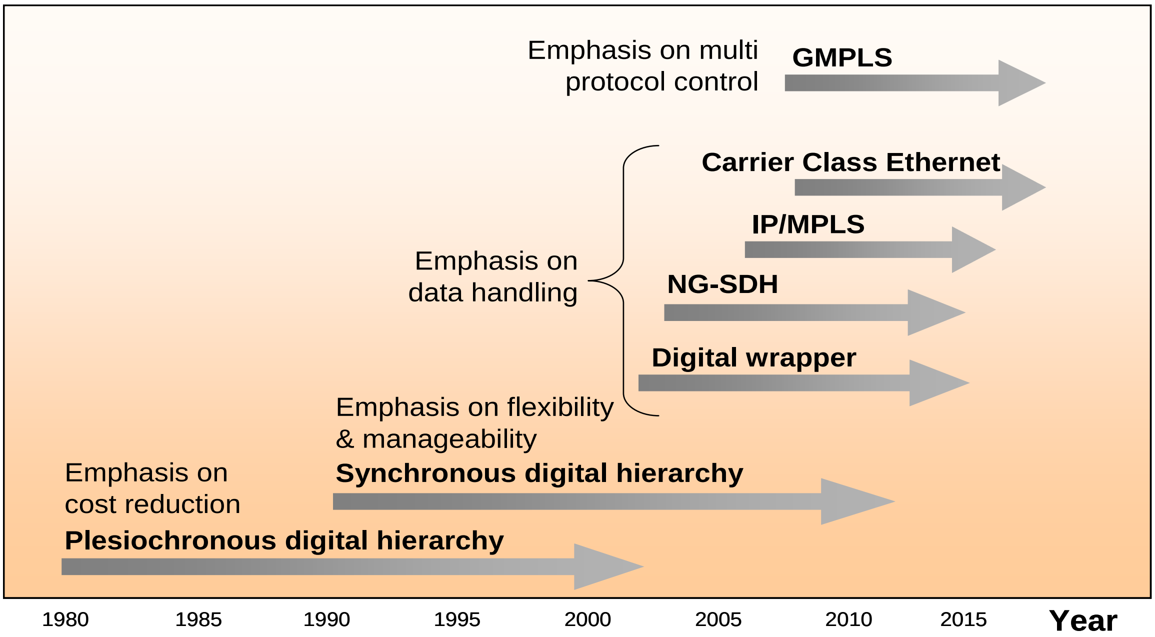
Although increased system speeds could be achieved, as speeds increased the available power budget limited the system range. The invention of EDFAs gave the solution, allowing the digital signals to be amplified (but not regenerated)

The demand for higher speed systems continued to increase progressively. However technical difficulties associated with higher speed operation slowed down the rate of development. By 1995 the US was faced with the prospect of installing new fibre cables in its long distance networks. Up to this point systems had operated at a single wavelength. However newly developed WDM offered a much cheaper upgrade strategy. The following year saw the first WDM systems introduced into Europe, particularly in longer distance networks.


Optical circuit switching
Hybrid o-e interfaces
OADM
WDM
Optical amplifiers
Single-mode fibre
Multi-mode fibre


Slow growth of TDM
Further growth of TDM
Rapid growth of TDM
100 Gb/s
40 Gb/s
10 Gb/s
2.5 Gb/s
565 Mb/s
140 Mb/s
34 Mb/s
8 Mb/s
2 Mb/s


Rapid growth of WDM
Slow growth of WDM
No growth of WDM
1λ
4λ
8λ
16λ
32λ
80λ
160λ


Emphasis on multi
protocol control
GMPLS
Carrier Class Ethernet
IP/MPLS
Emphasis on
data handling
NG-SDH
Digital wrapper
Emphasis on flexibility
& manageability
Emphasis on
cost reduction
Synchronous digital hierarchy
Plesiochronous digital hierarchy
1980
1985
1990
1995
2000
2005
2010
2015
Year

The adaptation of EDFAs was critical to the success of WDM systems. Initially designed for single wavelength channel operation, they were soon adapted to multi-wavelength working when WDM systems were needed. Modified designs included mid-stage access which allowed performance enhancing components to be inserted such as wavelength flattening filters and dispersion compensating fibre. Once the pieces were in place for WDM working, actions within the ITU led to an agreed wavelength grid standard and the stage was set for the rapid development of WDM systems.

Up to this point the main driver for improved systems was the demand for higher capacity to meet requirements first for voice networks, and later for private circuits. The private circuits provided the inter-site links for corporate networks and they carried increasing amounts of data traffic. However SDH was designed with 64 kb/s voice channels in mind and it has not been efficient at carrying higher bandwidth data traffic. With the growth of the Internet, there has been an increasing need for a transport system that can handle data more efficiently than SDH. With this in mind there are several initiatives under development within standards to address this requirement.

ANNEX 2: THE IPSPHERE FRAMEWORK

Sources used:

"IPsphere Framework Technical Specification (Release 1)", June 2007

"The Business of IP", IPsphere Forum, White Paper, June 2007

CONCEPT

The IPsphere Forum is a nonprofit organization dedicated to unleashing the business and societal benefits of IP convergence. An international consortium of industry leaders, the IPsphere Forum is developing a universal operational framework for the assembly and delivery of services on converged infrastructures - enabling providers to streamline processes and drive operational efficiencies.

Today, multiple service providers may be involved in providing a typical user service. Service providers receive their financial returns under 'settlement agreements', so that each receives a fair proportion of the revenues. These settlement agreements can become very complex when 1000's of services are being offered by 100's of service providers. The concept behind IPsphere is to provide a technical way to create cross-service settlement in the provision of complex services. Settlement flow does not correspond to traffic flow on the Internet and the IPsphere framework does not provide a means to determine viable investment into infrastructure.

SCOPE

IPsphere uses a 3-layer model to define its scope (see Figure 3 below). The 'Packet Handling Stratum' handles the packet related functions, including routing, switching, forwarding and queueing etc. Above this the 'Network Policy and Control Stratum' allocates and tracks resources to ensure that QoS and security requirements are met. At the highest level, the 'Service Structuring Stratum' is used to define the service and to abstract and decompose the service requirements so that it can communicate with the Packet Handling Stratum via the Network Policy and Control Stratum. The focus of the IPSphere framework centres on the Service Structuring Stratum.

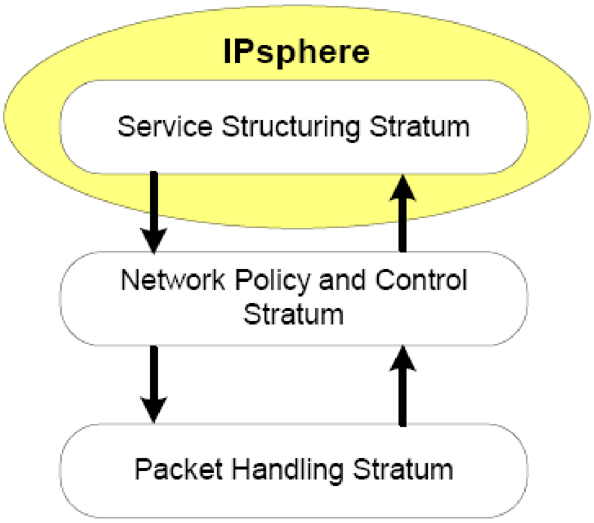


Figure 3 Three layer model

IPsphere modules interface to business support systems, operational support systems and to element managers, but not to the control, network or physical layers

PRINCIPLE

The IPsphere architecture is designed to allow any service to be delivered efficiently in a multi provider environment. It is technology independent so that network resources can be provided by multiple providers via any suitable technology. Provision of a user service by one provider may call on a number of network resources offered by different network providers. The principle is illustrated in Figure 4.

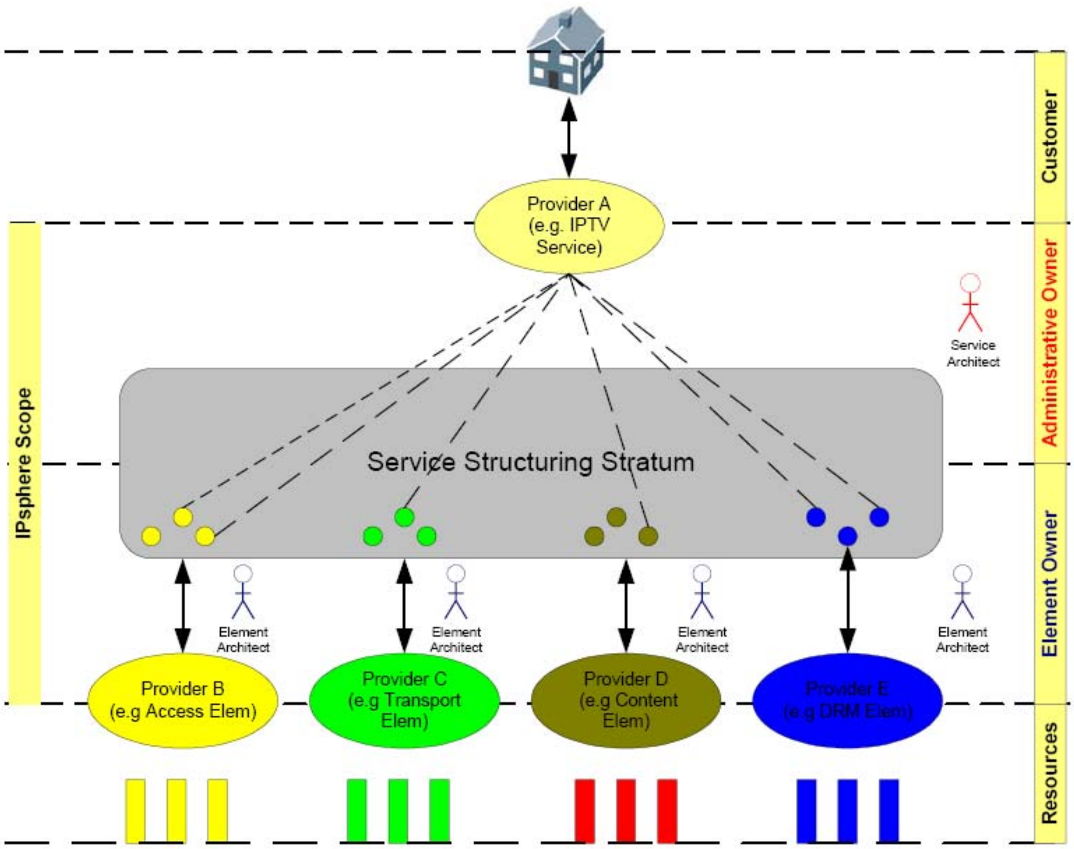


Figure 4 IPsphere Framework Context Diagram

So for example, a retail provider planning to operate a service uses the service stratum to develop a service template which outlines all of the components, both business and technical, needed to provide the service at the required quality. The template uses abstracted features of the required resources, so providing confidentiality for the resource provider. When a customer orders the service from the provider the template is activated and the needed components are ordered automatically. The components may come from the retail providers own resources or may come from other providers. Identity authentication and digital rights management are also automatically included. The system records the contribution of each partner so that, after the service has been delivered and the retail provider has invoiced the customer, resource providers are paid according to the agreed template.

The framework provides a top down mechanism for identifying the functional components needed to formulate a service and a bottom up mechanism for defining, in abstract terms, network elements that can be assembled by a services architect as needed to meet a market demand. Hence the IPsphere framework does not have a detailed view of the underlying resources and never interacts directly with them. All interactions are through the corresponding management and control systems. This approach assures confidentiality to the resource providers and allows the IPsphere framework to be applied to any carrier or content provider network without change to the infrastructure and irrespective of the technology used.

ANNEX 3: WORKSHOPS CO-ORGANISED BY PHOSPHORUS AND COLOCATED WITH OFC2007 AND 2009

Data from OFC 2009 workshop "Grid vs Cloud Computing and Why This Should Concern the Optical"

http://www.ofcnfoec.org/conference_program/Workshops_and_Panels.aspx#workshops

Organizers: Chunming Qiao[1], Dimitra Simeonidou[2], Bill St. Arnaud[3], Peter Tomsu[4]; [1]SUNY at Buffalo, USA, [2]Univ. of Essex, UK, [3]Canarie Inc., Canada, [4]Cisco Systems Ltd., USA.

Description:

Recently, there has been a lot of interests in Cloud, Grid and Utility computing and their influence in shaping the future network infrastructure. While Grid Computing is geared mainly towards scientific users and Grids, both Cloud and Utility computing are for enterprises.

The common point for both approaches is their reliance on high speed optical networks to provide advanced and flexibly reconfigurable infrastructure. Optical network researchers are facing big challenges in delivering the necessary technologies for supporting Cloud, Grid and Utility computing services. Such technologies and services will change the Internet in much the same way as distributed and parallel computing has changed the computation and cyber-infrastructure today. The workshop will discuss various Cloud, Grid and Utility Computing approaches and will present the challenges (research and implementation) for our community.

Schedule:

- Welcome/Introduction
- Clouds and Optical Networks, Bill St. Arnaud, CANARIE Inc., Canada
- Challenges in Enabling Cloud Computing over Optical Networks, Piero Castoldi, Barbara, Martini, Fabio Baroncelli, Scuola Superiore Sant'Anna Univ. Italy
- Challenges in Enabling Grid Computing over Optical Networks, Cees de Laat, Univ. of Amsterdam, Netherlands
- Virtualizing and scheduling network resource for emerging IT services: the CARRIOCAS approach, Pascale Vicat-Blanc Primet (INRIA) & Dominique Verchère (Alcatel Lucent BellLabs)

- Energy / cost beneifts of cloud computing, Rodney Tucker, U. Melbourne, Australia
- Opportunities in Optical Grid and Clouding Computing, Chunming Qiao, SUNY Buffalo, USA
- Panel discussion and Q&A

Data from OFC2007 workshop of Future Optical Networks

http://www.cse.buffalo.edu/~qiao/workshop/FON2/

Most of the material from this workshop represented developments on the data plane, but gave a strong view of future directions in this area.

The full list of speakers was as follows:

- Adel Saleh [DARPA/STO, USA]
- Paul Morton [NSF, USA]
- *Andreas Gladisch [T Systems, Germany]*
- Osamu Ishida [NTT Labs, Japan]
- *Dimitra Simeonidou [Univ. of Essex, UK]*
- Weisheng Hu [Shanghai Jiaotong Univ., China]
- Soichiro Araki [NEC Laboratories, Japan]
- Rod Alferness [Alcatel-Lucent, USA]
- *Peter van Daele [University of Gent, Belgium]*
- Yoshiaki Nakano [University of Tokyo, Japan]
- John Bowers [Univ California Santa Barbara, USA]

The following text tries to summarise some of the main points arising form the presentations [with respect to the evolution of optical networks]. There is a wealth of material in the slide set, much of which will be used in the e-Photon/ONe+ roadmap activity. Many issues were discussed and some the key issues are addressed below but the issues that are related to the roadmap can be summarised as follows:

Optical infrastructure is the core technology to achieve interoperability issues at control /service and data plane, since it can support new convergent transport architectures, flexible management and availability of resources. It may be the case that optical networking technology will develop to be cost effectively the main technology of the service oriented architecture of the network of the future.

Four Key Talks [2 US, 2 Japan]

- **GENI**

This talk was given by Paul Morton (NSF) and summarised the objectives of GENI and also gave a time line for its implementation. The conceptual design for the facility is almost complete; this would connect about 200 universities and also connect to different user communities. There is also the ambition to extend the facility on a Global scale. A specific concept is to realise a programmable networks where all network elements are programmable via open interfaces or by downloading user codes. This enables the concept of slicing and virtualisation where many simultaneous experiments can share the network resources. Optical networking plays a major role in GENI which will allow allow the inclusion of new optical technologies as they mature during the GENI lifecycle.

In order to deal with the security, availability/reliability, scalability and manageability issues of the Internet and also to be able to support mobility /sensing applications the GENI will investigate the new paradigm and implement an experimental facility that will mainly focus on addressing physical network and control and management issues. Three are the main areas: GENI facility, optical networking research and integration issues. Emphasis will be put on the vitrualisation of the network to support simultaneous utilization.

The current timeline indicates construction in about 2009 over a period of 5 years, with a 10 year lifetime.

- **Terabit LAN**

This is a very important paper indicating future directions and ambitions. This talk was given by Osamu Ishida from NTT Network Innovation Labs. The concept here is that domestic users will be fully satisfied by FTTH and eg 100 Mbps access. Essentially networks will be built to support such mass service, but with this infrastructure (based on WDM) providers can also support high end users. Emerging applications are usually low latency ones and very bandwidth demanding. In that case LAN has to drive the link technology . The T-LAN concept would provide interfaces from 10G to 1 T per host. Data plane would be dynamically assigned lambda paths and control plane on shared packet-based network. Ih this context multi-lambda (1000s of λs) will be supported in each LAN and one lambda per used for very demanding users.

The talk discussed the project Lambda Access [2006-2010], which has objective of user controlled >100G data transfer via backbone [10x10G].

- **Next generation Core Networks**

Talk given by Adel Saleh, DARPA Strategic Office. This set out the vision of a next generation network with increased robustness, security and throughput, together with reduced jitter, reduced CAPEX and OPEX.. Some key points:

- Need to move to 100Gbps per wavelength or higher
- As network load increases so does optimum line rate; eg if network load increases by factor of 10 from current value, optimum line rate moves to 160 Gbps.
- New CORONET project aimed at global core network;
    - Redesign the core network
    - IP over WDM architecture
    - Predominantly IP services (with differentiated QoS)
    - Scalable for up to 10x increase in aggregate network demand over today's state-of-the-art networks
    - Highly dynamic network with very fast service set-up and tear-down

- **Photonic Service Gateways in the Japan's Lambda Utility Project**

Talk given by Soichiro Araki, NEC Japan. One of the four projects supported by the Japanese Government [2006-2010]. Objective is to evolve the network to provide more user control, greater scalability and greater bandwidth.

Requirements:

1. Controlling and managing an optical path over multiple carrier networks with high scalability of more than 1000 nodes
2. Highly-spectral-efficient transmission link technology at 100Gbps and beyond
3. Modulation-format-independent all-optical 3R technology at 100Gbps and beyond

Some key features discussed (see slide set)

- Borderless Optical Path Control and Management

- Network abstraction interface
- Optical path performance monitor and control
- Inter-domain path control, protection and restoration
- Cooperation between distributed control and centralized management
- Scalability in GMPLS network

Note: In all of these projects, 100G transfer is a hot topic

Key bullet conclusions

- 100G very important
- Programmable networks
- High end user networks
- Scalability (for control/data and service plane)
- Integration
- Reliability (for control/data and service plane)

ANNEX 4: STATE OF THE ART FROM IST PROJECTS

There are four current IST projects concerned with network interoperability, each addressing the problem in different ways. These are useful to analyse as they identify challenges and issues to be addressed. The four projects are MUPBED, GEANT, PHOSPHOROUS and NOBEL. Key information from these are:

MUPBED (information abstracted from MUPBED presentations).

Objectives

Main Objective

- The integration and validation of state of the art on-demand circuit switching techniques, and in particular of ASON/GMPLS (Automatically Switched Optical Network/Generalised Multi Protocol Label Switching) technology and network solutions, in the context of user-driven large-scale testbeds, as enablers for future upgrades to European research

Other Objectives

- To identify service/network requirements of high-end applications for European research environments;
- To define the ASON/GMPLS features matching the above requirements and enabling, the penetration of broadband services in Europe;
- To find and experimentally validate solutions for interoperability between different network domains;
- To assess the ability of ASON/GMPLS solutions to support demanding research applications, such as Grid computing, through lab and field trials with a large user community (including NRENs);
- To develop guidelines for the introduction of ASON/GMPLS technologies and ultrabroadband services in future European research infrastructures.

Interoperability

The MUPBED network consists of multiple network domains

- Networks based on different
  - Network Layers
  - Technology
  - Vendor Equipment

  - Control
- Applications attached to heterogeneous networks
- Results in two inter-working areas
- Horizontal
  - Within one network layer
  - Identified in control plane between test beds based on ASON, ASON/GMPLS
- Vertical
  - Between different network layers
  - Identified between
    - transport network layers (SDH) and server/client layers (Ethernet, IP/MPLS)
    - Application and Network layers

Interoperability areas

- Heterogeneous network domains (Network)
  - Status
    - 'Layer 2 tunnels' to interconnect the test-beds
      - Required inter-domain routing/signaling protocols and interfaces
      - Interconnection with SDH not practically feasible, hence implementation using transparent Layer 2/Ethernet
  - Issues
    - High effort required for the maintenance of the layer 2 connections
  - Implementation
    - Virtual interconnection between NRENs based on ENNI
    - then Real UNI 2.0 ethernet link implementation between the NRENS;
      - data plane → MUPBEDs layer 2 connection,
      - control plane → IPSec tunnel over public internet.
        - Requires the UNI 2.0 ethernet interface to be easily available and easy to use and interworking between ASON/GMPLS network domains
- IP/MPLS domains, ASON/GMPLS and Ethernet domains

- Between GMPLS/ASON and IP/MPLS (Control Plane)
  - Technical Issues
    - The definition of interfaces eg UNI, NNI;
    - interworking between
      - the routing/signalling protocols,
      - addressing schemes and management concepts
    - The non standardised definitions of terms which depend on individual standardised bodies.
  - Implementation
    - Multi-domain interfaces implemented
      - ENNI between ASON/SDH
      - UNI between IP/MPLS, GMPLS/ASON and Ethernet
      - GMPLS UNI between GMPLS domains
  - Challenges
    - Staying aligned with standardisation works
    - ASON/GMPLS inter-working to be demonstrated using “UNI proxy server” implementation
    - PAN European multi-domain control plane enabled SDH interconnection
- Application and Network Interface
  - Status
    - 3 Models available (API, UNI, Functional)
    - Test and demonstrations early 2007
  - Issues
    - Currently application adapt to network. Propose a network that adapts to applications rather than application that adapt to network. Need application-network interface.
    - The solution must be flexible and usable by very different applications and the achievable functionality depends on available network information
  - Implementation
    - Suggestions include UCLP, web services etc
    - Example using Web Services

GEANT 2

Main Objective

- To improve the infrastructure of gigabit data transfer speed as well as to introduce advanced applications into academic networks in the course of the next four years

- **GEANT 2 JRA3 "Development of New Services"**
- **Main Objective**
    - To develop new generation networks, by using optical technologies as the upgrade of the existing classic and advanced IP protocol-based services and to create a Bandwidth on Demand system which can operate in heterogeneous inter-domain environment
- **Objectives**
    - Streamline interdomain setup of end-to-end paths
    - Multi-technological domains
    - Step by step process automation
    - Advanced reservation

Interoperability

- **Multi-domain (Inter Domain) provisioning**
    - Using an inter domain manager shown below
    - Independent IDM multi-domain research to be continued autonomously
- **Intra-domain provisioning within each domain**
    - Configured manually
    - Accommodates domains that have GASON/GMPLS CP 'out of the box'
    - Provides necessary information to the IDM for inter-domain set-up
    -
- **Each domain managed by inter domain manager and domain manager regardless of the individual domain technology**

Issues

- Finding a path between domains to the desired domain
  - Solution: Path finder in the IDM module that is able to provide paths between domains
- Authentication and authorisation
- Monitoring and security
- Exchange of inter-domain information independent of technology
- Clear specification of required service
- Domain independence for technology choices and resource usage policies

PHOSPHORUS

- Objectives
  - Provide solutions for seamless interoperability and end-to-end dynamic service provisioning across heterogeneous network infrastructures, such that applications use the network as a grid resource
  - To perform technical development to both internal functionalities and exposed interfaces in all identified planes.
  - Demonstrate solutions and functionalities across a test-bed involving European NRENs, GÈANT2, Cross Border Dark Fibre and GLIF connectivity infrastructures
  - To enhance the GMPLS control plane in support of seamless, end-to-end Grid Network Services,
  - To promote the interoperation among different Network Resource Provisioning Systems

Interoperability

PHOSPHORUS

- Two inter-working areas
  - Horizontal
    - Within one network layer
    - Identified in
      - Grid middleware
        - UNICORE as a reference point
        - AAA policies
      - Three types of NRPS
        - UCLP
        - DRAC
        - ARGON
      - Two kinds of GMPLS
        - Standard
        - Grid Enabled
  - Vertical
    - Between different network layers
    - Identified between
      - transport network layers, GGMPLS layer, NRPS, Grid Middleware layer
      - Application and Network layers

NOBEL

- NOBEL deals with interworking in data, management and control planes within the network
- Some issues were realised during phase 1 of Nobel that hindered the complete achievement of the objectives
- These issues are grouped into the three inter working areas
  - Data Plane
  - Control Plane
  - Management Plane

Data Plane

- OEO conversions are sometimes done in nodes with passing-through wavelengths.
  - Potential Solution: Elimination of these nodes should be done depending on how far bit stream can travel before it needs regeneration. This reduces CAPEX.
- Bandwidth adjustment is difficult due to statically deployment of optical wavelengths
  - Potential Solution: Introduction of OXC, OBS, OPS permit bandwidth adjustment in steps with fine granularity and short provisioning time,
- Packet delay and jitter significant in real-time applications
  - Potential Solution: Use of prioritisation to distinguish between delay sensitive applications and other applications
- Market competition on different levels on the network
  - Potential Solution: analysis of metro-core interface helps in enabling market competition on the metro and core levels of the network.

Control Plane

- Discovery and control of network resources not automated.
  - Potential Solution: Exploit ASON/GMPLS to take the opportunity of discovery, identification and control of network resources with reduced management cost. The management cost will be independent of the number of network elements.
- Insufficient addressing space under IPv4 to cope with the growing number of network equipment and user terminals
  - Potential Solution: Better management of the number of addresses. NAT servers introduces too much network complexity
- Incompatibility between old and new equipment
  - Potential Solution: Need to ensure complete compatibility between old and new equipment during migration to a new network

Management plane

- Multi vendor networks sometimes have incompatible management interfaces which have to be managed separately increasing complexity, and inhibiting competition.
    - Potential Solution: Development and introduction of an inter-domain management standard to manage end-to-end connectivity crossing different administrative domains.
- Time between installation of software updates too frequent
    - Potential Solution: Organizing the required software in a number of independent parts with clear interfaces in between, could help to increase the time between updates and reduce complexity.

ANNEX 5: E-PHOTON/ONE+/IST PHOSPHORUS ROAD MAP MEETING: NETWORK INTEROPERABILITY - THE ROLE OF OPTICAL TECHNOLOGIES

Held in Internationales Congress Centrum (ICC), Berlin on 16 September 2007

OBJECTIVE

The purpose of the meeting was to gather information and views for the e-Photon/ONe+/IST Phosphorous Road Map report: "Network Interoperability - the Role of Optical Technologies". Twelve experts from Europe, USA and Asia attended the meeting and each was invited to give their view according to the brief below. Each expert contributed a written view and a selection of these was discussed during the meeting. Their views, which are personal and not necessarily that of their organisations, are recorded in this report.

BRIEF

Delivery of services over today's telecom networks is complicated by the many network types needed to provide an end to end service. In this environment networks are evolving towards a new architecture that provides a more flexible relationship among the various entities and which separates services operations from transport networks operations. The architecture relies on an intervening convergent packet layer to ensure that any service can be carried over any suitable infrastructure. However, as the evolution progresses services will become more diverse in their demands on the network, and better controls will be needed.

This Road Map recognises that optical fibre technology will be a critical part of the new infrastructure and it will highlight how the technology will impact on future networks interoperability.

The Road Map will be approached from two directions:

1. Projections following the trends and evolution that are associated with the industry developments
2. More radical approaches that are perceived as breaking the conventional network design rules

As guidance, we seek views on how optical network technology, in a broad sense, impacts on each part of the end to end service delivery and on the interoperability of public and service provider networks of all kinds: access to metro/collector network, metro/collector network to core network, access to core, core to service provider network and content provider networks.

The experts were asked to contribute their views in the format given.

1. The concept, including what new optical technology features are needed to improve interoperability and end-to-end network service delivery
2. The nature of the research in the particular area
3. The critical factors and dependencies
4. The possible impacts that would accrue from successful research

The experts completed a pro-forma describing up to two network interoperability situations according to the template overleaf.

CONTRIBUTIONS FROM PARTICIPANTS

The summaries of the experts are listed below and can be found at the private part of the e-photon/ONe+ website.

Name: Ben Yoo – Organisation: UCDavis

Topic 1: Optical label switching

State the concept, including what new optical technology features are needed to improve interoperability

Network interfaces using optical labels

Comment on the nature of the research in the particular area

Systems, components, test bed studies. OLS router development. OLS router, components, networking testbed, tunable lasers and filters

What are the critical factors and dependencies?

GMPLS extension standardisation is critical

Describe the possible impacts that would accrue from successful research

High performance, intelligent, agile networking

Topic 2: Intelligent programmable network elements

State the concept

Universal router interfacing any network to any network (wireless, optical, wireline etc.). "Impedance matching" of different networks with different characteristics.

Say what new optical technology features are needed to improve interoperability

Intelligent, adaptive and programmable linecards

Comment on the nature of the research in the particular area

Edge routers (without significant adaptability) have been developed but no universal and adaptive routers developed. For wireless – wireline – optical this development is critical.

What are the critical factors and dependencies?

Machine learning and embedded systems are necessary.

Describe the possible impacts that would accrue from successful research

High performance (high throughput, low latency/jitter etc.) end to end through impedance matching.

Name : Anna Tzanakaki – Organisation: AIT, Greece

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Mostly control and management plane features need to be proposed and developed to ensure interoperability and communications across different domains.

Comment on the nature of the research in the particular area

The related research needs to take into consideration the specific features & characteristics of the underlying data plane technology & how it can be directly exploited to satisfy requirements in the most efficient way.

What are the critical factors and dependencies?

Virtualisation of network resources will be critical

Describe the possible impacts that would accrue from successful research

Management & allocation of network resources

New network node architectures & technologies. Multi granularity switching nodes to support various granularities.

Name: Franco Callegati – Organisation: University of Bologna, Italy

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Optical user interfaces for terminals

Comment on the nature of the research in the particular area

Interaction between terminal hardware architectures and optical interface. New architectures for terminals and applications.

What are the critical factors and dependencies?

Currently terminals cannot carry data close to the capacity of the bit pipe.

Describe the possible impacts that would accrue from successful research

More interest to have access to optical networks directly at the desk

Topic 2:

State the concept, including what new optical technology features are needed to improve interoperability

Define descriptors for optical networks to be used by service ‘constructors’.

No specific technology, but methods to describe the technology in a standard way.

Comment on the nature of the research in the particular area

Match the service requirements with optical network characteristics.

What are the critical factors and dependencies?

Consensus.

Describe the possible impacts that would accrue from successful research

Great impact on easy service provisioning.

Name: Artur Binczewski – Organisation: PSNC

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Control plane supporting Ethernet

Comment on the nature of the research in the particular area

Concentrate on the interface and interoperability

What are the critical factors and dependencies?

Standards bodies

Describe the possible impacts that would accrue from successful research

Allows to create global optical network

Topic 2:

State the concept, including what new optical technology features are needed to improve interoperability

Introducing tera scale of optical network.

Signal format, interfaces, ROADM, tunable lasers and filters

Comment on the nature of the research in the particular area

New coding systems

What are the critical factors and dependencies?

Availability of optical hardware technologies & co-operation with vendors.

Describe the possible impacts that would accrue from successful research

New generation of optical systems

Name: Ioannis Tomkos – Organisation: AIT, Greece

Topic 1: Optical technologies supporting users/networks in motion

State the concept, including what new optical technology features are needed to improve interoperability

Novel optical technologies to ensure proper integration among fixed and mobile networks with the goal to offer broadband services to mobile users. The new optical technologies should support such applications by ensuring easy adaptation with wireless networks.

Comment on the nature of the research in the particular area

Should be multidisciplinary covering issues related to physical layer (e.g. radio over fibre) but also with new MAC layer that considers the unique features of the hybrid fixed/wireless network.

What are the critical factors and dependencies?

Wireless access networks are also evolving rapidly and can potentially offer very good capabilities. The involvement in relevant standards activities and multi-vendor support is required.

Describe the possible impacts that would accrue from successful research

This research topic should allow the delivery/availability of services that are not currently supported by any technology to end users (e.g. Gb/s capacity to users in offices/hotels) & fast moving users in trains etc.

Topic 2: Network/IT Resources availability

State the concept, including what new optical technology features are needed to improve interoperability

IT resources should be shared through the intelligent use of the underlying infrastructure in the same way that network resources become available through the use of new control planes. Resource reservation for IT services may be based on new optical transport solutions like OBS or OFS.

Comment on the nature of the research in the particular area

Research should focus on the network protocols and cross-layer optimisation issues with the supported services.

What are the critical factors and dependencies?

Support of the research developments from both NREN and telecom service provider on a global scale.

Describe the possible impacts that would accrue from successful research

Availability of new services, service virtualisation and sharing of expensive resources from multiple users, greatly reducing the costs.

Name: Dominique Verchere – Organisation: Alcatel-Lucent, France

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Features to enable different network switching capability to interoperate. With high transmission capacity network, optical network can enable open dedicated networks in order to provide services.

Comment on the nature of the research in the particular area

To provide interface at the physical layer but also at the control to enable networks to exchange traffic.

What are the critical factors and dependencies?

Standardisation of the solutions. Agreement between manufacturers to deliver unified interface to enable interoperability.

Describe the possible impacts that would accrue from successful research

To trigger the interest of interoperability, the solution should be single and provide advantage to network operators such as to enhance their existing network infrastructure by providing new services. Leads to return on investment.

Topic 2:

State the concept, including what new optical technology features are needed to improve interoperability

Interoperability between multiple network operator domains. To define reference points that enable controlled exchanges of configuration information. Flexibility of configuring wavelengths in the network (e.g. WSS, AWG etc.)

Comment on the nature of the research in the particular area

To understand if services can trigger network configuration over the network.

What are the critical factors and dependencies?

Interactions between Distributed Applications requiring specific network services (QoS, performance and security)

Describe the possible impacts that would accrue from successful research

Security of distributed service to be used by enterprises.

Name: Weisheng Hu – Organisation: Shanghai Jiao Tong University, China

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Define standard interfaces of both control and transport planes such as GMPLS, OTN and Ethernet. Also to develop unified building blocks.

Comment on the nature of the research in the particular area

Packet transport network (e.g. T-MPLS), OTN (G.709) to contain 2.5 Gb/s to 100 Gb/s payloads

What are the critical factors and dependencies?

Bandwidth demand is the determining factor. HD or SHD video will be one of the forces.

Describe the possible impacts that would accrue from successful research

Data intensive (image file, such as PPT)

Bandwidth consuming (HD/SHD TV)

Topic 2:

State the concept, including what new optical technology features are needed to improve interoperability

PTN oriented technology. Integration and massive produced devices … or fundamental one

Comment on the nature of the research in the particular area

Integration

What are the critical factors and dependencies?

Integration & yields of cost effective building blocks.

Describe the possible impacts that would accrue from successful research

Not clear.

Name: Wei Guo – Organisation: Shanghai Jiao Tong University, China

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Resource notification, task scheduling, integrated management.

Comment on the nature of the research in the particular area

Joint resources allocation for workflow applications.

What are the critical factors and dependencies?

Resource management in integrated model and optimal scheduling algorithms.

Describe the possible impacts that would accrue from successful research

Resources are used by application drivers

Topic 2:

State the concept, including what new optical technology features are needed to improve interoperability

For some applications the source and destination nodes for optical core networks don't know initially. How to set up a connection according to the requirements and use the network resource efficiently is a problem. We need an interface to get the network resources and allocate network and IT resources jointly.

Comment on the nature of the research in the particular area

In workflow based applications the tasks are dependent on each other. The users don't know where the resources are and we need middleware to allocate resources and direct the application to run using suitable resources.

What are the critical factors and dependencies?

How to get the network resources and schedule the application.

Describe the possible impacts that would accrue from successful research

Define new interface and develop a new management plane.

Name: Chunming Qiao – Organisation: University at Buffalo, USA

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Different applications require different services, and thus it is important for the underlying optical networks to be able to support both optical circuit switching and optical packet/burst switching.

Comment on the nature of the research in the particular area

Research is needed to come up with a truly universal and yet integrated control & signalling framework for both OCS and OBS/OPS

What are the critical factors and dependencies?

Since fast (nsec/microsec)switching is needed for OBS/OPS thus the ability of advantage of the integrated framework depends on the availability /low cost implementation of the fast switching technology. (Otherwise have two separate networks).

Describe the possible impacts that would accrue from successful research

The optical networks will become truly ubiquitous and capable of supporting various applications effectively.

Topic 2:

State the concept, including what new optical technology features are needed to improve interoperability

A related concept is to support applications directly over optical networks, bypassing unnecessary and often inefficient overlays as well as TCP/IP layers. The optical networks have to be very agile and controllable by standard interfaces. In particular they have be able to reconfigure and support any granularity (large or small).

Comment on the nature of the research in the particular area

Address the scalability of the approaches as many applications may be running at the same time.

What are the critical factors and dependencies?

In addition to hardware technologies such as switches, design & development of efficient middleware for resource management is also crucial.

Describe the possible impacts that would accrue from successful research

The inefficiencies associated with the current TCP/IP layers in supporting high end applications go away with this paradigm.

Name: Peter Van Daele – Organisation: IBBT, Belgium

Topic 1:

State the concept, including what new optical technology features are needed to improve interoperability

Starting point is applications run on all networks, independent of the technology and invisible to user. Optics provides the core network and access to wireless access points. Optics are used for high speed and high capacity.

Comment on the nature of the research in the particular area

Improve speed at all points: switching and transmission. Also inside racks (short distance optical connections).

What are the critical factors and dependencies?

Critical factors on physical layer are the cost of higher speed and shorter distances where optics is introduced.

Describe the possible impacts that would accrue from successful research

Further introduction of optics deeper into the systems and racks, for higher capacities and lower power.

Topic 2:

State the concept, including what new optical technology features are needed to improve interoperability

Optical switching only makes sense if this is combined with in-systems optical interconnections. Short distance optical interconnections at low cost.

Comment on the nature of the research in the particular area

What are the critical factors and dependencies?

Describe the possible impacts that would accrue from successful research

Name: Piero Castoldi – Organisation: Scuola Superiore Sant'Anna

Topic 1: Transparent Network Domain Extensions

State the concept, including what new optical technology features are needed to improve interoperability

Strength of optical technologies is in line speed and span length. Transparent domain may span access, metro, core segments in terms of optical bypassing.

Comment on the nature of the research in the particular area

Mainly the interfaces among PON - metro ring - mesh core segments are equipped with o-e-o and no optical bypassing is deployed.

What are the critical factors and dependencies?

Setting up lightpaths across different segments. Respect physical impairment limitations. Allow end to end transparency as far as possible.

Describe the possible impacts that would accrue from successful research

Reduction of network cost (CAPEX). Improved transparency to formats (scalability). Less need for network planning.

Topic 2: Invocation of optical services in view of OBS/OPS

State the concept, including what new optical technology features are needed to improve interoperability

Bandwidth management at the optical level can flexibly bring large benefits for privileged users and third party operators. (LX VPN). Flexible, adaptive access to optical transport objects based on optical transmission.

Comment on the nature of the research in the particular area

Service oriented architectures for optical nodes are receiving great attention. Lack of standardised approach to the problem.

What are the critical factors and dependencies?

Service interface to be standardised. Virtualisation approaches. Overlay model.

Describe the possible impacts that would accrue from successful research

Time to market of optical services is accelerated. Larger deployment of optical networks. Future proof technology for bandwidth demand increase.

DISCUSSION TOPICS

High bandwidth services to mobile users

- Redesign fibre-wireless interface to offer high bandwidth service to mobile users at both physical + MAC layers.
- Standards needed. 3 to 4 years for a prototype solution.

Interface between any networks

- Develop new protocols for impedance matching, so that any network can be interfaced to any network.

Flexible and agile optical networks

- What are the limits of optical transparency.
- Limit is ultimately set by practical considerations and costs.

Services at Layers 1 and 2

- User interfaces need a lot of tuning and experimentation

100GbE transmission

- Technology was not considered to be an issue, only its cost.

Programmability of the end to end network for high speed services

- GMPLS to the user for business 'on demand' services
- How to deliver over multi domains