Metro Architectures enabliNg Subwavelengths: Rationale and Technical challenges

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Abstract: This paper proposes a new Metro Network Architecture based on two key technological pillars: the subwavelength optical switching technologies in the Data Plane (i.e. optical bursts and packets), and an enhanced GMPLS architecture in the Control Plane to extend network control to the subwavelengths, and ease the interworking of network and IT resources. The proposed architecture promises greater cost efficiency, lower resource consumption, improved reliability and lower latency, compared to current metro network architectures..

Keywords: Metro network, OPST, OBST, GMPLS, Cloud Computing, distributed server approach, XML, virtual PC, NCS.

1. Introduction

Many operators are interested in developing new business opportunities through the implementation of Network Centric Services (NCS), where the operator combines both network resources (raw connectivity) and IT resources (content storage and computing). Some examples of NCS include: PC virtualization, VoD, 3D Internet gaming, SaaS and SAN. These types of services and the expected continuous growth in Internet traffic (mainly driven by video) will imply a huge impact in the metro network. The network costs of current metro architectures depend significantly on traffic growth; the higher the traffic the higher the network costs. Consequently, any cost increase will impact on the ISP's margins (ref. Figure 1). The network architectures of the last 20 years were never designed to cope with these new types of service demands. Therefore, new architectural solutions are needed to deliver the huge expected increase in traffic in a cost-effective way, and ensure low cost broadband Internet access in Europe.

Figure 1: Economic threats of current metro network architectures.

This paper presents a new network architecture, elaborated and prototyped in the European research project IST FP7 MAINS (Metro Architecture EnabliNg Subwavelength), which aims to solve the structural limitations of the current IP architectures. As depicted in Figure 2, the MAINS application scenario is the Metro-Regional network, which comprises the network segment between the access network and the long-haul core network. The MAINS architecture is independent of the technologies used in access and core networks; however, specific interoperability issues with NG-PON and WSON are considered as critical use-cases because of the emerging popularity of these technologies in the access and core segments.

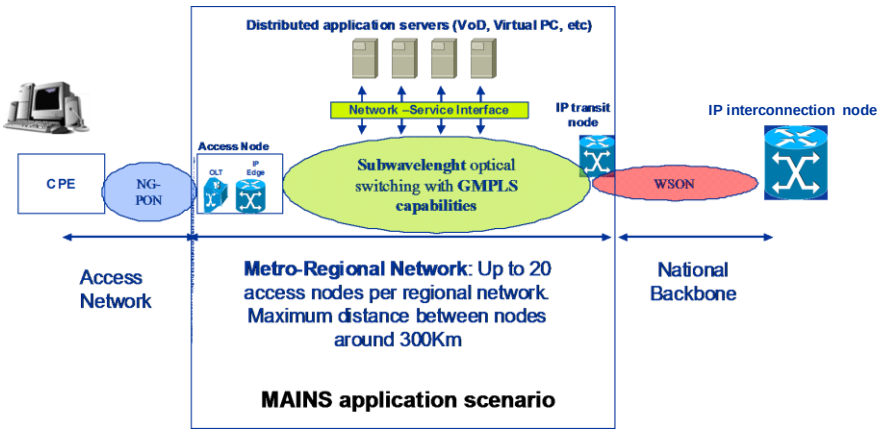

Figure 2: MAINS architectural concept

MAINS relies on a superior and dynamic infrastructure based on optical subwavelength transport technologies with enhanced Control Plane capabilities allowing applications and network interworking.

2. MAINS rationale

2.1 – Need and justification for subwavelength switching in metro networks

MAINS data plane is based on subwavelength switching (i.e. the time-shared utilisation of a single wavelength by optical bursts, packets or slots). The introduction of subwavelength granular all-optical switching technologies in metro-regional networks is motivated by many studies on the evolutionary trend of network traffic and emerging technologies, as further confirmed by the traffic estimations in the Madrid MAN elaborated by Telefonica (ref. **Error! Reference source not found.**).

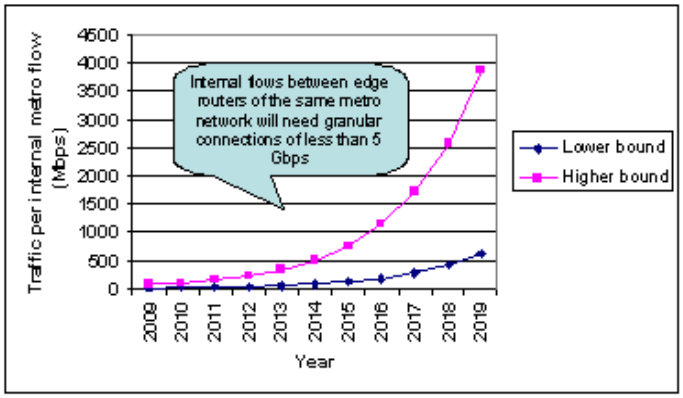

Figure 3: Expected traffic evolution in Madrid metropolitan area (Telefónica internal estimates).

In this framework, subwavelength switching has the main advantages of:

- *Minimizing CAPEX*: by optimizing the number of expensive high capacity optoelectronic IP ports. A single optical tuneable transmitter per node can connect with the other local access routers in the same metro area.
- *Minimizing OPEX*: space and power consumption could be significantly reduced by using optical switching instead of electronic switching matrices. Furthermore, operational costs could be considerably reduced by minimizing the number of electronic switching nodes.
- *Fulfilling the granularity requirements of metro regional networks*: the network traffic between two IP edge nodes in the same metropolitan area will typically request connections for less than 5Gbps, as confirmed by the trends shown in **Error! Reference source not found.**.

2.2 –Rationale behind subwavelengths support in GMPLS Control Plane

Main benefits achieved by extending control plane to the subwavelengths can be summarized as follows:

- **Operational simplicity** by using control plane mechanisms able to dynamically establish, restore or reallocate GMPLS tunnels within a subwavelength network.
- **Multidomain interoperability** by designing OAM procedures and multi-domain control plane protocols for different subwavelength technologies (i.e. OPST and OBST) based on already standardized techniques.
- **QoS assurance** by implementing an QoS aware control plane mechanisms able to dynamically allocate network resources according to the services requirements in terms of jitter, delay, packet loss, and survivability.

2.3 – Network and IT resources interworking

In the MAINS architecture, the optical layer resources are accessed from the service layer, on-demand and with subwavelength granularity. Consequently, servers can be distributed in the metro network, as illustrated in Figure 2, to provide a very cost-efficient solution in terms of bandwidth and server commodities. The bandwidth consumption is reduced due to the distribution of service flows around the network. Also service flows do not follow the same path to a central server which may cause bottleneck problems. Furthermore, ISPs can maximize the performance of distributed IT servers by dynamically managing their computing and storage resources. Therefore, the quantity and processing power of the distributed ISP's IT servers can be minimized. As a result, the cost of a distributed server

approach, using a network-service interface as discussed in the following section 3.2, could be smaller than in a centralized solution.

3. MAINS architecture

3.1 – Data Plane architecture

A key concept in MAINS is the use of subwavelengths (bursty time-shared use of a single wavelength) implemented through a dynamic time-shared use of ultra-fast tuneable optical components and optical burst switching systems. Industrial subwavelength switching solutions, such as Intune's OPST (Optical Packet Switch Transport) platform (ref. Figure 4), are starting to appear in the market.
The OPST nodes contain a fast tuneable laser capable of tuning between wavelengths at nano-second speeds. Each node also contains a fixed wavelength filter which is the wavelength-routed address of the ports of the system. Basic operation involves reading incoming packet addresses, translating them into wavelengths and queuing them in virtual output queues. A scheduler forms bursts from the queues of packets and modulates a burst onto a tuneable laser transponder whose wavelength is rapidly tuned to the destination wavelength. Then the packet is sent out on the ring while a distributed scheduling system ensures fair access onto the ring.

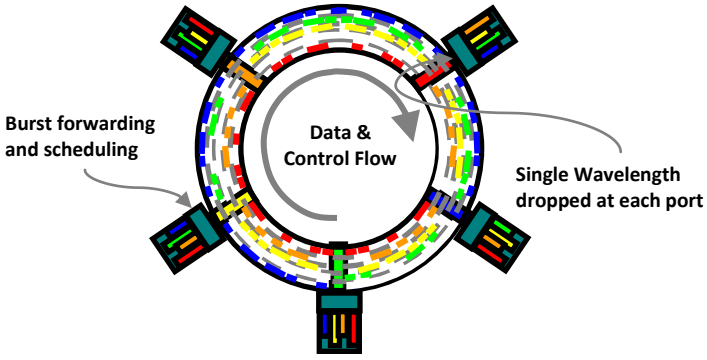

Figure 4: Illustration of a wavelength routed system – Intune OPST

Although current industrial subwavelength solutions such as OPST are deployed in ring topologies, MAINS also considers other experimental alternatives for meshed topologies such as OBST (Optical Burst Switching Transport). Experimental research in several aspects of OBST such as application-aware OBS networks [1], service-oriented OBST networks [2] and multi-granular OBS-based networks [3] has been conducted to identify the requirements and challenges of creating OBS network services. MAINS will leverage from the existent research knowledge and infrastructures, with the goal to create a network solution allowing multidomain interworking between different subwavelength technologies (i.e. OBST and OPST). In particular, MAINS proposes a multi-domain architecture for this scenario based on the combination of both OPST rings and OBST meshed topologies. As shown in Figure 5 multiple metro-aggregation OPST rings could be interconnected by means OBST based metro-core network. According to this architecture, traffic between two IP edge nodes of the same region could be transported over subwavelengths.

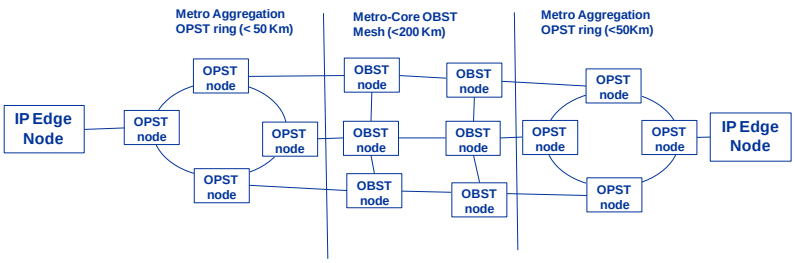

Figure 5: Multidomain subwavelength metro-regional network.

3.2 – Control Plane architecture

The Control Plane architecture is based on two complementary paradigms: support of subwavelength granularity and seamless control of IT and network resources.

Control Plane extensions for subwavelength granularity

The MAINS architecture allows the transport and switching of subwavelength flows across two different networks administered by a common GMPLS Control Plane. As shown in Figure 6, a GMPLS Control Plane gateway will be implemented to parse and escalate information from/to the GMPLS protocol stack through a novel XML based proposed API for delivering end-to-end services across OPST rings and OBST mesh networks. A service request received by GMPLS will be translated into the specific network control commands for the OPST and OBST regions to configure the required subwavelength path. In order to allow the interoperability of the three systems in the path set-up across the network, an XML-based interface (XML#3) is used to configure the transport network resources. The XSLT (Extensible Style sheet Language Transformations) provides the translation between Control Plane requests and specific XML-based OPST and OBST configuration interfaces (XML#1 and XML#2).

This kind of interworking between GMPLS Control Plane, OPST and OBST networks will provide the opportunity to integrate different forwarding approaches, allowing a dynamic configuration of the network depending on the specific requirements of each service.

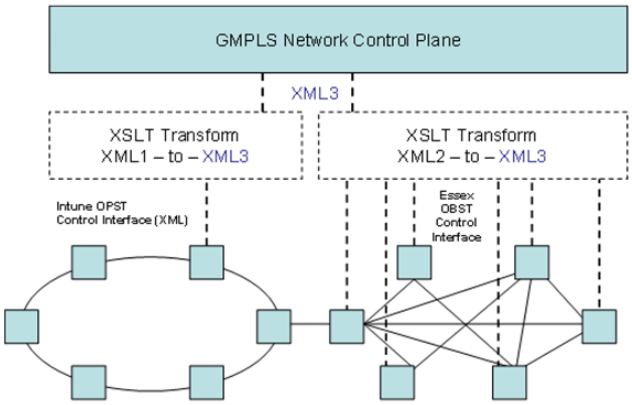

Figure 6: XML interfaces for transport resource configurations.

MAINS will consider and address the multi-domain interworking aspects of network service transparency across the OPST ring and OBST mesh network solutions. Both subwavelength network solutions have their own internal scheduling, routing and provisioning mechanisms. Innovative software-hardware procedures on the description (buffer, schedulers, etc.), control (signalling, routing, access control), and re-configuration of the OBST nodes and resources will enable traditional OBST mesh networks to provide subwavelength services. These enhancements will allow the translation of technology

specific information (aggregation, scheduling, and path allocation on a subwavelength level) in a technology-agnostic format that can be exchanged with the GMPLS Control Plane through an XML interface. As a result, multidomain interworking will be provided using generic information decoupled from domain specific solutions. In addition, mechanisms on level of abstraction and frequency of subwavelength routing information of an OBST domain passed to GMPLS Control Plane will be considered. This will form an integral part of the end-to-end routing and provisioning of subwavelength multi-domain interworking. In the transport level, there will be conversion points between the OPST transparent ring domain and the OBST transparent mesh domain to both maintain domain specific transport solutions (optical packets/bursts) and also interoperate with each other at an Ethernet level.

Interworking with core networks is another important MAINS requirement. Considering the end-to-end network services deployment, the subwavelength capable GMPLS for the metro network could need to interwork with other peering standard GMPLS CPs controlling the backbone network (e.g. based also on optical technologies, WSON **Error! Reference source not found.**[5][5]).

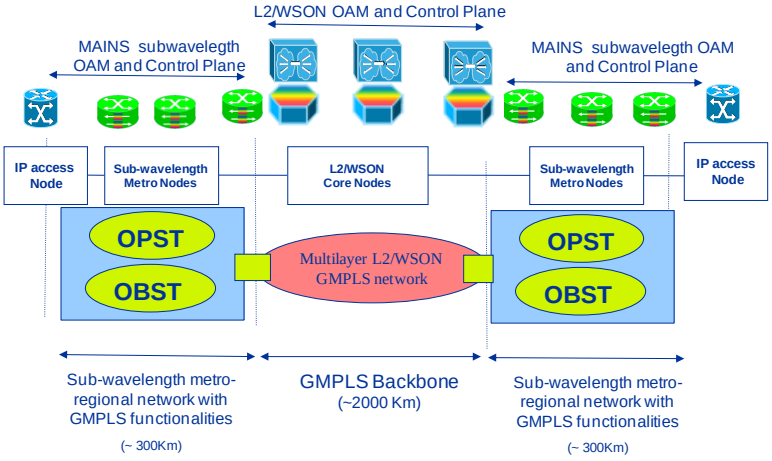

Figure 7: Interworking between Metro-Regional and Core Networks.

IT and network interworking

Subwavelength switching technologies such as OPST and OBST grant simple and rapid access to direct subwavelength flows of packets. This new capability of accessing subwavelengths in a highly responsive manner ideally supports varied application-driven (e.g. PC Virtualisation, Cloud Computing) bandwidth and QoS requirements. MAINS is also proposing a new service to network interface, providing direct access to subwavelength granularity services from the application layer so that, the applications running in the distributed servers will be able to transfer high volumes of information in a single burst, without the overhead of TCP incurred in current circuit-switched networks. This service-to-network interface will be used for the node-to-node communication through the optical mesh and ring metro networks. It is expected that the end-to-end throughput requested by the services will be in the order of hundreds of Mbps, with stringent jitter and delay requirements. According to it, MAINS plans to go deep down into the network interface card driver and provide the best solution to interwork with the optical switch.

4. Technical challenges

4.1 – Data Plane implementation

The Ring-Mesh interconnection node will introduce new design rules to create and deliver innovative and application-agnostic OBST transport services. Specifically:

- Burst aggregation and scheduling strategies need to be implemented for synchronous burst trains and/or variable-size asynchronous burst transmission on hardware-accelerated devices (e.g. FPGAs and PowerPC processors).
- A gateway to interact with the GMPLS Control Plane and provide application-awareness to transport devices is needed.
- Flexible and dynamic software-controlled electronic elements are needed to adjust node parameters (aggregation, wavelength allocation).

Data plane MAINS architectural concepts will be evaluated in lab facilities by means of:
- Bandwidth utilization measurements of different transport formats.
- Delay and jitter performance measurements to support use case applications.
- End-to-end network service delivery over OPST ring interconnected with OBST mesh.

4.2 – Control Plane extensions

The MAINS Control Plane is built on top of the core GMPLS specified by IETF [4] and includes specific extensions for the optical bursts and packets switching to both the architecture and the GMPLS signalling and routing protocols. Specific challenges in this area are briefly detailed in the following.

GMPLS routing enhancements.

The MAINS architecture integrates two different regions, i.e. the OBST and the OPST, which expose quite different switching granularities and capabilities. The modelling of these domains in terms of Traffic Engineering parameters and service capabilities is crucial for the source routing decision process. Although GMPLS natively supports Lambda Switch Capable (LSC) and Fiber Switch Capable (FSC) interfaces, and has procedures for building Forwarding Adjacencies (FA) across multiple switching regions, it currently cannot model OBS interfaces and OPST rings. The GMPLS routing extensions in MAINS allow to fill in this gap, by extending the routing protocol (i.e. OSPF-TE) and the route computation elements to advertise new network capabilities and implement new service models for the OBST and OPST network regions.

GMPLS signalling enhancements.

The short-lived fast-paced connections in subwavelength networks and specifically in OBS, require a new approach in setting up the connections through GMPLS signalling protocols. As well as the new traffic parameters that are needed to describe both bandwidth and QoS requirements for subwavelength connections (e.g. bandwidth, delay, latency, burst duration, etc.), the specific signalling procedures need to be adapted and sped up to cope with the new fast-paced and time-shared use of subwavelength resources. Moreover, a highly dynamic setup and release of FAs and/or LSP detours may be needed to allow the OBS nesting into OPST tunnels or any fast reaction to emergency conditions, such as faults in neighbouring domains, or traffic blocking on specific nodes/interfaces.

Multidomain control plane interworking over GMPLS.

As described in section 3.2, the GMPLS Control Plane in MAINS has a XML-based southbound interface (XML#3) to control/configure both the OPST ring and the OBST physical nodes.

4.3 – Operational aspects

MAINS operational aspects will be evaluated over an end-to-end OPST Ring field trial on Primetel's network infrastructure in Cyprus. The Cypriot field trial will be based around Primetel's existing network infrastructure in Limassol and will provide PC virtualization services to real users. These include optical fibre facilities and POPs

where OPST will be installed, DSLAMs and ADSL2+ infrastructure for the trials, also as FTTH Ethernet concentrators etc. The evaluation of the test trials will be completed with a pilot large scale scenario where at least 100-300 ADSL users will be committed. The specific operational aspects which will be validated over the field trial include: **automatic network operation**(i.e. automated discovery of network updates, dynamic path provisioning and restoration,etc), **power consumption** and **Quality of Experience** feedback~~s~~ from real users running the PC virtualisation services

4.4 – Potential impact on standardization

The MAINS architecture and technical challenges can contribute to the definition/improvement of standards for Metro Networks, leveraging on the extensive validation of the proposed concepts in test bed and field trial environments. Specific aspects of the MAINS architecture that can influence the standards, include, the GMPLS signalling and routing extensions for subwavelength switching granularities, the integration of optical burst and packet switching domains and the generalized internetworking of network and IT resources. In particular, the GMPLS extensions can contribute to the activities of the IETF CCAMP working group, and the TE specification of subwavelength network resources and the related signalling and routing procedures. The integration and seamless control of network and IT resources can contribute to the activities of the OGF NSI working group, which is a more appropriate forum for cross-layer issues, independent of the underlying provisioning systems. Finally, the MAINS Data Plane technical challenges can also influence regulation of electronic communications in Europe, with potential contributions to ITU-T and ETSI activities on the emerging optical switching technologies.

5. Conclusions

This paper presented a new Metro Network architecture promising cost-efficiency in terms of network and IT resources consumption by using optical subwavelength transport technologies with enhanced Control Plane capabilities allowing applications and network interworking. The paper also discussed the rationale and the main technical aspects of this new subwavelength switching paradigm. The MAINS architecture will be developed under an FP7 European research project with the same name.

Acknowledgements

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