A European Multiwavelength Optical Network*

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Abstract

A number of research issues are considered in the study of a european multiwavelength optical network. The main part of the study is the design of an all-optical network to overlay the european national networks and link major centers therein. We survey most of the issues considered in this respect within the frame of two projects funded by the European Commission. Another part of the study focuses on the underlying european national networks and their possible development to interface with the proposed overlay. The main aim of this paper is to put together these two parts and oversee the prospect of a european ultra-high capacity multiwavelength optical infrastructure.

1 Introduction

Multiwavelength optical networking has been attracting considerable interest in the current decade. This interest is demonstrated in a number of research projects carried out by academia and industry in the USA and Europe. This paper focuses on the efforts to envision a large-scale optical network across Europe. These efforts have been ongoing mostly within the frame of two research projects which are funded by the European Commission; namely COST 239: Ultra-High Capacity Optical Transmission Networks and RACE R2028: Multiwavelength Transport Network (MWTN). COST (European COoperation in the field of Scientific and Technical research) aims at the coordination of basic or precompetitive research in Europe. Research is done through concerted actions having their own objectives and time tables. A major objective of the action COST 239 is to propose a scenario for a European Ultra-High Capacity Optical Network which may interconnect the main centers of Europe[1]-[5]. RACE (Research and development in Advanced Communications technologies in Europe) is known as an important research scheme the aim of which is to promote the competition among the European Union's telecommunications industry, operators and service providers. The major target of the RACE program is to introduce Integrated Broadband Communications (IBC) in Europe[6, 7].

The core of the proposed optical infrastructure is a transparent European Optical Network (EON) which would interconnect major centers in Europe via a topology of high capacity pipes. This EON is an all-optical network that may perform both switching and transmission using optical techniques. The network is "transparent" as signals flowing around it remain entirely within the optical domain[4]. Fig. 1 depicts this EON which is characterized by a relatively small number of nodes (20), high capacity requirements and large physical span (diameter is in excess of 3000 km). In the following section, we review some of the major issues investigated within COST 239 and RACE 2028 concerning the EON. In section 3, we discuss some related issues concerning the possible developments in the underlying national networks in europe. Finally, section 4 concludes the paper.

2 The Transparent EON: Major Elements of its Study

In the network of Fig. 1, each node represents a gateway into a national network and the aim is to design a transparent network which will carry all the international traffic among these nodes. Such a design would essentially require a detailed study with large number of elements. In the following we summarize some of these elements.

2.1 Topology

The nodes of the EON were taken to be national capitals, with the associated population, for use in traffic estimation, taken to be that of the entire country (there are one or two exceptions to this rule). The topology

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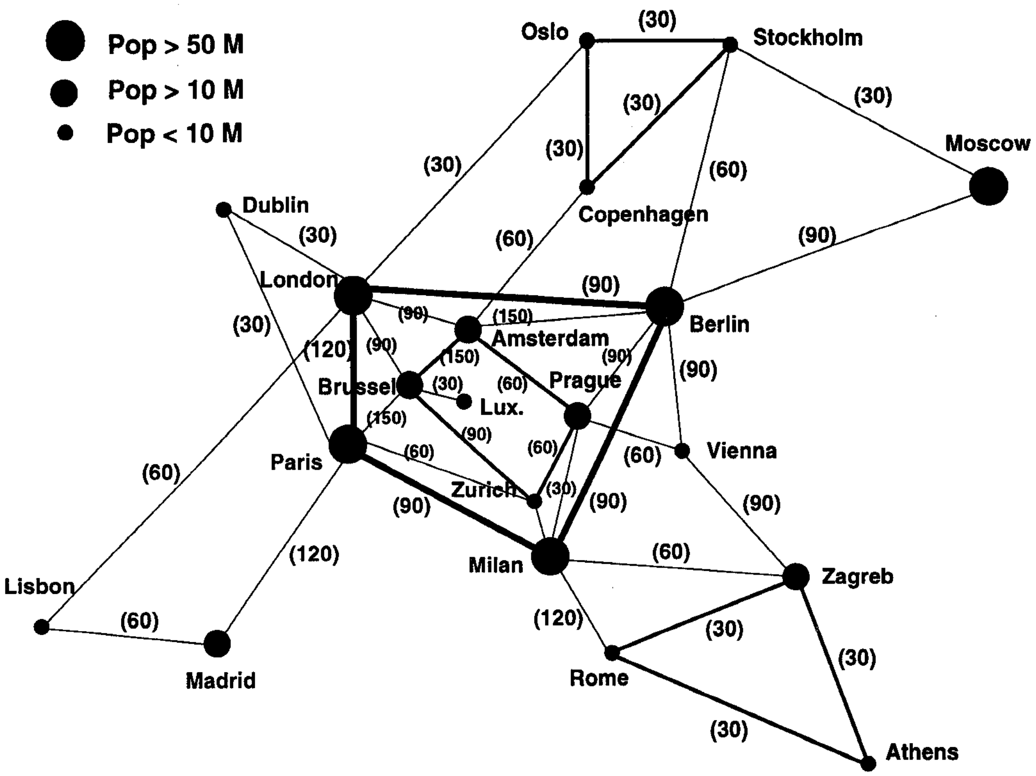

Figure 1: The proposed EON Topology (numbers between brackets indicate link capacities in Gb/s.)

design was based on what were considered reasonable assumptions about the possible traffic distribution and incorporating suitable structures to enhance reliability. Reference[8] highlights the suitability of a topology of two almost-concentric interconnected rings to the central part of the network. This approach was indeed adopted. First, the largest conveniently located central nodes (London, Berlin, Milan and Paris) were formed into a central ring. Then, four of the innermost nodes (Brussels, Amsterdam, Prague and Zurich) were joined into an inner ring. Two outlaying islands were then created from groups of three nodes; namely: (Oslo, Stockholm and Copenhagen) & (Rome, Zagreb and Athens). Finally, all the remaining nodes were connected to either the central or outer ring, ensuring that all individual nodes (except for Luxembourg) and islands were dual-parented i.e., have two separate links to the center (Fig. 1) [1],[3]-[5].

2.2 Traffic and Capacities

One of the most important inputs to the process of designing and dimensioning the EON is a practical traffic matrix. This input was not readily available, and proved not to be easy to obtain. Reference[9] reports a study in this concern. Initially, no reliable data were made available. Therefore, it was decided to develop a simple model for traffic estimation, i.e. the Population-Distance (PD) model[1]. Later, a suitable source of telephony traffic was obtained through the International Telecommunications Union (ITU). However, this was found incomplete for those countries which did not release some or all of their international traffic data to the ITU. It was thus decided to develop an improved traffic model, i.e. the Population-Factor-Distance (PFD) model that may fill the gaps in the ITU data, and which could be scaled for future traffic estimation[9]. However, in the absence of detailed traffic figures at the time of the EON analysis, it was decided to adopt the PD model[1, 4, 9] where the traffic between two nodes s and t was taken to be:

$$\mathrm{Traffic}_{s,t} = K_{(traffic)} \frac{\mathrm{Pop}_s \mathrm{Pop}_t}{\mathrm{Dist}_{s,t}} \qquad (1)$$

$K_{(traffic)}$ is a suitable constant (5.25 Erlangs) and the populations are in millions and distances in Kilometers. Subsequent analysis of international traffic have shown this to be a reasonable model to start with. Certain simplifying assumptions were made about routing and link availability[4]. The network was then analyzed to obtain the link blocking probability, taking into consideration both traffic blocking and link failures. The link capacities

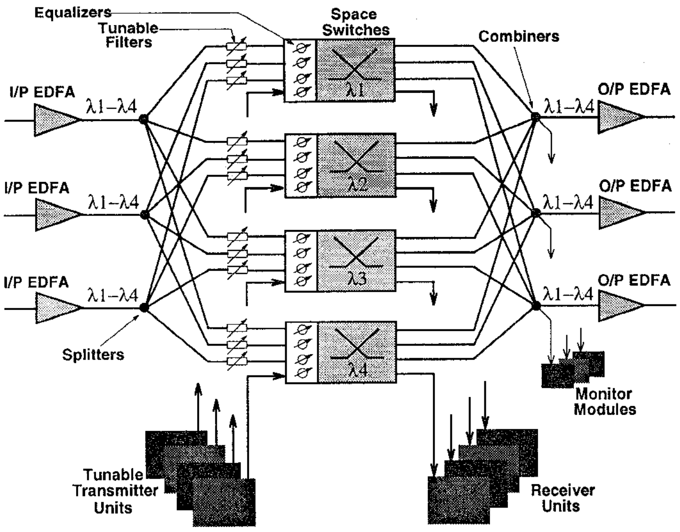

Figure 2: Schematic of the node architecture adopted by RACE MWTN project (re-drawn as per Refs. [4] & [6]).

were adjusted to the smallest multiple of 30 circuits that gave all link blocking probabilities less than 10%. The resulting overall grade-of-service (i.e. the overall proportion of network traffic lost due to both traffic blocking and link failures) was 0.33%. Using the relative link capacities a scaling factor was used to derive the capacities of the proposed network in Gb/s. Within COST study group it was decided to adopt three scaling factors to represent immediate, medium term and long-term demand. In Fig. 1, the numbers in brackets represent the long term link capacity demand in Gb/s [4].

2.3 Node Architecture

Several technologies can be suggested to realize the nodes in Fig. 1 [5], but the transparent optical cross-connect developed within the RACE project R2028 [6, 7] is so far the main candidate. Fig. 2 is the schematic of this optical node architecture. Three fibers enter and leave the node. Each fiber supports four wavelength slots separated by 4 nm. The signals are demultiplexed by a combination of optical splitter and filters, and a 4 × 4 optical space switch is associated with each wavelength. The optical switch uses Lithium Niobate technology in its first implementation and InP technology in the second phase. At the switch output the signals are recombined for onward transmission. The node arrangement therefore allows a signal on an incoming fiber and wavelength to be either routed straight through the network or dropped off locally. EDFA's are deployed at all inputs and outputs in order to compensate for power losses. Indeed, the node (which is designed to support bit rates of 622 Mb/s and 2.5 Gb/s) is characterized by high insertion loss and as the number of wavelengths are increased, this loss increases and so does the switching complexity. Therefore, minimizing the number of wavelengths is an important requirement[4, 6] and so is power budget management[10]. Reference[11] discuss the deployment of this node in a ring architecture.

2.4 Transmission Limitations

The requirement of transparency means that signals must be capable of traversing the network without undergoing optical to electronic conversion. Thus, in designing the architecture it is necessary to understand the constraints on transmission in terms of number of wavelengths × distance × bit rate. In other words, the study of transmission limitations is of utmost importance. A detailed study of this issue is given in reference[4]. In the following, we merely summarize the main outcomes of that study.

The transmission path of a typical signal across the EON will encounter various components; including optical amplifiers. These amplifiers are needed to compensate for the high insertion loss of nodes as well as in-line losses. Among the drawbacks of EDF amplification is the introduction of noise and the possibility of Signal-to-Noise Ratio (SNR) ceilings in some transmission links (this later problem is not normally encountered in a point-to-point system where EDFA's are used as linear repeaters). Thus, the necessity of maintaining an adequate SNR limits the number of nodes that can be traversed by a signal. It has been shown, given certain parameters, that a maximum of 18 nodes can be traversed at 622 Mb/s (11 nodes at 2.5 Gb/s) [4]. In addition, the end-to-end bandwidth of a long path will be determined by a concatenation of amplifier and optical filter bandwidths. An initial amplifier bandwidth of 30 nm can be reduced to less than 10 nm in a concatenation of 50 amplifiers. This observation argues, once again, for using a small number of as closely spaced wavelengths as possible[4]. EDFA's may also increase the significance of fiber non-linearities. Maintaining mW optical power levels in several channels over long distances leads to long interaction lengths. Consequently, nonlinear effects can be observed at very low input power levels. Fiber non-linearities effectively constrain the maximum number of wavelengths possible over a particular distance[4].

Due to the non-ideal characteristics of the optical filters and switches, crosstalk may also be introduced[12, 13]. Analysis has shown that to minimize the most significant crosstalk, filter response must be at least 20 dB down at an adjacent, out of band, wavelength. In the case of the MWTN node, an end-to-end filter-concatenation bandwidth of 0.5 nm is also required. Therefore, simple filters such as Fabry-Perot's do not offer sharp enough passband characteristics[4]. Finally, chromatic dispersion of fiber make it necessary to use dispersion shifted fiber (DSF) with which transmission distances of 8×10^4 km and 5×10^3 km would be theoretically possible at bit rates of 622 Mb/s and 2.5 Gb/s respectively. In practical implementations, however, it is expected that the dispersion limit will make these distances shorter[4].

2.5 The EON Architecture

Wavelength Routing (WR) is the commonly preferred technique for a network of the type described above. This is because it permits wavelength reuse and thereby allow the use of lower number of wavelengths. The MWTN nodes (Fig. 2) can support WR. Since WR introduces the possibility of blocking (due to wavelength contention), a complementary technique, such as wavelength translation, is required to get around this limitation[4].

Clearly, the realization of any particular link capacity would include economic considerations in deciding the relative numbers of fibers and wavelengths to be deployed. The network shows a number of very long distance links with potential high capacity requirements. The studies of transmission limitations show that this can only be achieved with few wavelengths. What is important, is to decide how many wavelengths are required to satisfy the capacity demands, given particular number of fibers. It is clear that transparency can only be achieved through careful design. Indeed it may well be that only limited transparency is possible. On one hand, analysis has shown that more than 8 wavelengths can not be used over the longest distances; on the other hand, studies suggest that too few wavelengths may result in considerable wavelength blocking and unacceptable end-to-end performance. Therefore, it is suggested to partition the network into optical islands as depicted in Fig. 3; i.e. a main network and three secondary ones. These divisions represent areas of relatively high local traffic. The distances involved within any of the individual networks are such that any reasonable number of wavelengths may be employed to interconnect the nodes. Interconnection between the four networks may be accomplished in different ways. We here mention two approaches. The first would be by regenerative gateways, in which case transparency is partially sacrificed. The second approach is detailed in[4] where it is suggested to develop an architecture which combines partitioning with a wavelength hierarchy. A set of wavelengths will be assigned for local communications in all four networks. A second set my serve communications between the main network and the secondary ones. A third set would interconnect secondary networks. Some of the nodes, namely those used for internetworking access, will have to have a modified architecture to that presented in Fig 2 [4].

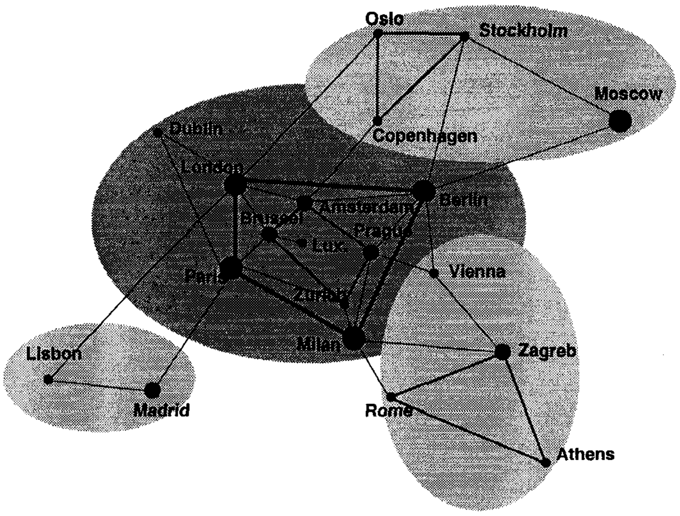

Figure 3: Possible partitioning of the EON. Dark shade indicates main net.; Light shades specify secondary ones

3 Beyond the Transparent EON Layer

The previous discussion has been restricted to the study of a transparent EON which would represent an overlay to many European National networks. The main goal of the work reviewed above was to understand the extent to which transparency can be achieved in such a large network[4]. However, one may question the effect of national networks on the design and performance of the EON to be overlayed thereupon. The implications of the EON on national networks is similarly important. Clearly, an interface layer may be needed. References[2, 5] provide a study in this direction. This study addresses the end-to-end communications among network users who are attached to their respective national networks and may communicate thereby across the transparent EON. The main concept adopted in this study is that a user-to-user communication will have to be

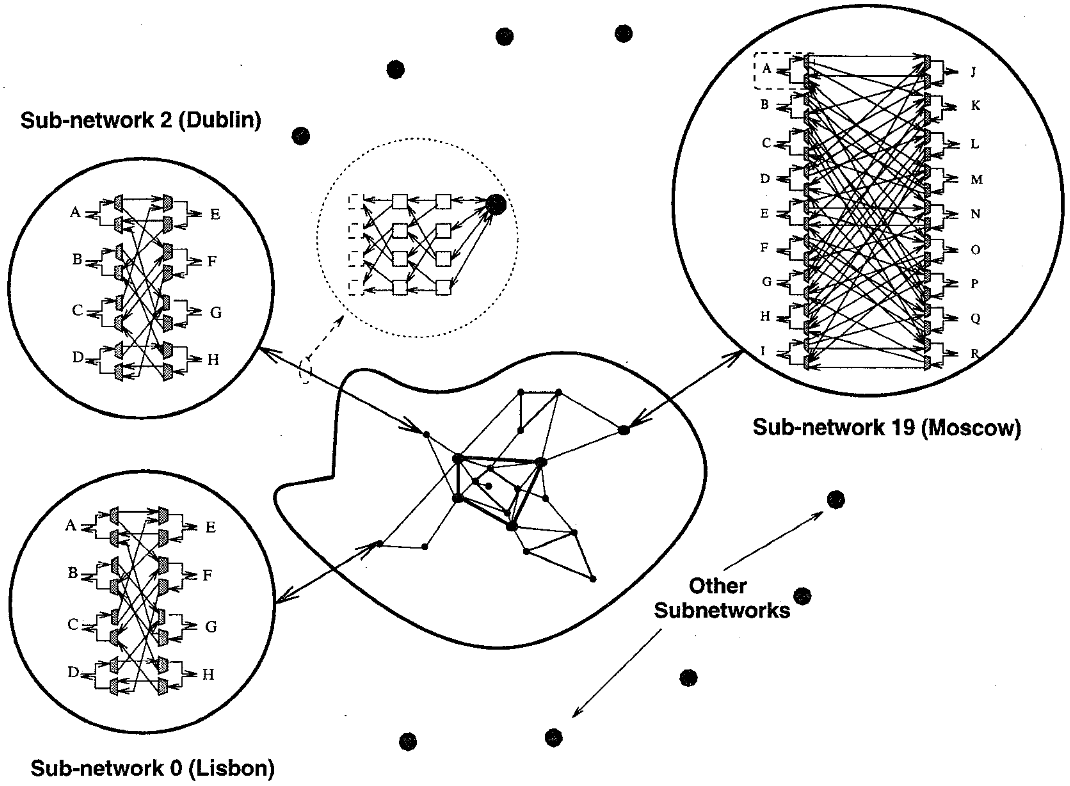

Figure 4: A Hypothetical European Multi-ShuffleNet [2,5]

served via some multihop transmission mechanism. Having understood the EON transparency limitations, one can see that this adoption is practical. The perspective of a european multihop architecture was therefore examined. The traditional form of a hypothetical large-scale architecture had to be replaced by a group of comparatively smaller ones that can be as distributed as the european national networks. The principle model shown in Fig. 4 explains the picture. The underlying top national architectures are assumed to be ShuffleNets relying on wavelength routing and wavelength translation[2, 5]. This assumption is made for analytical ease, but each of these subnetworks may assume any different architecture. There would be some small pool of wavelengths, probably 2-6 wavelengths, out of which each ShuffleNet will have its set of carriers. Fig. 5 shows the variation of the expected number of hops versus the number of network nodes in a symmetrical Multi-ShuffleNet architecture as compared to a corresponding large-scale straight ShuffleNet; according to the analysis in[5]. In this model, we assumed that the path through the EON will add one hop to the typical user-to-user communication. This assumption would match with the deployment of regenerative gateways, rather than a wavelength hierarchy, to interconnect the networks in Fig. 3. We envision the Multi-ShuffleNet network of Fig 4 at the level of main national exchanges. For example, the 8 nodes of the subnetwork of Dublin, hypothetically, may represent 8 main exchanges, each of which is acting as a gateway

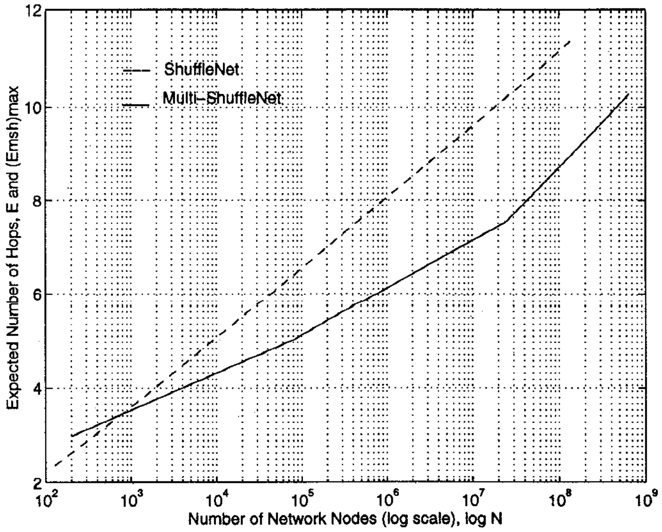

Figure 5: Number of hops versus number of network nodes in the ShuffleNet and Multi-ShuffleNet[5].

to a larger sub-subnetwork which can, in turn, be composed of a number of underlying local exchanges, and so forth. The hierarchy can be developed in this sense to whatever extent needed. This means that the existing infrastructure in any member country can be exploited, and overlaying optical interconnections may be implemented flexibly to include the member subnetwork in the architecture. The process of constructing a european optical infrastructure can thus be performed gradually within the frame of upgrading and developing the existing infrastructure. The overall network thereby can carry international traffic and may replace, at least in part, many national trunks. It is shown that this approach offers many attractive features[5]. First, a better combination of scalability and structural flexibility is possible. Second, any user-to-user communication will involve less number of hops than normally encountered in traditional multihop approaches. Finally, this approach is inherently hierarchical, which make it useful in the study of networks of the type considered here. Although the approach is along the lines of normal telecommunication practice, it is new to the field of large-scale multiwavelength multihop optical networking.

4 Conclusion

We have reviewed the research efforts to envision a large-scale ultra-high capacity transparent european multiwavelength optical network. There are many technological obstacles to the realization of transparency in such a large network. It is likely that transparency may only be partially achieved under the present state of the art. A user-to-user communication will most probably be served by multihop transmission. The general prospect of a european optical infrastructure, based on these outcomes, is outlined.

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