Analysis and dimensioning of interconnected single-layer “switchless” all-optical networks*

A. Bianco¹, N. P. Caponio², G. Galante¹, E. Leonardi¹ and F. Neri¹

(1) *Politecnico di Torino, Torino, Italy*
{bianco,galante,leonardi,neri}@polito.it

(2) *Optical Technology Center (OTC), Torino, Italy*
currently with *Agilent Technologies, Torino, Italy*
paolo_caponio@agilent.com

Key words: All optical networks. Switchless networks. Multiple router interconnection.

Abstract: A “switchless” all-optical network requires neither electronic switches nor active optical cross-connects because the switching function is implemented at terminals via time and wavelength agile transceivers. Terminals are grouped into passive optical networks which are connected to a single passive wavelength router. One centralised controller grants the terminals access to the time/wavelength frame. This paper defines a simple non-uniform traffic pattern based on a locality principle and evaluates the hardware/software complexity required to cover the same user population with either one or four fully interconnected “switchless” networks.

1. INTRODUCTION

The European Union ACTS project SONATA explored the feasibility of a single-layer nation-wide all-optical network. The network design aims at exploiting the best features of photonic technologies, such as the very large bandwidth available on optical fibers, and the flexibility in modifying the

* This work has been partially funded by the European Union ACTS Programme within the Project SONATA.

end-to-end connectivity provided by optical channels, without trying to emulate in the optical domain the features available in electronic networks. With respect to electronic networks and to other, more conventional, optical network designs (such as wavelength routing networks based upon optical cross-connects), the proposed architecture avoids the need for large and fast switching nodes, drastically simplifying both the network structure and the layer architecture within the network. It is a very innovative design, in which new solutions specifically designed for the optical domain are devised to gain cost and performance benefits.

The SONATA architecture is said to be “switchless” because it is completely buffer-less and none of the nodes has to be equipped with either electronic switches or active optical cross-connects. This is possible because the switching function is removed from the nodes and distributed at the terminals where it is implemented by transceivers which can be quickly tuned on a large number of frequencies (also called wavelength channels).

Depending on the amount of traffic generated, either a street cabinet, or an IP router, or a LAN switch, or a workstation can be connected to the network through a terminal interface (or, more briefly, terminal) equipped with one fast-tuneable transceiver.

Terminals are partitioned in many large groups each of which is served by a passive optical network (PON). In each PON the traffic originated by terminals is multiplexed into wavelength channels (also called light-paths) via a WDM/TDM access protocol implemented by the time/wavelength agile terminal transceivers. The same holds for demultiplexing the traffic carried by light-paths into their contributing flows. All of the PONs are connected to one centralised passive wavelength router node (PWRN). The PWRN provides full connectivity among PONs linking each pair of PONs by means of one dedicated light-path.

A pool of wavelength converters arrays (WCA) directly connected to some extra PWRN ports allows both additional connectivity and network flexibility in adapting to any traffic pattern.

The access to network resources must be reserved end-to-end by terminals: a centralised network controller (NC) grants the terminals access to the time/wavelength frame, and manages the wavelength converters. The network is designed to provide both connection-oriented and connectionless services, in the sense that terminal requests can be for “persistent” or for “non-persistent” slot allocations.

The SONATA network feasibility, the components that should be used, the physical limitations that should be taken into account when dimensioning the network are discussed in [1]. The specification of the signalling protocol between terminals and the NC is given in [2], while a thorough description

and performance analysis of the resource allocation algorithms to be used by the network controller is given in [3].

This paper defines a simple non-uniform traffic pattern and evaluates the hardware/software complexity required to cover the same user population with either one or four fully interconnected "switchless" networks. In particular, Section 2 describes the architecture of a single network and its extension to the case of L fully-interconnected networks. Section 3 defines a simple telephone traffic model and evaluates the call arrival rates. The two-level traffic distribution used here is based on a locality principle, i.e. topologically near terminals exchange among them a higher traffic rate than farther ones. In Section 4 both one and four fully interconnected networks are dimensioned for the traffic distribution defined in Section 3. The number of router ports and wavelength converters required is evaluated together with the number of calls received and processed by each network controller. Section 5 summarises on our results.

2. NETWORK ARCHITECTURE

This section describes the structure of the "switchless" networks utilised in the sequel of the paper. Section 2.1 reviews the architecture of a single router network, while Section 2.2 considers the case in which the network is split into L identical sub-networks. Each sub-network has its own passive wavelength router and its own network controller. The PWRNs are connected in a full mesh through some additional router ports attached to active interconnection boxes.

2.1 Single router network

Terminals are grouped into N identical PONs. Each PON sends its data to one input port of the passive wavelength router through a fiber and receives data from one output port of the PWRN via a different fiber (see left and right hand side of *Figure 1*).

Figure 1. Single router network

The passive wavelength router implements a fully interconnected topology among its ports because each output port is reachable from any input port using a known (and fixed) wavelength channel. Both the input and the output side of the PWRN have 1 port connected to the network controller, N ports attached to the PONs and d ports (called “dummy” ports) through which it is possible to reach the arrays of wavelength converters.

Each terminal has one transmitter and one receiver quickly tuneable over $N+d+1$ different frequencies; therefore each fiber carries $N+d+1$ wavelength channels having a bandwidth of $B = 622$ Mb/s each.

The fast-tuneable transmitters, the wavelength converter arrays and the fast-tuneable receivers interconnected via the wavelength router behave as a three-stage switch. The NC controls the three-stage switch configuration (i.e. the logical topology of the network) by programming the wavelength converter arrays. In this way connectivity among PONs is given in two forms: via direct (or “wired”) wavelength channels, and via channels recirculating through wavelength converters (also called “programmable” channels).

Terminals can request both connection-oriented and connectionless services to one centralised network controller by means of a signalling protocol. The NC grants the terminals access to the time wavelength frame avoiding all conflicts among transmitters and receivers. More precisely the NC stores the requests received from the terminals during a time frame, processes them in the subsequent frame and then responds to the users in the following frame; only after this response there will be the transmission of data among end-users. Note that, as shown in Figure 2, these four phases can be pipelined and an extra delay is required between the reply frame and the transmission frame because of propagation delays in the network.

Figure 2. NC operations scheme

Four types of signaling packets are required:

- Connection-oriented/connection-less bandwidth requests (upstream)
- Acknowledge (reply) packets (downstream)
- Reconfiguration packets (downstream)
- Wavelength converter arrays programming packets (downstream)

Packets of the first kind are sent by users to the NC to request or release bandwidth. Packets of the second kind are sent by the NC to end-users to accept bandwidth requests and to identify allocated slots. Packets of the third kind may be sent by the NC to the end-users when a reconfiguration of the logical network topology takes place. Packets of the fourth kind, finally, are sent by the NC to the wavelength converter arrays to configure them each time the network logical topology is rearranged.

2.2 Multiple router network

Now we consider a multiple router network consisting of L identical sub-networks interconnected by a full mesh as shown in Figure 3 for $L=4$. Each sub-network has its own network controller (NC i) and is served by its own wavelength router (PWRN i) which has N ports for direct PON connection, d "dummy" ports and r additional "remote" ports. Any router can send data to the other $L-1$ sub-networks by $L-1$ sets of $r/(L-1)$ fibers, each passing through an interconnection box (SW $i-j$).

The network adopts a single-hop routing policy. This means that remote traffic, i.e., traffic whose source and destination terminals are not attached to the same router, is directly routed from the source router to the destination router, without traversing intermediate routers.

Each interconnection box (switch) must realise at least a full wavelength switching matrix to reach each PON of the destination sub-network from each PON of the source sub-network. These switching boxes can be implemented either all-optically, or using electro-optical conversions.

Figure 3. Multiple router network

If an interconnection box contains a complete time and wavelength switching matrix, the problem of allocating a new connection between sub-network i and sub-network j can be decoupled for the two routers, since a full T- λ switch can map any free slot belonging to any input wavelength to any free slot belonging to any output wavelength. Therefore NC i , to establish a new connection, has to allocate a suitable number of slots on a wavelength (i.e., on one of the $r/3$ remote ports) from the calling terminal to switch SW $i-j$, while NC j needs only to allocate the same number of slots on the wavelength from switch SW $i-j$ to the called terminal, without even knowing the slot allocation map at NC i . In this case, a different process can handle the forwarding of requests on each of the r remote fibers.

The third possibility is to add to the time-wavelength matrix a space switching matrix, thence any time slot on any wavelength carried by an input fiber of switch SW $i-j$ can be mapped to any slot belonging to any wavelength on any output fiber SW $i-j$, thereby granting the maximum interconnection flexibility to the system.

Local traffic, i.e. traffic exchanged among terminals belonging to the same sub-network, is handled by the network controller of the related sub-network using the signalling protocols described in Section 2.1.

Remote traffic management requires two levels of interaction: local signalling between the terminals and their own network controller, remote signalling between the two involved network controllers. The operations needed to establish a new connection between terminal t_i belonging to sub-network i and terminal t_j belonging to sub-network j are (see Figure 4) the following.

Figure 4. Delays implied in opening a inter-router connection

1. Terminal t_i sends a signalling request to $NC\ i$
2. The request is processed by $NC\ i$ during the next time frame and, if it can be accepted, it is forwarded to $NC\ j$ in the subsequent time frame
3. $NC\ j$ processes the request in the time frame after its arrival and, if it can be scheduled, generates two signalling messages: one addressed to $NC\ i$, the other addressed to terminal t_j . These messages will be transmitted during the next time frame
4. The message is processed by $NC\ i$ during the subsequent time frame and a signalling message is generated to be sent to terminal t_i during the next time frame.

3. TRAFFIC MODEL

We consider the traffic model that was taken as a reference in the SONATA project for the study of multiple-router networks. The approach taken in this paper can however be extended to other traffic models.

The population to be served by the networking infrastructure is made of $T = 20,000,000$ user terminals (which can be workstations, IP routers, street cabinets, etc.). These T terminals are divided into $N_c = 40$ geographical areas (which can be metropolitan areas, regions, or countries) called cells, containing $T_c = 500,000$ terminals each. Note that the terminals belonging to the same geographical cell may end up belonging to one PON or to more PONs, and also to one router or to more routers, depending on the network dimensioning.

The traffic is not uniform, in the sense that the amount of traffic exchanged between two terminals belonging to the same cell is different from the amount of traffic exchanged between two terminals belonging to different cells. We assume for simplicity that all cells are alike.

We assume that each terminal generates an average traffic $b = 10$ Mb/s, out of which 7.8 Mb/s are uniformly distributed over the users belonging to the same cell, and 2.2 Mb/s are equally divided among the remaining

19,500,000 terminals. Therefore each terminal sends an average of $b_c = 7.8$ Mb/s / 500,000 = 15.6 b/s toward each terminal of the same cell and $b_o = 2.2$ Mb/s / 19,500,000 = 0.113 b/s toward the remaining terminals. This traffic pattern is represented by the matrix in *Table 1*. Note that the aggregate network capacity is 200 Tb/s.

Table 1. The considered traffic matrix

Cell		1				2				...				40			
	Terminal	1	2	...	T_c	1	...	T_c					1	...	T_c		
1	1	0	b_c	...	b_c	b_o	...	b_o	b_o	...	b_o	b_o	...	b_o			
	2	b_c	0	...	b_c	b_o	...	b_o	b_o	...	b_o	b_o	...	b_o			
	$\vdots$	b_c	b_c	$\ddots$	b_c	b_o	$\ddots$	b_o	b_o	$\ddots$	b_o	b_o	$\ddots$	b_o			
	T_c	b_c	b_c	...	0	b_o	...	b_o	b_o	...	b_o	b_o	...	b_o			
$\vdots$	$\vdots$	$\vdots$			$\vdots$			$\vdots$			$\vdots$						

Under the assumption of telephone traffic with a rate of 64 kb/s and a call duration of 3 minutes, each call transmits $64 \text{ kb/s} \times 180 \text{ s} = 11,520 \text{ kbits}$. The time interval between two successive calls between one pair of terminals belonging to the same cell is $t_c = 11,520 \text{ kb} / b_c = 11,520 \text{ kb} / 15.6 \text{ b/s} = 738,461 \text{ s} = 8 \text{ days } 13 \text{ hours } 7 \text{ minutes } 41 \text{ s}$ and the corresponding call arrival rate is $\lambda_c = 1/t_c = 1.35 \times 10^{-6} \text{ calls/s}$. Instead, the time interval between two successive calls between one pair of terminals belonging to different cells is: $t_o = 11,520 \text{ kb} / b_o = 11,520 \text{ kb} / 0.113 \text{ b/s} = 101,946,902 \text{ s} = 3 \text{ years } 84 \text{ days } 22 \text{ hours } 35 \text{ minutes } 2 \text{ s}$ corresponding to a call arrival rate $\lambda_o = 1/t_o = 9.8 \cdot 10^{-9} \text{ calls/s}$.

4. NETWORK DIMENSIONING

Network dimensioning is performed by a decomposition of the two-level traffic matrix defined above into a uniform traffic matrix and a non-uniform traffic matrix. The uniform traffic portion is then routed through the “wired” channels of the passive wavelength router, while the non-uniform part is subject to wavelength conversion. The number of terminals in each PON (also called PON split) is chosen in order to fully utilise the bandwidth available in wavelength channels.

Since there are many ways of splitting the traffic matrix in two parts, we choose the one which minimises the number of wavelength converters. Therefore a matrix contains the maximum uniform component while the other captures the minimum non-uniform component as shown in *Table 2* and *Table 3*.

Table 2. Maximum uniform component of the traffic matrix

Cell	1				2				...				40			
	Terminal	1	2	...	T_c	1	...	T_c					1	...	T_c	
1	1	0	b_o	...	b_o	b_o	...	b_o	b_o	...	b_o	b_o	...	b_o	b_o	
	2	b_o	0	...	b_o	b_o	...	b_o	b_o	...	b_o	b_o	...	b_o	b_o	
	$\vdots$	b_o	b_o	$\ddots$	b_o	b_o	$\ddots$	b_o	b_o	$\ddots$	b_o	b_o	$\ddots$	b_o	b_o	
	T_c	b_o	b_o	...	0	b_o	...	b_o	b_o	...	b_o	b_o	...	b_o	b_o	
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	

Table 3. Minimum non-uniform component of the traffic matrix

Cell	1				2				...				40			
	Terminal	1	2	...	T_c	1	...	T_c					1	...	T_c	
1	1	0	$b_c - b_o$	...	$b_c - b_o$	0	...	0	0	...	0	0	...	0	0	
	2	$b_c - b_o$	0	...	$b_c - b_o$	0	...	0	0	...	0	0	...	0	0	
	$\vdots$	$b_c - b_o$	$b_c - b_o$	$\ddots$	$b_c - b_o$	0	$\ddots$	0	0	$\ddots$	0	0	$\ddots$	0	0	
	T_c	$b_c - b_o$	$b_c - b_o$	...	0	0	...	0	0	...	0	0	...	0	0	
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	

Note that this approach to network dimensioning does not take into consideration how flexible the network must be in terms of adaptability to traffic fluctuations. For example, if we consider a uniform traffic scenario, in which all terminals are alike and we do not make any difference between inter-cell and intra-cell traffic, the approach proposed here would lead to SONATA networks without wavelength converters (all the traffic would be routed through “wired” channels).

This approach is just one of several possible approaches to network dimensioning: other dimensioning criteria were proposed for SONATA networks. For example in [4] different criteria are proposed, permitting more flexibility in traffic allocation.

4.1 Single router network

The number s of terminals in one PON is computed imposing that the uniform portion of traffic $s(s-1) \times b_o \approx s^2 \times b_o$ generated either toward the same PON or toward each of the remaining PONs is equal to the bandwidth B of the “wired” wavelength channel that will carry it. In this way $s = \sqrt{B / b_o} = 74,250.8$. Choosing $s = 62,500$ the number of PONs becomes $N = T / s = 320$, so there are 320 PONs / 40 cells = 8 PONs / cell. This means that we are in the situation in which more than one PON is needed to attach the terminals belonging to the same cell, and each cell is completely served by a particular router.

The number d of wavelength channels passing through the wavelength converters is determined by the extra traffic generated by one PON both

toward itself and toward the other 7 PONs belonging to the same cell, therefore $d = 8 \times (b_c - b_o) \times s^2 / B = 778.9 \approx 779$ channels. The total number of router ports (and thence wavelength channels) needed is $N + d = 1,099$.

Note that each router port attached to a PON carries up to $N + d = 1,099$ channels (we neglect here and in the sequel the channel used to communicate with the NC), while each router port attached to an array of wavelength converters carries $N = 320$ channels. Each array needs therefore $N = 320$ converters, and the total number of wavelength converters is $N_{wc} = N \times d = 249,280$.

The call rate from one PON toward itself is $s(s-1) \lambda_c = 5,289.6$ calls/s, while the call rate between two PONs belonging to the same cell is $s^2 \lambda_c = 5,289.7$ calls/s; these two call rates will be assumed to be identical. The call rate between two PONs belonging to different cells is $s^2 \lambda_o = 38.3$ calls/s. Therefore the call rate between a PON and the 20 millions of terminals in the network would be $8 \text{ PONs} \times 5,289 \text{ calls/s} + 312 \text{ PONs} \times 38.3 \text{ calls/s} = 54,261 \text{ calls/s}$ and the call arrival rate of the whole network would be $320 \text{ PONs} \times 54,261 \text{ calls/s} = 17,363,712 \text{ calls/s}$.

The overall memory requirement at the NC for the data structures needed to run the network control algorithms (both the time-scheduling and the logical topology design algorithm, see [3]) can be seen to be about 27 Gigabyte.

4.2 Multiple router network

We consider now the case in which the T terminals are divided into $L=4$ subsets of $T_s = T / L = 5,000,000$ terminals and each subset is connected to a different wavelength router. Thus, the first $T_s / T_c = 10$ cells are assigned to the first sub-network, cells from 11 to 20 are assigned to the second sub-network, cells from 21 to 30 are assigned to the third sub-network and, finally, cells from 31 to 40 are assigned to the last sub-network.

The number of users per PON s remains the same as for the single router case because it depends only on b_o and B . Moreover each sub-network has $N_s = N / L = 80$ PONs and still needs $d = 779$ auxiliary wavelength channels because each cell covers 8 PONs as in the single router network. Since each fiber connecting a “dummy” port to a wavelength converter array carries N_s channels, each sub-network needs $N_{wc} = N_s \times d = 62,320$ wavelength converters to route traffic internal to the sub-network.

The number of remote ports and, thence, the number of fibers to be used in the interconnection among sub-networks can be reduced at the price of adding some wavelength converters to the topology. Here we explore 3 alternatives:

a) no additional wavelength converters

- b) some additional wavelength converters
- c) some additional wavelength converters and shared use of the converters already connected to "dummy" ports.

In the first case, the number r of wavelength channels needed by a PON belonging to one sub-network to send its remote traffic to the remaining 3 sub-networks is given by $r = (L-1) \times T_s \times s \times b_o / B = 170.3 \approx 171$. The total number of router ports (and hence wavelength channels) needed is $N_s + d + r = 1,030$. The N_s PON ports carry $N_s + d + r = 1,030$ channels, while the number of channels carried by each of the r remote fibers (and by the d dummy ports) is $N_s = 80$. Therefore the number of wavelength converters needed in the interconnection boxes attached to each sub-network is $N_s \times r = 13,680$ converters.

Another possibility would be to re-circulate part or all of the remote traffic through some additional wavelength converter arrays local to each router. By doing so, more wavelength channels will be accommodated on remote fibers, with the advantage of reducing the number of remote fibers, hence of interconnection costs. Since we need r ports to carry remote traffic, we can have r' remote ports attached to interconnection boxes and $r'' = r - r'$ extra dummy ports connected to wavelength converters. If we assume that these r'' extra dummy ports are dedicated to incoming and outgoing remote traffic, they carry $N_s + r'$ channels each; thus, the number of additional wavelength converters (outside the interconnection box) is $r'' \times (N_s + r')$. We have constraints on r' and r'' : the number of remote channels is $r' \times (N_s + r'')$ and this must be at least equal to $r \times N_s = (r' + r'') \times N_s$. This means that r' can range between N_s and r . For example, we can assume that remote connections are re-circulated through $r'' = 90$ additional dummy ports; the number of remote ports is reduced to $r' = 81$, each carrying $N_s + r'' = 170$ channels. Therefore, the number of wavelength converters should be increased by $r'' \times N_s = 7,200$ for outgoing connections and by $r' \times r'' = 7,290$ for incoming connections. The number of wavelength converters needed in the interconnection boxes attached to each sub-network would be $r' \times (N_s + r'') = 13,770$. Note, however, that the number of router ports remains $N_s + d + r' + r'' = 1,030$ since $r = r' + r''$.

A more drastic reduction in the number of remote ports can be obtained by using all $d + r''$ dummy ports to route remote traffic. In this case r' can be reduced to the minimum $r' = r \times N_s / (N_s + d + r) \approx 13.3$ (assuming that the maximum number of channels per fiber is equal to the number of router ports $N_s + d + r$). Since r' must be an integer multiple of $L-1 = 3$, we can take $r' = 15$ and $r'' = 156$. The number of additional wavelength converters becomes $r'' \times (N_s + r') + d \times r' = 26,505$ while the number of wavelength converters needed in the interconnection boxes attached to each sub-network is $r' \times (N_s + d + r) = 15,450$.

Note that the numbers of wavelength converters given above in the hypothesis of all-optical implementation of the interconnection boxes can be arguably related to the number of necessary tuneable lasers required for an electro-optical implementation (in which received optical channels are converted to electronic streams, possibly stored, and later re-converted to optics with tuneable lasers).

Table 4 summarises the project parameters of one of the sub-networks for the three alternatives: the column labelled “# of extra λ converters” shows the number of wavelength converters needed to lower the number r' of interconnection fibers among routers. The column “Total # of λ converters” is the sum of the number given above, the number of wavelength converters connected to the “dummy” ports (always 62,320) and the number of wavelength converters put into the interconnection boxes. Note that the number of wavelength converters is dominated by the requirements of unbalanced intra-cell traffic.

Table 4. Architectural alternatives for interconnected routers

Conf	Remote traffic through ...	r'	r''	# of extra λ converters	# of λ converters in interconnection boxes	Total # of λ converters	# of λ on remote fibers
a	No dummy ports	171	0	0	13,680	76,000	80
b	Dedicated dummy ports	81	90	14,490	13,770	90,580	170
c	Shared dummy ports	15	156	26,505	15,450	104,275	1030

The call arrival rate between one PON and the other terminals of the same sub-network belonging to different cells is $72 \text{ PONs} \times 38.3 \text{ calls/s} = 2,758 \text{ calls/s}$, therefore the call rate between a PON and the terminals belonging to the same sub-network is $8 \text{ PONs} \times 5,289 \text{ calls/s} + 72 \text{ PONs} \times 38.3 \text{ calls/s} = 45,070 \text{ calls/s}$. Finally the call rate between a sub-network and itself is $80 \text{ PONs} \times 45,070 \text{ calls/s} = 3,605,568 \text{ calls/s}$. The call arrival rate between a PON and the 240 PONs belonging to the other sub-networks is $240 \text{ PONs} \times 38.3 \text{ calls/s} = 9,159 \text{ calls/s}$, thence the call rate between two different sub-networks is $80 \text{ PONs} \times 9,159 \text{ calls/s} = 732,792 \text{ calls/s}$. The total call arrival rate toward the network controller of a sub-network is 5,071,152 calls/s and consists of 3 contributions:

- 3,605,568 calls/s coming from the sub-network
- 732,792 calls/s going to the network controllers of the other sub-networks
- 732,792 calls/s coming from the network controllers of the other sub-networks.

Since the complexity of the NC grows much faster than linearly with the number of calls/s to be processed, the architecture with several interconnected sub-networks leads to significant savings in complexity at the NC.

Since each sub-network is exactly $\frac{1}{4}$ of the whole network, the upstream and downstream signalling bandwidth requirements of one sub-network are exactly $\frac{1}{4}$ of the ones of the single router network.

The overall memory requirement at the NC of each sub-network for the data structures needed to run the time-scheduling and logical topology design algorithms can be seen to be about 7 Gigabyte, while each interconnection box needs at least 100 Megabyte of memory to store the time/wavelength switching matrix.

5. CONCLUSIONS

The European Union ACTS project SONATA devises an advanced transport architecture for a single-layer all-optical WDM network covering a nation-wide area. Its outstanding features are a very simple passive star topology built around a passive wavelength routing node and terminals equipped with fast-tuneable transceivers. The architecture is said to be "switchless" because no explicit switching devices are used; the only elementary switching function resides in the tuneability of the wavelength converter arrays around the central node (i.e. the PWRN) and of the terminals' transceivers.

In this paper we describe the structure of a single-router network and outline the steps required to extend it to a multiple router architecture. Then we dimension two network architectures consisting of one and four interconnected routers for the same simple non-uniform telephone traffic pattern.

On the one hand, the single router network has 320 PONs and 779 wavelength converter arrays connected to "dummy" ports, so it requires a 1,099 ports router and 250,000 wavelength converters. While the network controller hardware must be equipped with 27 Gigabyte of memory and has to be fast enough to process 17,000,000 terminal requests/second. Although this is a very large complexity, the aggregate capacity is very large (order of 200 Tb/s), and the network can be considered as a nation-wide telecommunications infrastructure.

On the other hand, in the interconnected architecture, each sub-network has 80 PONs, requires 171 "remote" ports and still needs 779 wavelength converter arrays, thus each sub-network is built around a 1,030 ports router. The number r' of "remote" ports (and therefore of fibers) used for

interconnections among routers can be varied between 171 and 15 simply increasing the number of wavelength converters used from 300,000 to 400,000. Each network controller hardware must be equipped with 7 Gigabyte of memory and has to be fast enough to process 5,000,000 terminal requests/second.

In this way we have shown that it is possible to reduce the tremendous hardware complexity (which scales more than linearly with the number of terminal requests/second) of the single router network controller by distributing it over more satellite network controllers at the price of increased delays for non-local traffic and higher costs for passive wavelength routers, wavelength converter arrays and interconnection fibers.

REFERENCES

- [1] N.P.Caponio, A.M.Hill, F.Neri, R.Sabella, *Single-Layer Optical Platform Based on WDM/TDM Multiple Access for Large-Scale "Switchless" Networks*, European Transactions on Telecommunications, Special Issue on WDM Networks, January 2000.
- [2] A.Bianco, E.Leonardi, M.Mellia, M.Motisi, F.Neri, *Specifications of signalling functions in SONATA*, contribution to deliverable D9 (see [4]) of the ACTS Project SONATA AC-351, Politecnico di Torino, 1999.
- [3] A.Bianco, E.Leonardi, M.Mellia, F.Neri, *Network Controller Design for SONATA, a Large Scale All-Optical Passive Network*, IEEE Journal on Selected Areas in Communications, Special Issue on Protocols and Architectures for the Next Generation Optical Networks, October 2000
- [4] ACTS Project SONATA AC-351, *Final Report on System Studies*, Deliverable D9, 2000.