Path Protection in Transparent Networks

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Abstract— **Transparent optical networks are considered an interesting option for future optical transport networks instead of opaque optical networks. In most previous studies, transparent optical networks have always proven to be an economically viable alternative, by the reduction in transponders. Currently, there is a lot of research into restoration of optical networks. All competitive future optical transport networks will have some restoration mechanism implemented. In this paper, we study the effects of shared protection on the CAPEX of transparent and opaque networks.**

I. Introduction

Recent advances made the availability of ultra long haul (ULH) WDM transmission systems possible at extremely competitive prices. This has opened up new perspectives in the design of cost-effective optical transport networks [1]. The attraction comes from the possibility of the introduction of transparency in the network, allowing for a reduction in expensive optical-to-electrical-to-optical (OEO) regenerators. According to the utilization of OEO devices, three types of networks are identified: opaque, transparent, and translucent networks. An opaque network is characterized by OEO regenerations at every node. In a transparent network the signal bypasses the OEO devices during its transmission. The maximum transparent length (MTL) of a system puts a limit on the size of a completely transparent network. A hybrid of the two previous types is called a translucent network where both opaque and transparent functionalities co-exist in a node. The aim of a translucent network is to employ the smallest possible number of transponders in order to maximize cost savings. Nevertheless, translucent networks need higher performance devices [2].

Communications networks are subject to a wide variety of unintentional failures, caused by natural disasters, wear out and overload, software bugs, human errors, and so on, as well as intentional interruptions due to maintenance.[3] As core communication networks also play a vital military role, key telecommunication nodes were favored targets during the Gulf War, and could become a likely target for terrorist activity. For business customers, disruption of communication can suspend critical operations, which may cause a significant loss of revenue, to be reclaimed from the telecommunications provider. In fact, availability agreements now form an important component of Service Level Agreements (SLAs) between providers and customers.

In this paper, we study CAPEX reduction when introducing protection mechanisms into optical networks. There has been a lot of research into the possible cost savings of transparent networks [2][4][5], however, the influence of restoration mechanisms on these cost savings has been left out of the equation.

II. Path Protection

For the path protection (PP) schemes, we consider two well-known schemes, being 1+1 dedicated path protection (DPP), and 1:1 shared path protection (SPP). Our choice for path protection over other protection mechanisms like p-Cycles [6] is because of its relative simplicity and because a comparison can be made without altering paths between schemes. We did not optimize to allow for a fair comparison of opaque versus transparent networks, without biasing results with different degrees of effectiveness of optimization procedures.

The main idea of PP is to provide two disjoint end-to-end paths for every connection in the network to provide against single failures. These paths are labeled a working path (WP) and a backup path (BP). In a failure-free scenario, the WP is operational and carries all traffic. If a failure occurs, the traffic is switched over to the BP. In some cases, load balancing between the two paths is possible, but we did not consider this in our study

Lighting up or tearing down a wavelength in an operational network introduces changes in the power profile on the links, which causes signal degradation on other operational wavelengths. These fluctuations are called transients and have a negative impact on overall stability and recovery speed. In order to avoid the transient of lighting up a wavelength on a backup link that is by definition unaffected by the failure, backup paths can be lit up. This is called hot standby. In an opaque network, all path segments are terminated in every node because a link can be lit up independently of other links. Therefore, capacity sharing on certain links with hot standby can be implemented quite easily. In contrast, the best way to restore an all-optical ULH network after failure is still uncertain [9]. In a transparent network, we have an additional constraint to take care of. The entire path is lit up at once on a single wavelength. What this means is that, if we light up two backup paths in hot standby in a fully transparent way, there can be no capacity sharing if they have a common link. If we want full transparent sharing, there are two options.

The first option is to go to cold standby for one (or both) of the backup paths. If the failure occurs on a WP with a cold standby BP, the BP is lit up after the failure. This causes the transient problem and thus some degradation in recovery speed.

The second option is to terminate the backup paths in certain nodes, in order to allow for sharing. This option introduces extra OEO equipment and will therefore be more expensive than the previous one.

III. Network Architecture

As stated above, we consider two node architectures, namely a solution based on SDH equipment (Electronic Cross Connects, EXC) and WDM terminals, and a transparent solution consisting of optical cross connects (OXC), based on the Wavelength Selective Switch (WSS) architecture.

Most of today's Optical Transport Hierarchy (OTH) EXCs are hybrid EXC's providing also switching functionality in SDH (VC-4) granularities. We will however focus solely on STM-64 switching and tributary traffic is also assumed to be STM-64. EXC port cards can be used on both sides of an EXC: either on the client/tributary side or on the network/trunk side. On the trunk side the EXC is usually connected to a WDM system. There can be two implementations of the EXC interfaces on the trunk side (Figure III-1)

- The use of grey interfaces and separate WDM transponders
- The use of colored EXC interfaces without separate transponders.

Usually the latter implementation is cheaper than the use of separate WDM transponders. We have focused on the use of colored EXC interfaces.

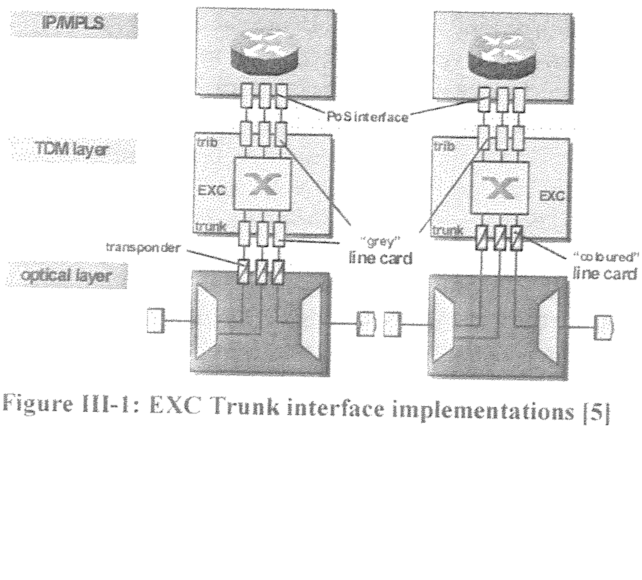

Figure III-1: EXC Trunk interface implementations [5]

In this EXC model we just need a WDM terminal for multiplexing the channels onto a single fiber. For this study we assume an 80 channel DWDM model.

Our transparent solution is based on Wavelength Selective switches.

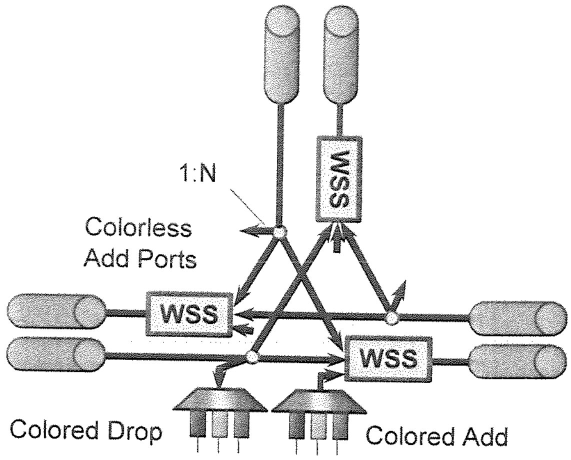

Figure III-2: Functional view of an OXC

This OXC provides multiple fiber ports and is capable for cross-connecting wavelength channels (Figure III-2). In our model we assume that OXCs additionally provide local add/drop functionality of particular wavelength channels.

In the transparent solution, traffic is sent end-to-end using a sufficiently powerful colored transponder. These transponders convert the input grey wavelength and feed it into the OXC using a colored add port.

A. Cost Model

In order to evaluate these different options, we used a cost model. This cost model is coming from within the IST-NOBEL projects. As OXCs are not widely deployed and realistic vendor prices are difficult to obtain there is a generic price model for OXCs: The total price depends on the capacity of the optical line systems (80 channels in our case) and on the number of fiber ports N ($2 \leq N \leq 8$). Note that the WDM multiplexing equipment is included in the cost of an OXC, one amplifier is used per input fiber port for coping with insertion losses.

In short, for the opaque solution, we include the costs of the switch (EXC), interface cards and WDM terminals. For the transparent solution, the cost of the OXC node, input amplifiers and transponders are included. The cost of the transmission links is not considered in this study, because they will be similar in all considered solutions.

TABLE I

COST MODEL

Equipment type	Relative cost
EXC 640 Gbit/s	13.33
EXC 1280 Gbit/s	26.67
EXC 2560 Gbit/s	69.33
EXC 5120 Gbit/s	180.26
Grey STM-64 Interface Card	.67
Colored STM-64 Interface Card, 750 km	1.50
Colored STM-64 Interface Card, 1500 km	1.75
WDM Terminal, 80channel	10.83
OXC node, N degree, 80 channel system	9.17*N + 2.75
Amplifier for insertion loss compensation	1.25
Transponder, STM-64, 750 km	1.00
Transponder, STM-64, 1500 km	1.25

IV. SIMULATION SETUP

For this study, we computed the link and node dimensioning for a German reference network (Figure IV-1). We consider five different strategies for the network.

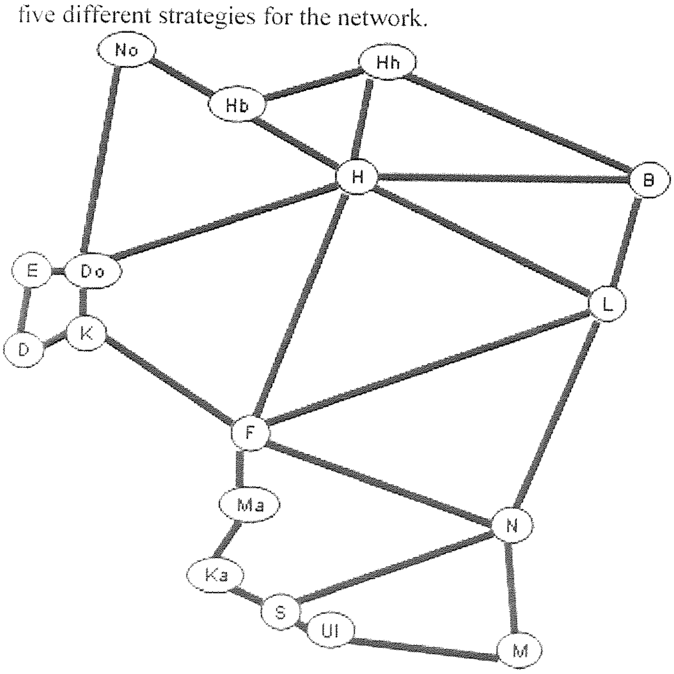

Figure IV-1: Network Topology

The first two strategies are fully transparent networks. Here, all paths (WP and BP) are switched through OXC equipment. The first option considers DPP and the second option considers SPP. In DPP we have a hot standby backup path. in SPP the backup path is pre-calculated and lit up after the failure. We will have slower restoration in the SPP case due to transients.

The third and fourth strategies are opaque networks. In these networks all paths are switched through EXC equipment. Both DPP and SPP with hot standby backup paths are considered.

The fifth strategy is a hybrid one. Here we try to combine fast recovery with SPP in transparent networks. The working paths are switched transparently, while the backup paths are switched through EXCs in order to allow hot standby wavelengths for the SPP. All backup paths are terminated in every node. This can be optimized, but we feel it will be very complex and will yield little improvement over termination in every node. After initial results this option was scrapped because it will prove too expensive with regard to pure transparent switching.

For every piece of equipment, the cheapest needed option is used (minimal EXC/OXC size and minimal required reach). All calculations are done with in-house software.

Paths are calculated using a shortest cycle algorithm to find the working and backup paths, and these are the paths used in all the comparisons. The shortest ends of the cycle are the working paths. No extra optimizations were done. Traffic is routed in STM 64 units.

V. SIMULATION RESULTS

Source Node	Destination Node	Distance	#WL-DPP	#WL-SPP
Düsseldorf	Essen	36,9715	64	45
Köln	Frankfurt	182,0636	108	97
Essen	Düsseldorf	36,9715	64	45
Düsseldorf	Köln	40,9159	64	61
Hannover	Berlin	294,9023	53	36
Berlin	Leipzig	173,2702	66	44
Hamburg	Hannover	160,9585	50	34
Berlin	Hannover	294,9023	53	36
Bremen	Norden	144,3164	56	43
Hannover	Dortmund	220,4173	122	105
Nürnberg	Leipzig	274,6524	119	90
Norden	Bremen	144,3164	56	43
München	Ulm	145,5660	68	60
Leipzig	Berlin	173,2702	66	44
Hannover	Frankfurt	313,9546	109	70
Dortmund	Essen	37,4606	64	61
Bremen	Hamburg	114,7636	31	21
Frankfurt	Köln	182,0636	108	97
Frankfurt	Leipzig	352,5642	70	32
Karlsruhe	Mannheim	63,8856	71	49
Norden	Dortmund	279,7461	56	43
Frankfurt	Mannheim	85,4628	71	64
Hamburg	Berlin	306,3330	45	33
Ulm	München	145,5660	68	60
Köln	Düsseldorf	40,9159	64	61
Essen	Dortmund	37,4606	64	61
Hamburg	Bremen	114,7636	31	21
Ulm	Stuttgart	87,1283	68	64
Köln	Dortmund	40,9159	86	64
Frankfurt	Hannover	313,9546	109	70
Hannover	Hamburg	160,9585	50	34
Bremen	Hannover	121,3766	55	46
Karlsruhe	Stuttgart	75,5252	71	40
Dortmund	Norden	279,7461	56	43
Hannover	Bremen	121,3766	55	46
Frankfurt	Nürnberg	224,0593	108	89
Nürnberg	Stuttgart	188,7344	131	93
Stuttgart	Ulm	87,1283	68	64
Dortmund	Hannover	220,4173	122	105
Nürnberg	München	180,7966	68	64
Nürnberg	Frankfurt	224,0593	108	89
Mannheim	Karlsruhe	63,8856	71	49
Berlin	Hamburg	306,3330	45	33
Dortmund	Köln	84,3348	86	64
Stuttgart	Karlsruhe	75,5252	71	40
Leipzig	Hannover	257,1705	99	72
München	Nürnberg	180,7966	68	64
Leipzig	Nürnberg	274,6524	119	90
Mannheim	Frankfurt	85,4628	71	64
Hannover	Leipzig	257,1705	99	72
Leipzig	Frankfurt	352,5642	70	32
Stuttgart	Nürnberg	188,7344	131	93
TOTAL REQUIRED CAPACITY			3946	3040

Figure V-1: Link dimensioning

First, we dimension the network links (Figure V-1) . This is independent of the switching solution used. The result is that we need a capacity of 3946 (wavelengths*links) for the DPP options and 3040 for the SPP schemes. This is a gain of 23%.

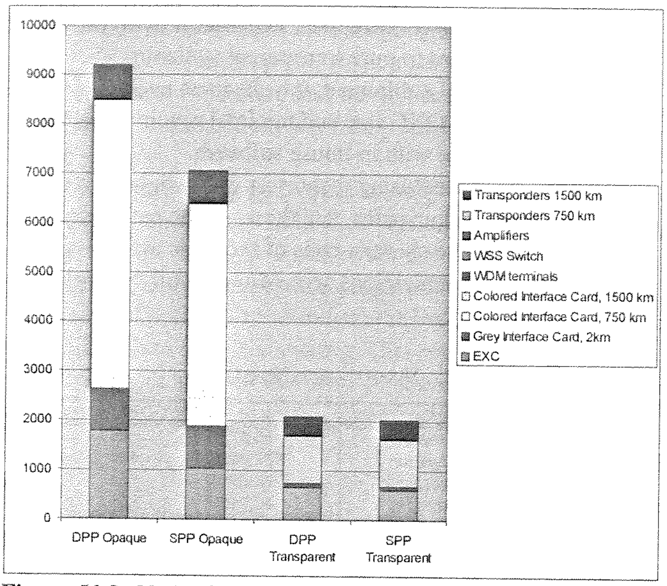

Figure V-2: Node CAPEX

All node dimensioning results are summarized in Figure V-2.

A. Opaque Solution

For dedicated path protection, the total relative network cost for the opaque solution is 9190. This consists of the cost for the switches (EXCs), Interface cards and WDM terminals. When we introduce shared path protection in this network, the total node CAPEX drops to 7043, or a 23% reduction. This is without optimizing the paths for protection sharing. The figure clearly shows cost savings in every type of equipment, except of course the grey tributary line cards, which remain the same. Because there are a lot of EXCs just over the threshold in the DPP scheme (used little over 50%), there was a huge cost saving in EXC equipment of 41%, with a cost saving of around 23% in Interface cards and a decrease of 9% in the WDM cost.

B. Transparent Solution

For dedicated protection in the transparent case, the total node cost is about 2082. This is a huge cost saving over both opaque solutions, mainly to the effective removal of expensive interface cards for trunk traffic. WSS technology proves a very cheap solution for switching large amounts of trunk traffic. When we now implement SPP, we see there is almost no gain in CAPEX of the nodes. The overall node cost of the network is now 2020, or a 3% total cost reduction. This is because of the architecture of the switch, where the node degree is relatively stable with regard to minor changes (in this case around 20%) in traffic input. There are only a few nodes that allowed shrinking a degree because of protection sharing. Moreover, applying SPP in this way, will result in slower protection switching due to the transient problem mentioned. Introducing 3R regenerators in order to allow for hot standby backup will introduce a huge CAPEX increase, therefore shared protection will not be beneficial for CAPEX reduction in transparent networks. The effects on the blocking ratio in transparent networks due to less loaded fibers will be an important topic for further study.

VI. Conclusion

While protection sharing introduces huge cost savings in traditional opaque networks, future transparent networks will benefit far less from protection sharing in this sense. The overall node CAPEX gain drops from 23% in a network with opaque switching to 3% for the same network when a transparent node architecture is introduced. Moreover, a transparent solution based on WSS makes the node cost around 4 times less expensive. The benefits of SPP in transparent networks with regard to blocking ratio performance when the average link load decreases remains an important topic for future study.

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