

Diverse Routing Strategies for On-Demand Lightpath Provisioning in ASON/GMPLS Networks

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The average increment and the increasing variability of the traffic to be carried by ASON/GMPLS transport networks will require on-demand provisioning in the near future. In this scenario dynamic routing based on traffic engineering techniques is a key issue.

This paper shows through simulation experiments how using network failures information with dynamic routing in ASON/GMPLS networks can considerably impact on the performance of such network. Three routing strategies are considered differing only in its use of failure information. The performance is evaluated in terms of request blocking probability and availability over two different networks from a sparse one to another highly meshed.

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1. INTRODUCTION

The introduction of intelligence in Automatically Switched Optical Networks (ASON) [1] using a GMPLS control plane [2] allows provisioning of optical channels (lightpath) in seconds. This would open new opportunities related to better resource utilization, creation of new services, such as bandwidth on demand, and a range of traffic engineering mechanisms [3]. Client network layers (IP, SDH, etc) can request optical connections to the optical network through the User Network Interface (UNI) [4].

On the other hand, optical transport networks provide a huge amount of bandwidth in each lightpath connecting two main locations. In order to maximize the occupation of the lightpaths it is necessary to perform grooming. This groups together different client layer demands between locations. The difference of scale between lightpath and typical client layer demand bandwidth make lightpaths to be very stable in the time and are mainly permanent connections. Under these considerations, it is clear that the only way to improve availability in optical transport networks is by the means of recovery (protection or restoration) schemes. So, a lot of effort has been made to create, compare, develop, etc. different recovery schemes [5].

But the scenario is rapidly changing, the traffic to be carried by today's backbone networks increases very rapidly mainly due to the massive use of internet and multimedia applications. The difference of scale between transport and client bandwidth is falling down and the need to establish lightpath in an on-demand way as switched connections is rising. On the other hand, there are applications that need a huge amount of bandwidth between two locations for a determinate period of time. Examples of these applications are HDTV [6], Grid computing [7], Tele-immersion [8], etc.

Switched connections are more sensible about failures in the network than permanent connections because they are on-demand requested when they are really needed and much of the times would require the highest level of availability. Therefore, it is necessary to periodically update routing tables to avoid congestion and failures for new lightpath requests, allowing dynamic routing based on traffic engineering techniques, to find the best route in the network. In an ASON/GMPLS based network, this information can be advertised in OSPF TE LSAs [9].

This paper compares three diverse routing strategies based on a general diverse routing algorithm. The strategies differ as to whether failure information is taken into account for diverse routing or not. The performance is evaluated through simulation experiments in terms of request blocking probability and availability.

Two different kinds of networks are used in order to compare the performance. The difference in its topology lies in the average node degree of the network, and hence the degree of meshedness. These two topologies have been chosen based on the study presented in [10].

The rest of the paper is organized as follows. Section 2 provides background on segment protection, the influence of failure information on diverse routing and availability. In Section 3 we describe the simulation scenario. In Section 4 we present the performance evaluation of both strategies. Section 5 draws the conclusions.

2. BACKGROUND

2.1. END TO END PROTECTION VS. SEGMENT PROTECTION

A survivable network [11] should be based on a biconnected graph where at least two node-disjoint routes between every pair of nodes should exist. In such network, a 1+1 protected path consists on two fully disjoint routes between origin and destination (end-to-end protection). Some times, either when the network is not fully deployed in an area or the occupation of some spans in the network is high or there are failed spans, it is not possible to find a fully disjoint path pair. In these cases, the best protection option should be chosen, protecting where possible (Segment Protection). Figure 1 illustrates both concepts. Note that in segment protection other nodes in addition to the end nodes perform protection switching (nodes B2 and B3 in Figure 1b).

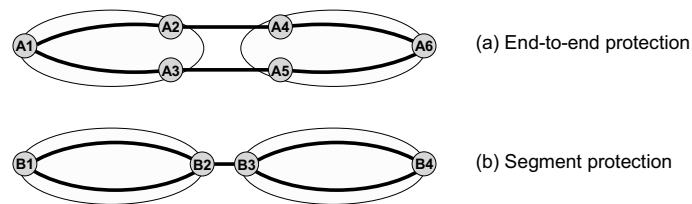


Figure 1 End-to-end vs. segment protection

In order to implement segment protection the graph representing the network has to be broken down in its biconnected components finding the nodes whose single failure would partition the graph into two separate subgraphs. These nodes are called articulation points. Figure 2 illustrate this.

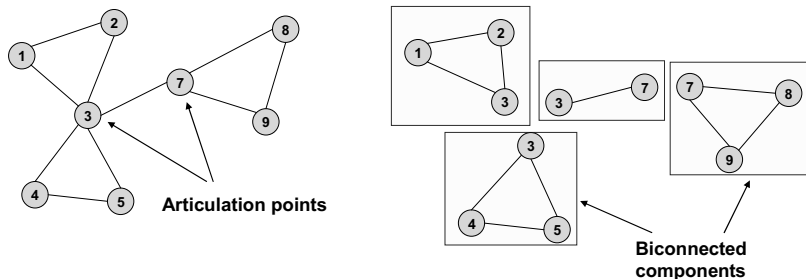


Figure 2 Biconnected componets

2.2. INFLUENCE OF FAILURE INFORMATION ON DIVERSE ROUTING

When computing protected paths one of the things to be taken into account is the global state of the network in order to know which resources are available to be used. Resources are available because they are not in use by any path in the network, but is it necessary to have into account its failure state too?

Figure 3a) illustrates a network with a failed span between nodes 2 and 3. A path request arrives at node 1 to establish a protected lightpath to node 4. Figure 3b) shows the route chosen taking into account the failures in the network at this moment. We call this Failure Driven Routing (FDR). If the failed span is repaired but the span connecting nodes 4 and 5 fails, the protected lightpath will be down with only one failed resource.

Figure 3c) shows the route chosen without taking into account the failures in the network (Failure Independent Routing, FIR). In this option if the failed span is repaired but the span connecting nodes 4 and 5 fails, the protected lightpath will continue working.

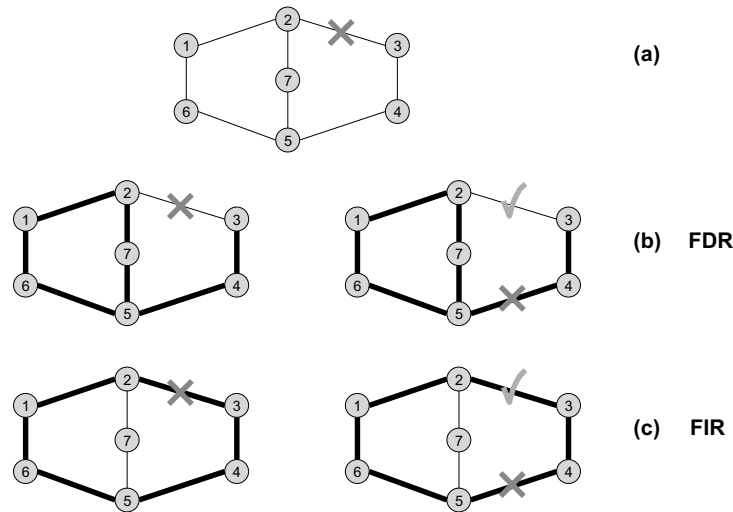


Figure 3 Two examples of influence of failure information on diverse routing

If the duration of the path is very short the probability of having two consecutive failures affecting the path is very low, so taking into account failures guarantees the path will be working when it is established. On the other hand, if the duration of the path is very long, it is more probable that the path will be affected by two consecutive failures, but paths have no guarantee of being in the up state when first established if both working and protected routes are affected by two different and simultaneous failures.

On the other hand, FIR strategy will always use the same resources independent of the failures in the network whereas FDR strategy can use more resources than FIR looking for a route without failed spans, or fewer resources than FIR if a disjoint route can not be found.

2.3. AVAILABILITY

An important issue when comparing different routing strategies in optical networks is lightpath availability. Availability is the probability that a system (in this case a lightpath) will be found in the operating state at a random time in the future. Availability (steady state availability) can be expressed as:

$$A = \frac{UpTime}{UpTime + DownTime} \equiv \frac{MTTF}{MTTF + MTTR} \quad (1)$$

where:

- MTTR: Mean time to repair, the expected time needed to repair the item.
- MTTF: Mean time to failure, the expected time to the next failure of the item, following completion of the repair. MTTF is usually expressed in hours or in FITs, number of failures in 10^9 hours.

In the study presented in this paper we assumed the figures presented in Table 1 for MTTF and MTTR [12].

Table 1 MTTF and MTTR typical values

Tx failure rate	10.867 FITs
Rx failure rate	4.311 FITs
Plug-replacement Equipment MTTR	2 hours
Fiber-optic cable MTTR	12 hours
Fiber-optic cable MTTF	4,39/year/1000 sheath miles

As illustrated, the component with highest failure rate is optical cable, so the availability of a path provisioned over a number of spans with no recovery mechanism would be accurately estimated as

$$A_{path} \cong 1 - \sum_i U_{link}^p(i) \quad (2)$$

where $U_{link}^p(i)$ is the physical unavailability of the i th link in the path.

Therefore, in this paper we confine ourselves to cable cuts analysis. The results thus derived can be adapted to equipment failure analysis.

3. SIMULATION SCENARIO

The simulation scenario consists of a reference network, in which events are being executed. At the end of the simulation the results are obtained based on the representative data of the network state stored during the simulation execution.

In the simulation model we assume that each node maintains global network state information for routing and this information is periodically updated.

3.1. TRAFFIC MODEL

While telephonic (voice) traffic is mainly exchanged between locations that are geographically close, the exchange of internet traffic is much less related to the distance.

In our simulation, traffic is modeled using the approach of Dwivedi and Wagner [13]. This model differentiates between three traffic types: voice traffic, transactions data traffic (business IP traffic) and Internet traffic (IP traffic not related to business). The resulting total traffic between locations A and Z is derived as the sum of the previous component patterns.

According to [10] telephonic traffic intensity is inversely proportional to the distance between origin and destination (DA-Z), transactions traffic intensity is inversely proportional to the square root of the distance, and Internet traffic is independent of the distance.

$$\text{Telephonic}_{A-Z} = \frac{C_v}{D_{A-Z}} \quad (3)$$

$$\text{Transactions}_{A-Z} = \frac{C_t}{D_{A-Z}^{1/2}} \quad (4)$$

$$\text{Internet}_{A-Z} = C_i \quad (5)$$

Constants (C_v , C_t and C_i) include parameters like population, number of non-production business employees, number of internet hosts and an estimation of traffic growth.

In this paper we assumed a mixture of traffic with 30% telephonic traffic, 50% transactions traffic and 20% of Internet traffic arriving to each location and all traffic demands are for protected lightpaths.

3.2. REFERENCE NETWORKS

In the simulation experiments, we have investigated the behavior of routing strategies over two different network topologies. These two topologies have been chosen based on the study presented in [10] for a pan-European fiber-optic backbone network evaluated in terms of cost of the network design and availability of the connections of the different traffic types. Both topologies connecting the same largest European cities are illustrated in Figure 4.

The topology called Ring Topology (RT) is a sparse topology, while the Triangular Topology (TT) is highly meshed, in fact it consists of little triangles.

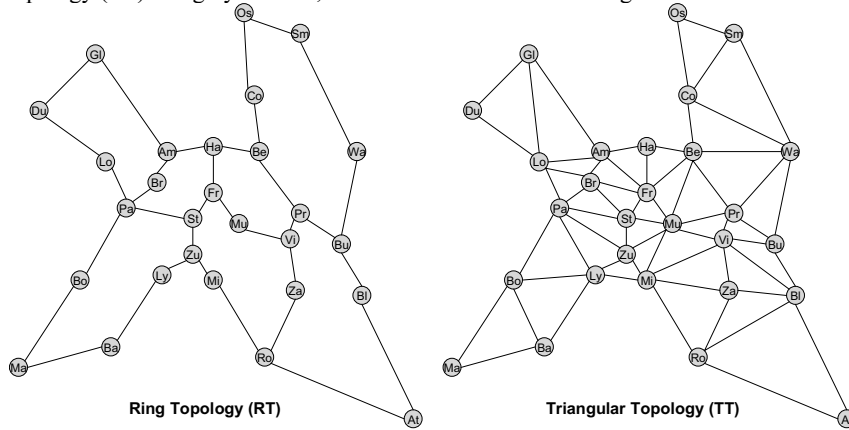


Figure 4 Network Topologies

In order to obtain the length of the fibers connecting the nodes in the presented topologies, the airline distance D between each node pair was calculated using the Haversine Formula [14] which takes as input the latitude and longitude coordinates of the node locations. The fiber distance L is related to the airline distance by [15]:

$$L = \begin{cases} 1.5 * D, & D < 1000Km \\ 1500Km & 1000Km < D < 1200Km \\ 1.25 * D, & D > 1200Km \end{cases} \quad (6)$$

In Table 2 some basic figures for the network topologies are summarized.

Table 2 Basic figures

	# nodes	# links	Mean Node degree	Mean Fiber Distance L (km)
RT	28	34	2.43	630
TT	28	61	4.36	638

Span distances are used to calculate the MTTF parameter of the span whereas airline distances are used to calculate the traffic intensity in telephonic and transactions patterns.

Initially each span has 40 data channels vacant to be occupied and released by paths.

3.3. ROUTING STRATEGIES

3.3.1 FAILURE INDEPENDENT ROUTING (FIR)

Failure Independent Routing compute path route taking into account only the occupation of the spans in the network. Each time a lightpath request arrives it creates a new network view locating the biconnected components of the network. For each biconnected component it constructs a new shortest path tree based on the min-hop criterion executing Modified Dijkstra algorithm. The route of the single path can be found following the tree from the destination to the source node in each biconnected component and linking them together to construct the complete route of the path. A more detailed description of the algorithms used here can be found in [11].

To compute the route of a disjoint path, Shortest Disjoint Path Pair Algorithm is used to calculate the disjoint path pair in each biconnected component. Again, connecting the segments the complete segment disjoint path pair is calculated.

3.3.2 FAILURE DRIVEN ROUTING (FDR)

The difference with the previously explained FIR strategy is that Failure Driven Routing strategy includes span failure state in order to construct the network view. This way, incoming path requests will be routed through working spans avoiding failed spans.

3.4. EVENTS

Four types of events have been considered in the simulation here presented:

- **Set up Path:** Given a demand (source node, destination node, duration of the path, single/disjoint path), try to establish (determine the route and reserve the resources) a new path in the network taking into account the current spans occupation (and the failure state of the spans if the case). If successful, schedule the tear-down event of the path.
- **Tear-down Path:** Release the path resources.
- **Cable cut:** Set the span in the failure state and schedule the repair event of the cable.
- **Cable repair:** Set the span in the non failure state.

3.5. STOCHASTIC PROCESSES

The simulation process is the sum of two stochastic families of independent processes [16]:

- **Connection Requests:** Connection requests arrive at each node in an independent way according to a Poisson process with a predefined mean interarrival time (iat). The connections holding time is exponentially distributed with a predefined mean (ht). The destination of each connection request and the decision of whether is a single or a disjoint path is defined by the mix of traffic patterns described above.

The average traffic intensity in Erlangs departing each node is therefore:

$$E=ht/iat \quad (7)$$

- *Cable cuts*: Cable cuts arrive at each span in the network in an independent way according to a Poisson process with a predefined mean time to failure (MTTF) and depending on the span distance. The mean time to repair (MTTR) is also predefined.

3.6. STATISTICAL COUNTERS

During the execution of the simulation at the end of each event, some statistical counters are compiled. The main counters are:

- *Number of Paths requests (RPn)*: This counter is incremented after the arrival of a set up path event.
- *Number of Paths created (Pn)*: This counter is incremented after the successful execution of a set up path event.
- *Number of span cuts (Cn)*: This counter is incremented after the execution of a cable cut event.
- *Number of span repairs*: This counter is incremented after the execution of a cut repair event.
- *Number of paths, P(t_i)*: The number of paths in the network at this moment.
- *Number of unavailable paths, U(t_i)*: The number of unavailable paths at this moment.

3.7. STATISTICAL MEASURES

After the execution of the simulation some statistical measures are calculated. The main measures are:

- Total Traffic (available + unavailable): Minutes of traffic.

$$Tt(n) = \int_0^{T(n)} P(t) dt \quad (8)$$

- Unavailable Traffic: Minutes of unavailable traffic.

$$Ut(n) = \int_0^{T(n)} U(t) dt \quad (9)$$

- Network availability:

$$A = 1 - \frac{Ut(n)}{Tt(n)} \quad (10)$$

- Blocking probability:

$$B = \frac{RPn - Pn}{RPn} \quad (11)$$

4. PERFORMANCE EVALUATION

The results presented hereafter are the average of 10 simulation executions. Each execution ends when both more than 200,000 events and more than 1,000 Cable Cut events have been simulated.

Figure 5 shows the network availability for the three routing strategies over the Ring Topology. The graph on the top represents the evolution with the holding time of the lightpaths for a traffic intensity of 2 Erlangs. To illustrate the two opposite effects explained above, the graph is divided into two zones.

For long holding times ($>10 \cdot \text{MTTR}$; Zone I) not taking into account failures in the network for routing (FIR strategy) results in better availability as the best disjoint path pair can be found by diverse routing algorithm.

However, for short holding times ($< 10 \cdot \text{MTTR}$; Zone II) eliminating failed resources for routing (FDR strategy) results in a much higher availability, as paths are guaranteed to be working when they are established.

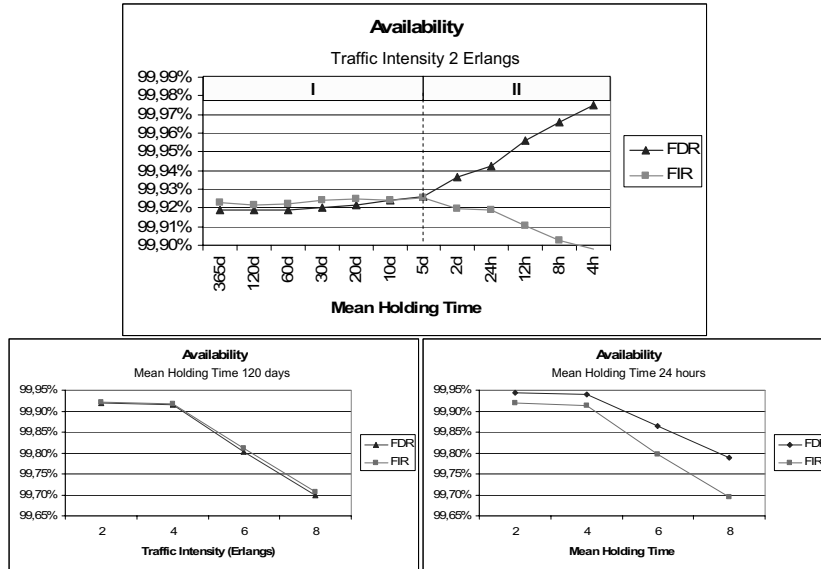


Figure 5 Availability in RT

Graphs on the bottom strengthen this. They represent the evolution with the traffic intensity for lightpaths with a mean holding time of 120 days (on the left) and 24 hours (on the right).

Figure 6 shows the network availability for both routing strategies over the highly meshed Triangular Topology. Here, the same effects can be appreciated.

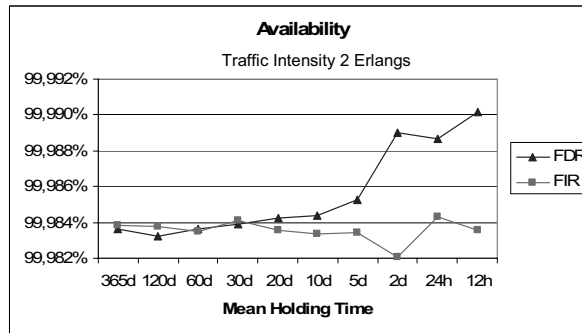


Figure 6 Availability in TT

Figure 7 shows the evolution of the blocking probability for both routing strategies over the sparse Ring Topology. The graph on the top represents the evolution with the holding time of the lightpaths for 2 Erlangs of traffic intensity.

As shown, blocking probability remains at the same level with FDR presenting a slightly higher probability over FIR strategy. This is due to the fact that FDR strategy first

looks for a route without failures and if it does not exist fails resulting in the increase observed. FIR strategy presents a 0% blocking probability as there are enough available resources in the network.

Graphs on the bottom represent the evolution with the traffic intensity for lightpaths with a mean holding time of 120 days (on the left) and 24 hours (on the right). As expected, blocking probability increases when traffic intensity increases but both strategies present equivalent figures.

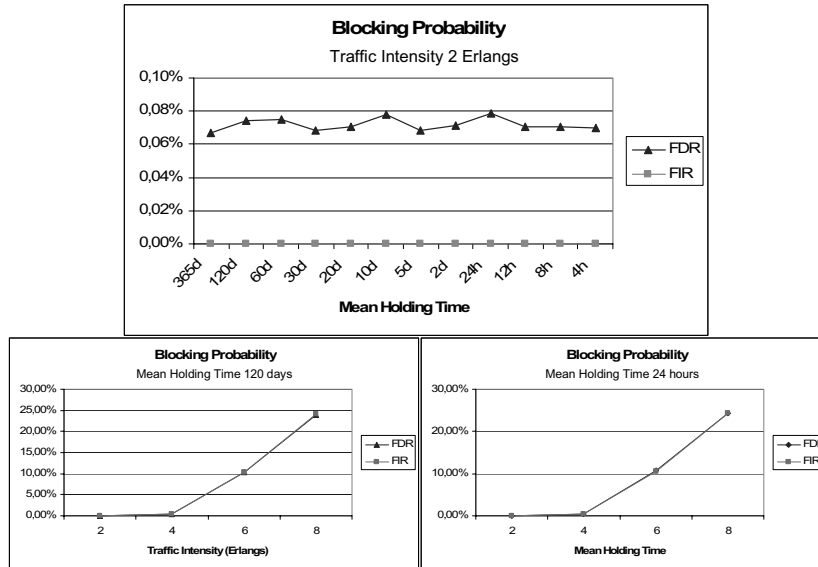


Figure 7 Blocking probability in RT

5. CONCLUSIONS

In this paper we have presented the influence of failure information over diverse routing. Two strategies have been evaluated through simulation experiments in terms of request blocking probability and availability over two different networks from a sparse one to another highly meshed.

For long holding times FIR strategy (not taking into account failures in the network for routing) provides better availability as the best disjoint path pair can be found by diverse routing algorithm. On the other hand, for short holding times using FDR strategy (eliminating failed resources for routing) results in a much higher availability, as paths are guaranteed to be working when they are established.

Regarding blocking probability, both strategies present mainly the same figures with FDR strategy presenting a slightly higher probability over FIR strategy. This is due to the fact that FDR strategy first looks for a route without failures and if it does not exist it fails.

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