GEAP: A Fault Management Scheme in Optical Networks

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One of the ways to offer QoS in optical networks, in a policy-based environment, is to use route protection policies. For each signed contract, the network administrator defines the type of protection (1:1, 1+1 or 1:n) through service classes (Gold, Silver, Bronze). However, the pre-planned backup routes can be inadequate to guarantee the SLA (Service Level Agreement). In case of failure, there is no way to guarantee that the choosen protection route will meet the client requirements. In this paper, a method for choosing the best backup route is proposed through Genetic Algorithms and PBM, called GEAP.

***Index Terms*—Optical Networks, Genetic Algorithms, Policy Based Management, Protection Fault.**

I. INTRODUCTION

WITH THE advent of optical networks of high transmission capacity, like DWDM (Dense Wavelength Division Multiplexing), several authors have been stating the lack of necessity to use mechanisms of intelligent management of the network resources and that only the transmission capacity of optical fiber, with photonic equipment, would be enough to guarantee Quality of Service (QoS). In a different way, others defend that even using this technology; there will always exist applications capable of consuming the offered resources, making necessary, therefore, the use of mechanisms of QoS. The fact is that the popularity of certain applications (e.g., Video-conference, VoIP, and IPTV) and the appearance of new services generate great demand for resources, causing overload and lowering the performance of the network.

As discussed in [13], [14] and [15], QoS is determined by the degree of the user's satisfaction in relation to a specific service, and each service has different demands (e.g., bandwidth, response time, variation of the delay, discard). In order to assure QoS at the application level, a user or company establishes an agreement on service level SLA, through a contract. In this context, the optical network is an important ally in the offering of resources; however its great transmission capacity doesn't assure the full service of these demands.

As a real example of the need for mechanisms that accomplish a SLA, we can mention the use of telemedicine applications, specifically surgery at long distance. In this situation, a surgeon can be operating on a patient using an robot equipped with a scalpel linked to the Internet. Any failures in the transmission of the commands of the robot's movement can be fatal, making it fundamental to use techniques that meet the requirements of these applications.

These requirements are inserted via SLAs, through policies, and they are guaranteed through the mechanisms of translation of those policies into SLS (Service Level Specification) and in the end, in the implementation of the mechanisms that are in a computational system and which constitute a computer network, that is always available.

One of the ways to guarantee availability is to use policies of route protection. For each contract, the network administrator determines the protection type (1:1, 1+1 or 1: n) according to service class (Gold, Silver and Bronze) [19] to be presented to the regular applications. However, pre-defined backup routes can be inadequate to satisfy the SLA contract. In case of failure, there is no guarantee that the chosen protection route will satisfactorily meet the customer's demands or even those of the application used. Therefore this choice doesn't take into account protection path quality (bit error rate and link protection type).

In this article, a method of choosing better backup is proposed through Genetic Algorithms (GAs) and PBM (Policy Based Management), denominated GEAP. The use of metaheuristics to solve this type of problem is widely used. One of the advantages is the short time required in the searching for a solution close to optimum. [1].

The remainder of this article is organized in the following way: in Section II, the related work is presented. Section III shows the initial considerations about each topic covered. The GEAP'S scheme protection, that is object of this article, is presented in Section IV. Following that, Section V shows the simulations and the results. Finally, Section VI presents the main conclusions and contributions of this work.

II. RELATED WORK

The occurrence of failures in optical networks requires solutions that are fast, not onerous and effective. Considerable work has been done on this using metaheuristics.

The use of genetic algorithms is explored in [1], which aims to improve the restoration of pre-planned backup routes.

In [7], a new traffic engineering scheme is described based on a reagent method of load balance to control traffic congestion in MPLS (Multiprotocol Label Switching) networks, using fuzzy logic techniques and learning based on genetic algorithms.

A study that unites GA and Fuzzy Logic is accomplished in [2], in which LSPs preemption policies implemented with a fuzzy controller is analyzed in MPLS/Diffserv networks.

The dynamic RWA (Routing and Wavelength Assignment) problem in WDM (Wavelength Division Multiplexing) networks with wavelength conversion is approached in [3]. A new hybrid algorithm is proposed based on the combination of mobile agents and genetic algorithms.

A genetic optimization algorithm to solve the load balance problem of the network is proposed in [5].

A construction methodology of a fuzzy controller, optimized by techniques based on GA, to configure the network provisioning starting from administration policies in order to improve QoS in a DiffServ domain is proposed in [6].

In this work, GA is used for the choice of a near optimum backup route using the BER (Bit Error Rate) and protection types for each link as parameters of route choice. In addition, PBM is used to manage the network and to differentiate the treatment, at the time of failure, for each service class.

III. Initial considerations

A. Optical Networks

Optical networks are used to satisfy the growing demand for resources in the Internet and the need to guarantee QoS in applications. In an optical environment data transmission involves several devices, such as: terminals, amplifiers and optical switches.

The optical terminals are formed by adapters of optical signals and multiplexers (OADM) with the multiplexing and demultiplexing functions. Optical amplifiers recover the signals lessened during the propagation. Optical switches (OXC Optical Crossconnect) supply the routes of the network in an automated way, to switch and/or to convert wavelengths of countless entrance ports to the exit and to make possible new routes in failure situations.

The protection routes in optical networks can be: (1) Protection 1+1, a protection route is allocated to the main route and the same information moves through each one. At the exit node, the signal with the best quality is selected and used; (2) Protection 1:1, the protection way, in conditions of non-failure of the main way, can be used to transport extra traffic. And, in case of failure, is used only for traffic of the main route; (3) Protection 1:n, similar to Protection 1:1, in non-failure conditions, the protection way can be used to transport extra traffic. The difference is that in this method, n way share the same protection.

In this work, the protection requested to supply necessary QoS for the applications is simulated through GLASS (GMPLS Lightwave Agile Switching Simulator)[9].

B. Policy Based Management (PBM)

Managing networks has become a very complex task due to the large amount of equipment involved, its heterogeneity, diversification of traffic and its demands and the need to provide QoS and security. It is no longer a task of equipment configuration, but has become a business operation, through agreements on service levels, known as SLAs (Service Level Agreements).

So, automation and configuration of the elements involved become necessary, as well as the control of the network itself in order to provide a established QoS. Therefore, a new paradigm was proposed by the IETF/DMTF (Internet Engineering Task Forces and Distributed Management Task Forces), seeking to cover those problems, called Policy-Based Network Management-PBNM) [18].

LARCES has developed in recent years as a generic platform for administration of networks based on policies (LARCES_PBM) [17]. This platform is based on the proposal of IETF. It has been exhaustedly tested and it was used in this work for the validation of the protection scheme.

C. Genetic Algorithms

This paper was used GA due to the network be dynamic. The Djikstra's algorithm, for example, don't adjust efficiently to the changes in the network. The GA have a hability to fit more fastly [20].

Genetic Algorithms (GA), proposed by John Holland in the sixties, are probabilistic algorithms that offer mechanisms of adaptive and parallel search. Although, sometimes they don't find the optimum point, they approach the optimum solution more rapidly than using conventional and exhaustive point-to-point search techniques [1].

Based on Darwin's theory of evolution that only more adaptive individuals will survive, GA begins with a population of individuals, which are chromosomes (chains of bits that represents a possible solution to the problem), randomly generated, representing the initial configurations of a problem.

Then each one is evaluated (application of the function objective) and the “best ones” are selected (those whose cost function reaches the optimum point are chosen). The probability of a chromosome being selected is proportional to its aptitude [16].

The individuals undergo crossover. So, a new chromosome is generated by exchanging the initial portion of one chromosome with the final portion of another [8].

The individuals also suffer mutation, which is used to guarantee a larger sweeping of the search space and to avoid that the algorithm genetic converges to a minimum local very early. The mutation alters the value of a gene of an individual randomly selected with a pre determined probability, called the probability of mutation, in other words several individuals of the new population can have one of their genes randomly altered, corresponding to the disturbances, in order to create a new population [4].

The process is repeated until a stop condition is satisfied. The individual with the largest aptitude is the solution for the problem.

IV. Description of Fault Management Scheme

The problem regarding the choice of the best backup route in an optical network can be hard to solve and usually requires great computational cost when trying to find an optimal solution. The fundamental idea consists of looking for good solutions to the problem, although it doesn't assure the optimum solution [1].

To say that a service has a pre-defined backup route is not a guarantee that, in case of failure, this route meets the specifications defined in the SLA. Also one cannot assert that the values of BER are appropriate for the given service class. A protected route (1+1, 1:1 or 1: n) guarantees that in case of failure the traffic will be redirected, however, the bit error rate (BER) of the protection route is not considered, reducing the QoS offered by the application. To deal with this problem it is necessary to have a mechanism to search for a near optimum backup route.

To solve this problem, this article proposes an optical network failure management scheme using GA and LARCES_PBM [17] (Figure 1).

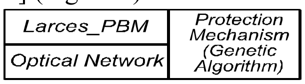

Figure 1. Proposed Architecture

This work considers protection policies for service classes, specified through LARCES_PBM, with the intention of meeting the demands of VoIP, IPTV, electronic transaction and common traffic applications. Following the proposed in [12], the necessary values were defined to relate the service class to the requested demand level, in way to meet SLAs in optical networks, see Table 1. In addition, it was taken into account the fact that optical networks require a restoration time of up to 100 milliseconds to execute a search for the best protection route before verifying data losses [13].

Service Class	Gold	Silver	Bronze	Best-Effort
BER	$<=10^{-8}$	$<=10^{-7}$	$<=10^{-6}$	$<=10^{-6}$
Service	VoIP	IPTV	E-Commerce	Common Traffic

Table 1. BER values according to protection policies.

Figure 2 shows a sequence diagram of the protection scheme. The Figure indicates the relationships among LARCES_PBM, the GLASS simulator and the calculation of the protection route.

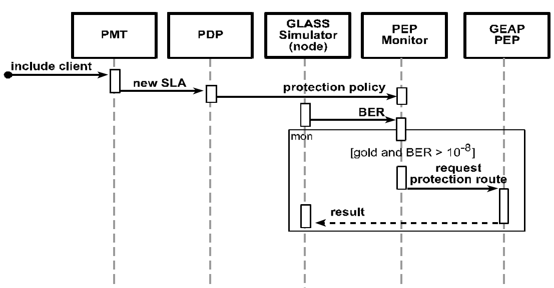

Figure 2. Sequence Diagram of the Protection Scheme

The customer and his respective service class are registered through PMT (Policy Management Tool) in the policies repository. After having established a connection among PEP (Policy Enforcement Point) and PDP (Policy Decision Point), the latter sends a decision of protection policies to the first.

Figure 3 shows the application of protection policies. The message received by PEP contains information on the customer and his service class (1). When using OSPF-TE protocol we can identify the link that the customer uses (2). This way, the monitor constantly verifies the bit error rate of the link in the device (3), in case this value doesn't meet the demands of the service class (e.g. BER>10^{-8}) of the customer (4), the monitor request the GEAP method to identify an appropriate protection route (5).

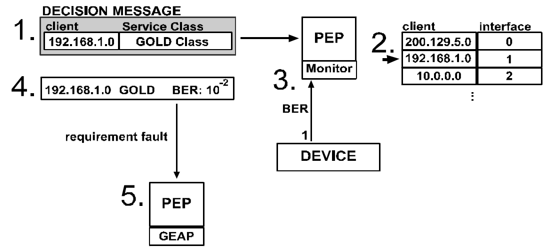

Figure 3. Example of Protection Policies

To accomplish the communication between LARCES_PBM and GLASS, a class was added to the resources library of the simulator (merlin2.jar) that works like a PEP. This class uses the communication protocol COPS-PR (Common Open Policy Service for Policy Provisioning) for exchange of messages with the external environment. There is also a function that monitors the BER value of the device (trigger) and calls for the GEAP method in case a requirement fails to be met.

Optical networks, as mentioned previously require a time of restoration of up to 100 milliseconds, to execute the search of the best protection route, before verifying losses of data [11]. The proposal has this restriction as a goal to be accomplished.

The chromosomes in GEAP are possible routes, that don´t have a fixed length, where the genes are their links. The routes need to have the same source and destination of the route that has failed. Each gene has an associated protection type and the BER value. The first generation of the population is randomly created and it is constituted of n individuals (routes), containing valid and invalid solutions.

There are several parameters (section IV.B) that influence the effectiveness of the genetic algorithm. In this paper, the fitness function performs a fundamental role in the choice of the best solutions. Therefore, it was necessary an appropriate formulation of the fitness function to solve the problem in question.

A. The Calculation of the Fitness Function

The calculation of the chromosome aptitude incorporates in the fitness function the contribution of each one of its genes. For each gene, two measures are considered: (1) the bit error rate (BER) and (2) the protection type that can be ONLY, SHARED or NEVER.

Considering the first measure, the bigger the BER value is, the smaller the contribution of the gene to the chromosome aptitude. To include the second measure in the calculation of chromosome aptitude, it is necessary to define weights that reflect how each protection type will influence aptitude.

The link with protection ONLY is exclusive; its resources cannot be shared with other customers. In this case, chromosomes that have this characteristic in some of its genes cannot be good choices. Thus this characteristic will influence negatively the aptitude of the chromosome. In the link with protection SHARED, the resources are shared with other customers, consequently the genes with this characteristic will influence positively the fitness level. Finally, in the case of links without protection, in other words, NEVER, the resources can be better used for protection of a main route, so they will have a more positive contribution in the calculation of fitness.

In this context, a route will have a very high quality, in other words, if it is constituted of links whose values of BER are low and protection values are NEVER. At the other extreme, a route will have a very low quality if the values of BER are high and the protection is ONLY. In the case of disable routes the fitness value should be zero, in other words, the chromosome doesn't have aptitude to participate in the process of peer selection, as it is an ineffective route.

1) Weight Approaches

In this approach, the value of aptitude of each gene in a chromosome is calculated in a single stage. The calculation takes into account the values of BER, the link protection described in the gene, and the values of importance, weights, of those attributes in obtaining the quality of the route. This approach considers an initial value k as fitness and at each iteration of the genetic algorithm, it increases (or decrease) this value as a function of the link attributes and the weight value. In order to penalize the large routes, the increase (or decrease) value is reduced by 80% at each iteration (constant 0.2 in Formula (1); this value proved to be the most appropriate to penalize routes with many links). The value of the penalization percentage was experimentally defined within values ranging from 20% to 80%, where the probability of picking a good route was used as evaluation criterion. Formula (1) specifies the function of fitness of a chromosome for this approach:

$$fitness = k + \sum_{i=1}^{n}((\alpha.f(ber_i) + (1-\alpha).g(prot_i)) * 0.2) \qquad (1)$$

Where $\alpha \in [0,1]$ and α is choiced to evaluate the differents results for the situations where it is given more priority to BER (α>0.5), to Protection Type (α<0.5) and no priority to both (α=0.5); k is a constant which prevents that fitness becomes negative; n represents the number of genes in the chromosome; and the functions $f(ber_i)$ and $g(prot_i)$ follow the formulas below.

Function of BER

$$f(x)\begin{cases}1, x<0\\0, x>1\\1-x, 0\le x\le 1\end{cases}$$

Function of Protection

$$g(x)\begin{cases}-0.98, x=ONLY\\0.2, x=SHARED\\0.98, x=NEVER\end{cases}$$

Therefore, depending on the value of alpha, the fitness function give greater priority, greater weight, for the value of BER or for the protection type.

B. Genetic Algorithm Configuration Parameters

One of the most important aspects of the Genetic Algorithms strategy is the correct configuration of parameters. As such parameters depend a lot on the type of problem; there is no generic methodology [6]. The availability of computational resources and execution times related to the problem also should be taken into account.

1) Population Size

With a small population, the probability of picking a solution close to a good one is smaller, since the number of individuals (possible solutions) is reduced. On the other hand, it requires less computational effort. A large population provides a higher coverage of the search space, increasing the chance of choosing an ideal solution. However, such population requires more computational efforts even for simpler problems.

Usually, a population size proportional to the number of genes in a chromosome is used [6].

2) Maximum number of Evolutions

There is no pre-defined ideal value for the maximum number of evolutions. Each problem has its own restrictions in a way that the best value should be chosen considering theses restrictions. In the GEAP method, the main problem restriction is the required time to find a good solution.

The value of 30 evolutions contributes to the resolution time be near of 100ms of restriction. Frequently, on search of a satisfactory solution, this value was efficient because it allows a reasonable occurrence of crossovers and mutations and avoids the convergence to a local optimum solution. Moreover, it allows that good solutions increase quantitatively in the course of generations, doing that a sub-optimum solution has more probability to be chosen.

3) Crossover Rate

Regarding the search performed by the GA, the crossover rate allows for the exploration of unknown areas. A low value for the crossover rate may restrict the search coverage making it difficult to find a good solution. With a very high value, new solutions with be introduced to the population more rapidly. However, solutions with high fitness values can be replaced more easily, possibly wasting good opportunities of finding an optimal solution. Furthermore, a crossover will not always generate a suitable route.

4) Mutation Rate

A low mutation rate reduces the possibility of including new chromosomes in the population, leading to a restricted search space. A very high rate practically makes the genetic algorithm search a random search. Many papers suggest the use of a value between 0.1% and 5% [6]. The 0.1% value was chosen due to the fact that, probably, a mutated element already in the population, since the original population, with 256 chromossomes, must contain this element. So, it is not necessary to have a great value to mutation rate.

In Figure 4, a hypothetical example of route mutation is shown. The original route was 1-2-6. After mutation a new was route constituted among links 1-3-7.

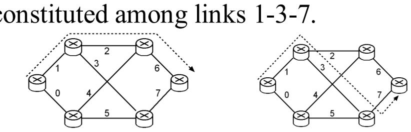

Figure 4. Mutation

5) Natural Selection Method

The Natural Selection method used was BestChromossomeSelector that selects the n best chromosomes (chromosomes with higher fitness values) to generate another population. This way, the search converges more quickly to sub-optimum solutions than using the roulette selection method.

V. SIMULATION, RESULTS AND ANALYSIS

This section presents the simulation of the proposed scheme and the obtained results. The parameters evaluated were: the quality of the chosen route to pass the traffic that needed to be rerouted, whether it is in accordance with the class of protection desired, the route length; and the time for rerouting.

In this work, the protection requested to supply necessary QoS for the applications is executed through a simulator. Among several existing simulators (e.g., MARBEN, NS, OpNet) GLASS [9] presented better adaptation to our proposal. With it, it is possible to add or to modify protocols, to simulate failure events and visualize the result of the routing. The only restriction is that the value of BER cannot be switched during the simulation, making it necessary to define a requirement break (high value of BER) before the beginning of the simulation.

A Genetic Algorithms JGAP [10] (Java Genetic Algorithms Package) was used. It supplies the basic mechanisms of the evolutionary approach and it allowed an easy adaptation of the code and modeling of the problem.

A. Topology

The tests were performed in the scenario of the United States network which is composed by 19 nodes and 31 links. Each link has the protection level specified (Only, Shared, Never) and a respective value of BER. (Figure 5).

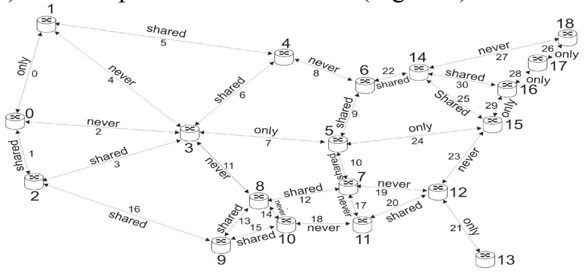

Figure 5. Topology used in the tests

In this scenario, the values of BER (10^{-8}) of the links 1 to 30 are adequate to supply service quality for applications GOLD, SILVER and BRONZE. Already the link 0 has a high value of BER (10^{-2}). In nodes (1), (2), (3), (6), (7), (9), (10), (12), (15), (16) and (18) there are PEPs, making possible the monitoring of all links in the simulated environment.

The route 0-5-8-22-27 is the route that failed. The monitor (node 1) shows that the value of BER for link 0 doesn't satisfy the customer's SLA. After detecting the requirement break the GEAP method is asked to find an appropriate protection route.

B. Results and Analyses

To obtain the experimental results, the parameters of the genetic algorithm assumed the following values: maximum number of evolutions = 30, fitness function (section IV.A), mutation rate = 0.1%, crossover rate = 50%, population size = 256 chromosomes [6] and the used coding was floating point. These values where obtained via experimentation. The analysis was performed by taking into consideration the times (<100ms) required to find good solutions. The algorithm stopping criterion takes into account the maximum number of evolutions or the average fitness of the individuals of a generation; in other words, the evolution finishes whenever the average of the fitness of the twenty best chromosomes is the same or superior to 99.95% of the value of the best individual's fitness.

With respect to stopping for average fitness, eight evolutions occurred on average before obtaining a solution and the necessary time was within a range from 3 to 81ms. When the stop criterion was equal to thirty evolutions, the time necessary to reach a solution was in a range of 63 and 141ms. This is not a good time for optical networks because some of them exceed 100ms and could lose a lot of data.

Figure 6 highlights the results of the Weight Approach. The values of α were changed (0.01-0.99) and three different routes were evaluated. For each α value it was realized 100 experiments. The route 0-4-11-14-18-17-19-23 has the worst fitness, the route 2-3-16-13-14-18-17-19-23-25-27 has an average value of fitness and the route 2-11-14-18-17-19-23-25-27 has the best fitness value. The Graph represents the percentage of route choices as a function of α. The peaks, both in ascent as in slope, are due to the different combinations of results of the GA. For example, sometimes the GA selects a bad initial population and have to improve this population over the generations. It´s possible to have a bad population in the last generation and this could decrease the percentage for choosing the best route.

Figures 7 to 9 were obtained using other values of α (0.1, 0.5 and 0.9) and the two stop criteria. In such figures, for each generation of a determined alpha value it were realized 1000 tests and shown the fitness average of the 1000 tests.

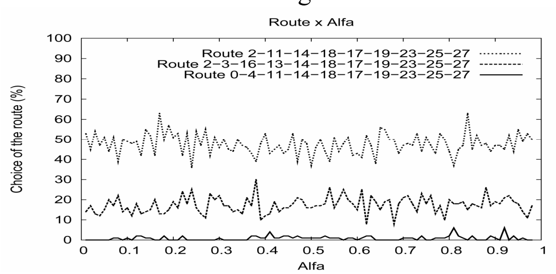

Figure 6. Percentage of choice of the route as a function *alpha* (0.01-0.99)

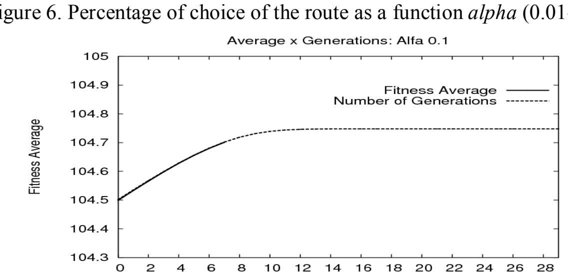

Figure 7. Average Fitness x Number of Generations (alpha 0.1)

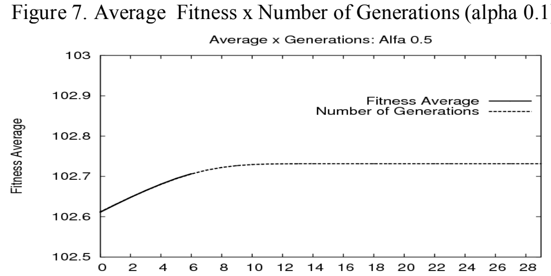

Figure 8. Average Fitness x Number of Generations (*alpha* 0.5)

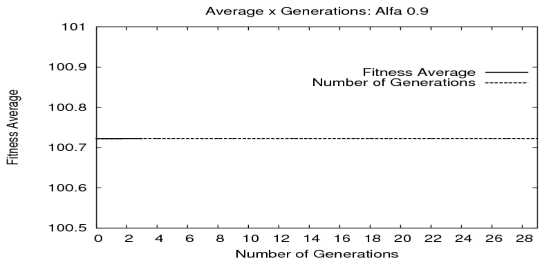

Figure 9. Average Fitness x Number of Generations (alpha 0.9)

As the time limits for rerouting traffic in optical networks is 100ms [11], the most appropriate stopping criterion is the average Fitness values of the individuals' of a generation. Such criterion indicates that in a generation several viable individuals exist and therefore increases the probability of an optimum route or a near optimum route being chosen. The result was quite adequate having a maximum time for problem resolution of 81ms.

With a low value of α, the type of protection is more important and routes with high values of BER have greater probability of being chosen. With a slightly higher value of alpha more importance is given to the value of BER and there is greater probability that routes with ONLY or SHARED links will be chosen.

Figures 6 to 9 show that when more importance is given to the type of protection, the average population fitness varies substantially, due to the different types of connection protection present in the topology. The higher the values of BER, more homogeneous are the average values of population fitness because the values of BER in the topology are very similar.

VI. Conclusion

This article describes a scheme of fault protection (GEAP) in optical networks through the use of genetic algorithms. Protection in these networks is a complex problem that has required attention, due to insufficient resources for the creation of protection routes. Therefore, this paper proposes a scheme based on a genetic algorithm in a way that allows protection to be requested only when the network is in a state of imminent failure to meet QoS requirements in accordance with SLAs.

GEAP provides stopping criterion based on a minimum value of the average fitness of the individuals in a generation, this allows for a quick solution that satisfies or almost satisfies the SLA and accomplishes autonomous management of the network.

Proposed solutions involving pre-selected backup routes for specific traffic can have very high BER values and fail to fulfill SLA requirements. This is avoided in our proposal.

VII. Future activities

As future activities for this work, it is intended to test other meta-heuristics for the solution of this problem. To use other optical network parameters for characterizing a connection using a Fuzzy and Genetic Algorithm approach for reducing the aptitude of the chromosome. Furthermore, it is intended to develop a class of events to simulate, within GLASS, variations in real time of the BER value.

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