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All-Optical Network Shared paths Protection Enhancement Using Integer Linear Programming (ILP).

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ABSTRACT

In optical network, WDM functions as the optical layer which the lightpath is the entity to be protectedso that the optical channel protection is also maintained. In case of failure, each single interrupted lightpath is switched on its protection path. Recovery operations are activated by the Och apparatus hosted in the end-nodes (source and destination) of the light path. The system also has the duty of monitoring light path for failure detection. The protected entity is called working lightpath while after the failure, the optical circuit is switched over a protection lightpath. The lightpath is pre-allocated or dynamically established. The OMS apparatus in the termination of the fibers that compose a single link locally manages fault-detection and protection switching. Protection mechanisms react to a failure by diverting the interrupted WDM multiplex to an alternative path; thus by passing the damaged components. The main difference from path protection is that all the lightpaths travelling along a broken fiber are simultaneously re-routed together. The optical cables composing a typical WDM transmission link are usually bi-directional, that is to say that the cable contains a set of fiber pairs, one fiber per each propagation direction. In two fiber OMS system, instead in each fiber of a couple of fibers in one direction, half of the WDM channels carry the working traffic, while the other half are used as spare resource to protect some other link. On the fiber of the pair of the opposite direction, the role of each wavelength is inverted if it was a working wavelength in the other fiber now has turned into a protection wavelength and varse-versa.When a failure occurs, the network activates a new connection to restore the faulty one. This increases the general flexibility of the network system which improves resource utilizations potentially for working traffic.
Keywords; WDM, Lightpath, Protection, Transmission, Enhancement.

INTRODUCTION

The wavelength division multiplexing (WDM) technology is widely used to cope with the ever rapidly increasing bandwidth demands [1]. This is because the survivability of the optical connections or switching has grown into an issue of greatest importance for wavelength division multiplexing network especially in the area of all-optical (O-O-O) networks.Modern optical networks are complex systems designed according to a layered approach. Several protocols can be stacked one over the other in various combinations [2]. It has become a universally accepted concept that the WDM optical layer must behave as a common platform able to carry all the possible protocol combinations. It is standardized as circuit-switching oriented multiprotocol transport level. This refers to its ability of transparently supporting many different upper layers protocol stacks, making its main task as high connectivity and bandwidth provisioning to electronic layers in a client/server relationship [3].

The provisioning service offered by the WDM consists of setting up optical point-to-point circuits or lightpath in order to fulfill requests of a point-to-point connection issued by the upper layers. A lightpath is set up by reserving to the virtual connection a sequence of WDM channels linking the source to the destination node throughout the optical network. Each lightpath carries a high bit-rate digital stream. It is added and dropped by electronic optical devices interfacing the WDM layer to the higher electronic layers which is transparently switched by each WDM switching devicecrossing along its path [4]. WDM switching is performed either by optical add-drop multiplexes (OADM) or by optical cross-connects (OXC) according to the network type which ring or mesh is under considerations in this work.

DISCUSSION/OPTICAL LAYER PROTECTION

However, in optical network, WDM functions as the optical layer which the lightpath is the entity to be protectedso that the optical channel protection is also the path protection [5]. In case of failure, each single interrupted lightpath is switched on its protection path. Recovery operations are activated by the Och apparatus hosted in the end-nodes (source and destination) of the light path. These systems also have the duty of monitoring light path for failure detection. The protected entity is called working lightpath while after the failure, the optical circuit is switched over a protection lightpath [6]. The lightpath is pre-allocated or dynamically established. OMS in WDM is called link protection. The OMS apparatus in the termination of the fibers that compose a single link locally manages fault-detection and protection switching. Protection mechanisms react to a failure by diverting the interrupted WDM multiplex to an alternative path; thus by passing the damaged components [7]. The main difference from path protection is that all the lightpaths travelling along a broken fiber are simultaneously re-routed together. Link protection is commonly implemented, adopting one of two alternative nodes four-fiber and two fiber model. The choicebetween the two implementation is strictly dependent on the physical design of the network.

The optical cables composing a typical WDM transmission link are usually bi-directional, that is to say that the cable contains a set of fiber pairs, one fiber per each propagation direction. In a link protected by a bi-directional transmission of the working traffic, a second pair is reserved for backup traffic of some other link in case of failure [8]. In two fiber OMS system,a couple of fibers in one direction is half of the WDM channels carry the working traffic, while the other half is used as spare resource to protect some other links. On the fiber of the pair of the opposite direction, the role of each wavelength is inverted if it was a working wavelength in the other fiber but has now turned into a protection wavelength and varse-versa. Provisioning also exists in a situation where there is an alternativepreplanning which is also called restoration [9]. The network is planned with an amount of resources that exceeds the real working traffic requirements and no spare capacity is reallocated.

When a failure occurs, the network activates a new connection to restore the faulty ones. This increases the general flexibility of the network system which improves resource utilizations potentially for working traffic. The layout technique is shown diagramatically in the figure below.

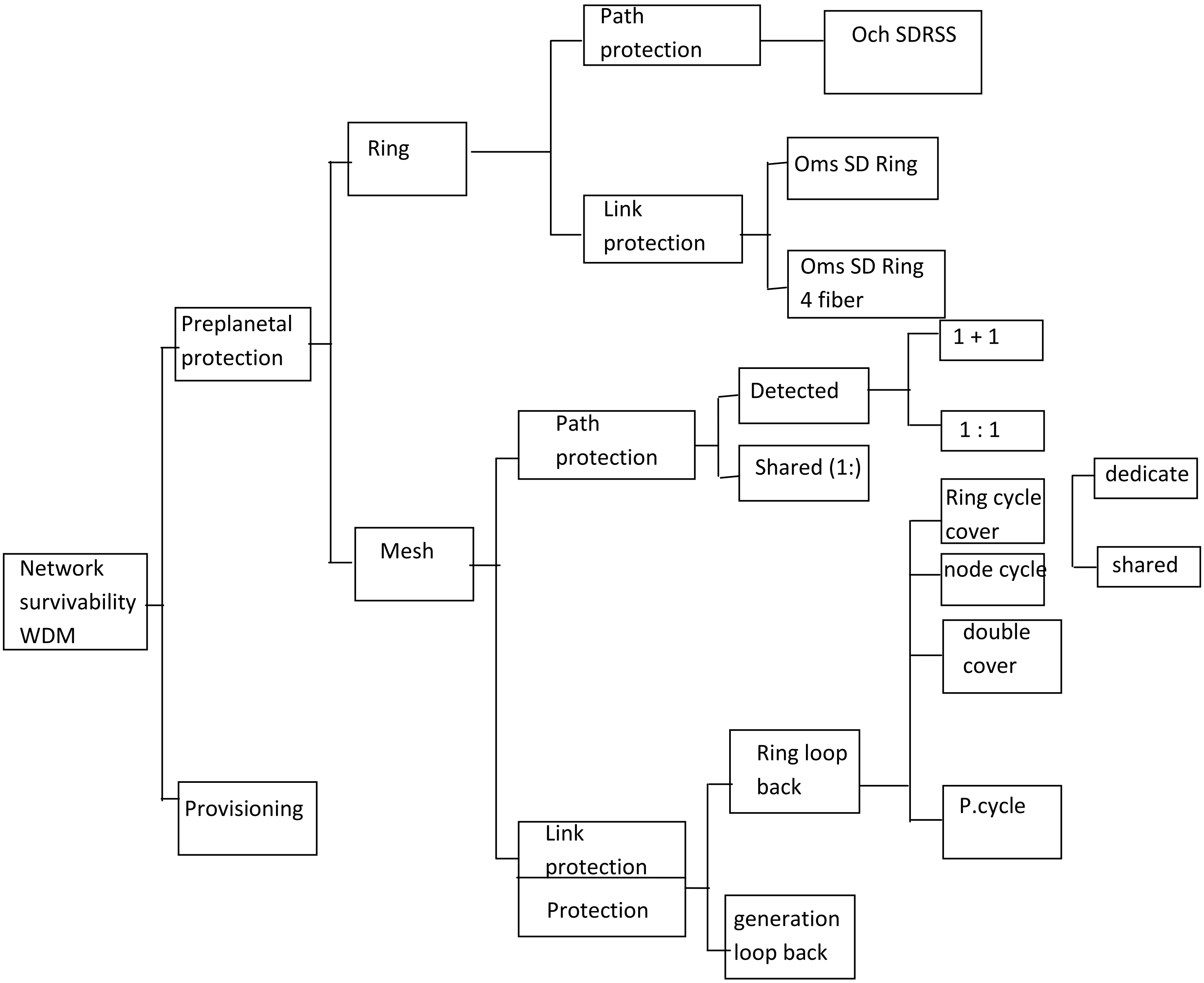


Fig 1: Scheme of protection Technique in WDM layer

WDM Ring Network Protection
For path protection, the OCh dedicated protection ring (OCh-DPRing) scheme in figure beloow, it is applied to rings that use two fibers to propagate the signals in opposite directions. Path protection is designed using both the fibers to establish two counter-propagating lightpaths around the ring [10]. The source node splits the signal in two identity, transmitting them simultaneously on the two different lightpaths. The receiver node selects the signal with the best quality. This scheme is defined as 1+1 dedicated protection (protection switching) and the architecture isknown as WDM self-healing ring.

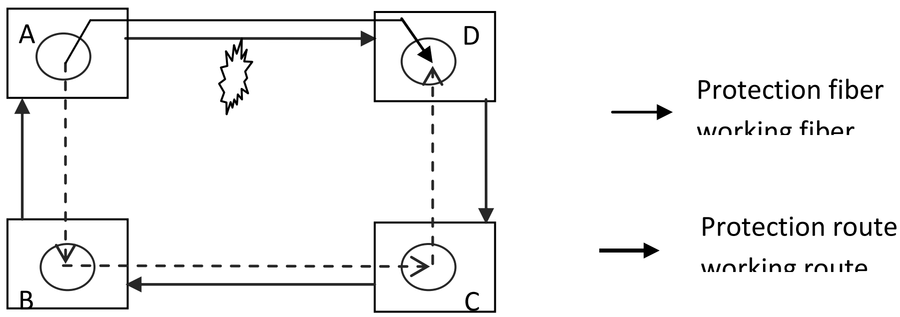
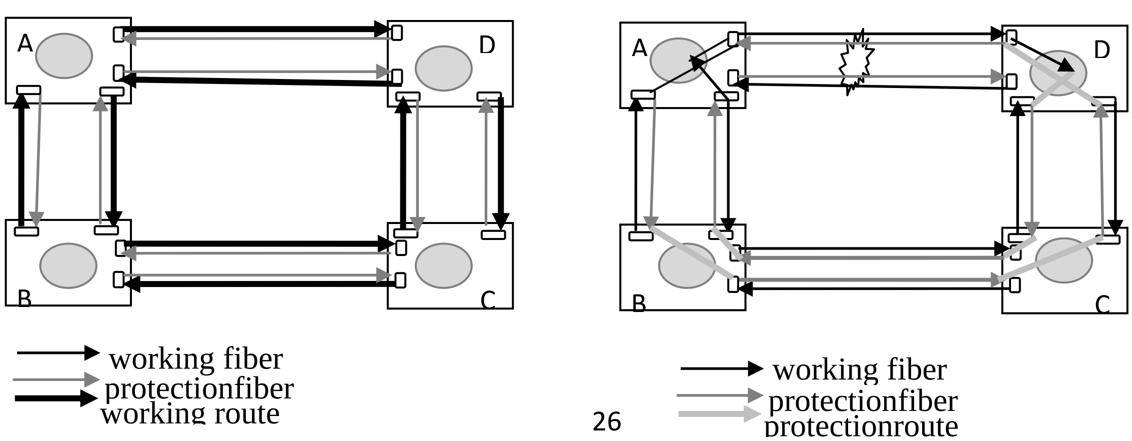


Fig 2: *OCh dedicated protection ring (OCh-DPRing): 1+1 protection of the lightpath.*

In case of failure no optical switching device has to be reconfigured, only the electronic receiver has to make the best choice. No signaling is necessary. Recovery time is then very fast and protection requires exactly 50% of the installed physical resources.

In the figre below, the OMS sublayer has two schemes of link protectionstandardized which are called shared protection ring (OMS-SPRing) for twoand four-fiber ring topology. In bothcases, protection switching is carried out by 2 × 2 optical switches with large optical bandwidth, able to switch the multiplex of WDM signals from one fiber to another. Switching occurs very fast, in the range of microseconds in case of opto-mechanical technology [11]. These devices (two and four in the two-and four-fiber schemesrespectively) are usually hosted into the optical add-drop multiplexers (OADM). In case of link failure, the two OADMs adjacent to the failed link, recover the connectivity by closing the ring (loopback operation) and rerouting the traffic on the fibers or the wavelengths reserved for protection of OMS-SPRings which able to react also to a node failure.

In such case the 2 × 2 optical switches inside the failed node itself operate the loopback. Reverting (normally preferred) or non-reverting implementations are possible, according on the fact that the system returns to its original state after the failure has been recovered. Protection needs again the 50% of the physical resources, in this case sharing does not give an actual advantage over the DPRing in terms of resources utilization. Signaling between the two terminations of the faulty link is required to coordinate the loopback operation [12].



(a) (b)

Fig 3: OMS shared protection ring (OMS-SPRing), four-fiber implention, the ring is represented in working conditions (a) and after a loopback (b) due to failure on link AD.

WDM Mesh Network Protection

WDM mesh networks had assumed more importance, due to the improving developmentof the OXC and the optical switching device in the mesh architectures where survivability is a more complex problem than in a ring topology because of the greater number of routing and design decisions that has to be taken care of. Besides, no WDM mesh protection mechanism has been commercially deployed on a large scale yet, and therefore all the techniques that we are going to discus in this section are equally likely to become the best choice in the near future.Path protection at OCh layer is obviously well applicable to mesh networks [13]. To satisfy each connection request, a pair composed of a working and a protecting lightpathhas to be established in the figure beloow.

For the protection mechanism to be effective against link failures, the links of the working and protecting-

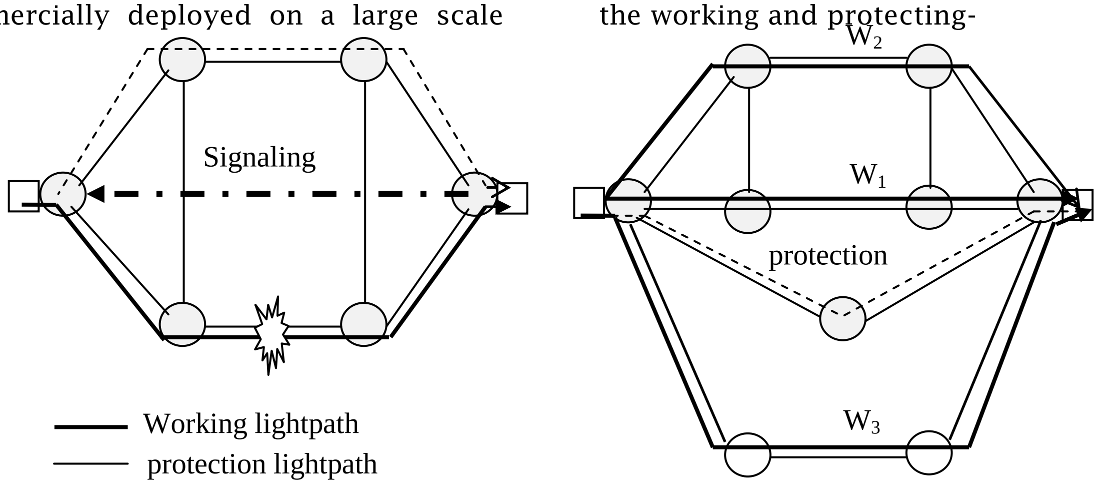


Fig 3: *Path protection in a mesh (a) 1:1 dedicated and protection, (b) 1:3 shared in protection*

lightpath must be independent in the sense of failure occurrence. In many cases, this condition is satisfied by setting up the two lightpaths in physical-route diversity, the primary and backup paths cannot share any link disjoint). If protection against node faults is also required, node independence between working and protection paths is also necessary [14]. Again, in most cases this is guaranteed by preventing sharing of a node by the two lightpaths: routing must be performed under the node-disjiont constraint. Both the 1+1 dedicated path protection and 1:1 dedicated pathprotection path are possible. In the second casecalled protection transferring,low priority traffic can be transmitted on the protection lightpath in absence of failure, but end-to-end signaling becomes necessary [15]. Dedicated path protection is quite resource-consuming in mesh network because of the physical route diversity constraint. Sharing of WDM channels among protection paths may reduce the physical resources employed for protection. Shared protection may be applied in an end-to-end sense using a single protection lightpath for**"n"** working lightpaths with the same source-destination node pair. This technique is a special case of sharing in which**"n"** protection lightpaths share all their WDM channels, and is also known as **"1:n"** protection. Obviously **"1:n"**protection requires that **"1+n"**link-disjoint or node-disjoint paths are available between the source and the destination nodes of the connection.

Shared path protection can also be implemented in a wider sense on a mesh network by allowing partial sharing among the protection lightpaths. In this case the additional constraint is dealt with and protection lightpaths sharing WDM channels must be associated with working lightpaths that are mutually link disjointor node disjoint [16]. It is important to notice that sharing allows savings in terms of transmission resources, but it also requires a more complicated management.

In 1:1 and1: nprotection, when a failure occurs, only the end-nodes are involved in the recovery process because the protection lightpaths are completely set up in advance.

When shared-path protection is adopted in the wide sense in a mesh network, the fault event activates a more complex recovery procedure that requires a lot of signaling among several network elements. It is, in fact, necessary to reconfigure all the OXCs that are terminations of shared WDM channels, see the Figure below according to which particular working lightpath needs to be recovered [17]. This inevitably increases the recovery delay, which will be limited by the time taken by the signaling messages to reach all the involved elements and the time taken to reconfigure all the OXCs. Since shared protection is still preplanned, the recovery operation could be controlled in a distributed rather than in a centralized way, thus eliminating the

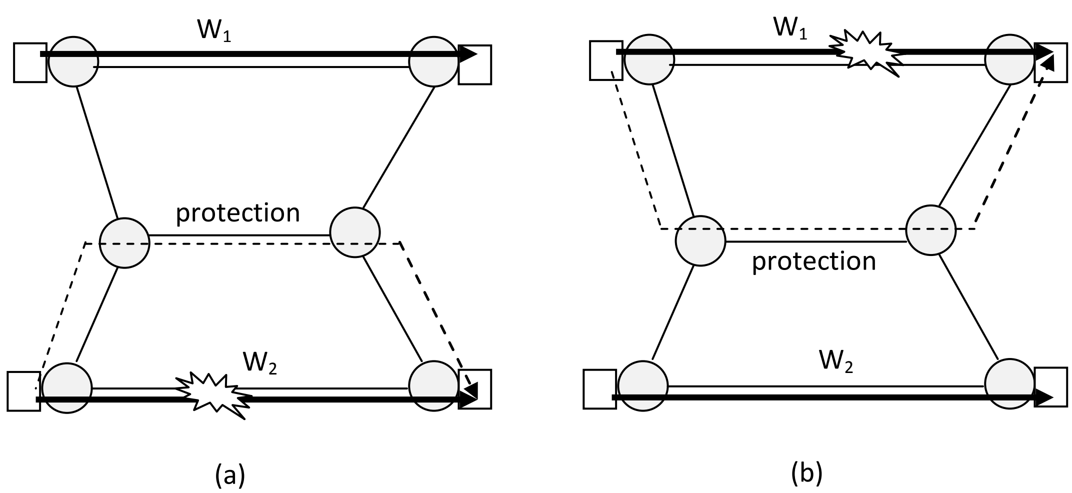


Fig 4: Shared path protection Lightpath.

intervention of the network management system and reducing the amount of signaling. In this case, the OXCs must be able to autonomously identify the faulty working lightpath in order to switch accordingly [18]. The first operation requires real-time detection of the lightpath identity and it is one of the main motivations that fostered the definition of an OCh identifier in the framework of the standardizationof the OCh supervisory channel.

RESULT ANALYSIS

The Optical network problems that have been under considerions are variants of the multifailure commodity flow problems. Having addressed some f them, they are being considered as the optical network design problems in the mathematical formulation through the use of ILP programming [19].

This is because the ILP programmings can act as useful benchmarks for optimizing network design matheuristically because they can be passed directly to ILP optimizers. The optimizers used here are

GAMS and CPLEX; GAMS is a preprocessor which takes the formulation or data entered, recast them in a shape that the CPLEX machine can handle and performs some simple pre-optimizations, before passing to another CPLEX which is the real optimization tool to produce results.There are two major ways to express multiflow failure problems in the ILP programmings which are;

1. Arc-flow formulation
2. Link-path formulation

The major difference is that in the arc-flow formulation, it is up to the optimizer to design the paths that will supply demands whereas in the link-path formulation one must precompute some paths for each demand, the optimizer only selects from the precomputed paths [20]. However, the arc-flow formulation was adopted because its easy, less cost and gives optimal result values like the later if only all possible paths are given as inputs.

Arc-flow formulation

In the arc-flow the network is considered as a set of N nodes, and at each node some wavelengths are released either from neighbouring nodes or from traffic source located in the node. The exact same amount that entered must leave the node and the seneario is known as conservation principle.

The flows are then indxed by the demands they supply and the wavelengths they use. The traffic flows along directed edges which the directed edges from node **n** to node **m** is carried together with the edge from node **m** to node **n** in a link {**n, m**}.

This implies that it is not possible to have more than one link between two nodes in the arc-flow. The optimization procedures for the arc-flow formulation is shown below schematically [21].

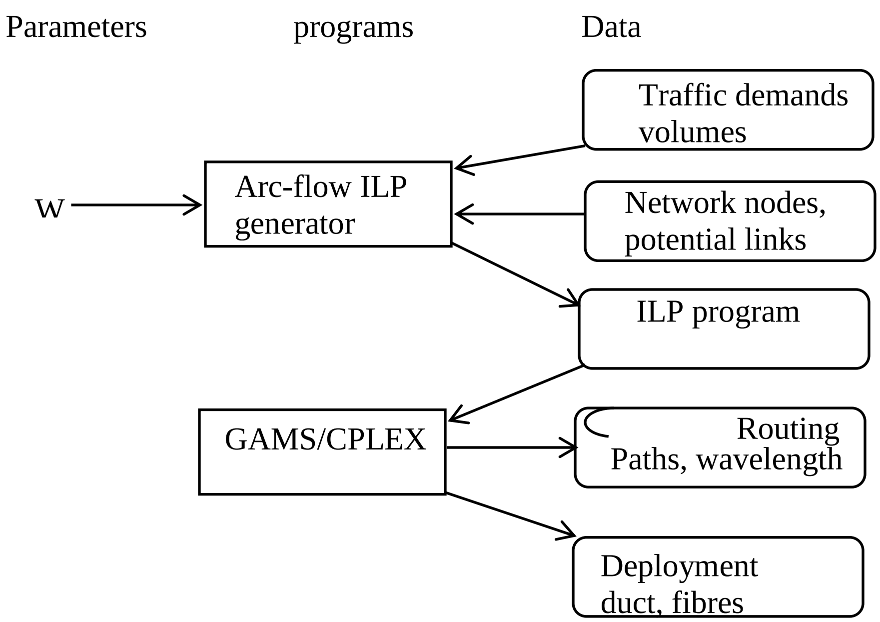


Fig 5: Optimizing WDM network using the arc-flow based ILP.

A simple generator produces the ILP program based on the traffic and network data then passes it to the GAMS/CPLEX optimizer which produces result.

In this work, the arc-flow formulation method is used to protect network from failure using both the TRP and PDP network protection model (i.e: using it to design network protection in both model). The results were compared.

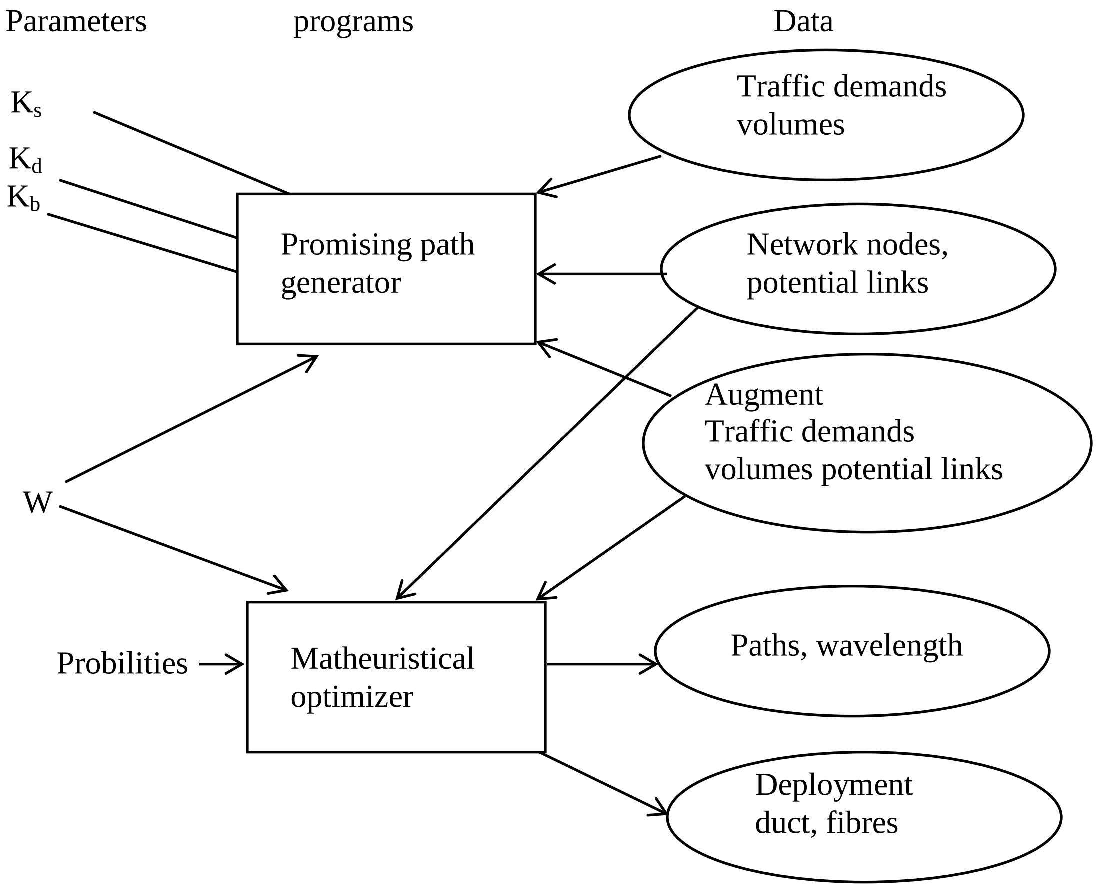


Fig 7: Optimizing WDM network matheuristically (SAN + SAL Approach).

The ILP programmings serve as formal approach of the network design problems which can be used directly as input to ILP optimizer, but there are some other variants of the multicommodity flow problem [22]. The heuristical approach which is more viable presents the two instances of matheuristics that perform optimization by stochastic algorithms; ***Simulated annealing** and **simulated allocation***. The overal structure is shown in figure above.

Networks are assumed to be in a set of states {0...... S} in which each set of a state, there is a failed edge unless otherwise stated. Each state S corresponds to one edge failure [23]. Though the state formulation is a general approach that allows modelling node failures by letting all edges incident with a node failure in state S be in ∊. But conventionally, S = 0 is considered to be in the normal state where there are no failures, that is, $\epsilon_o = \{\ \}$.

In all the network design problems, they share the following indexes, constants, basic variables and objective functions; but there are different constants peculiar to each of them.

Indexes:

d ∈ {1…….D}	Traffic demands
S ∈ {0…….S}	Network states
C ∈ {1…….w}	wavelengths
M, n∈ {1…….N}	Network nodes
(nm) $\epsilon\ \varepsilon \leq$ {1…….N}[2]	Directed edges
(nm) ∈ ε_s < E	Directed edges affected in state S
{n, m} ∈ L ≤ p{1…….N}	undirected links

Constants.

$V_d^s\ \epsilon\ N_0$	$Volume\ of\ lightpaths\ to\ be\ realized\ for\ demand\ d\ in\ state\ S$
$n_d^{src}\ \epsilon\ \{1 \dots \dots N\}$	$Indix\ of\ the\ source\ node\ for\ demand\ d$
$n_d^{dst}\ \ \epsilon\ \{\ 1 \dots \dots .\ N\}$	$Index\ of\ the\ destination\ node\ for\ demand\ d$
$C_{\{n,m\}}^{duct} \epsilon\ R_+$	$Cost\ of\ designing\ the\ duct\ on\ link\ \{n,m\}$
$C_{\{n,m\}}^{fibre}\ \epsilon\ R_+$	$Cost\ of\ deploying\ a\ fibre\ pair\ on\ link\ \{n,m\}$

Basic variables:

U{n, m} ϵR_+ Number of required fibre pairs on link {n, m}

α {n, m} ϵ {0, 1} Number of required ducts on link {n, m}

R_1 stands for a set of real numbers that help to speed up the ILP optimizers.

Total Re-routing Protection Network Design (TRP)

Having introduced the general or conventional procedures of the arc-flow formulation method, it is now being used to enhance optical network designed in TRP model. The design problem is done by extending the nominal design problem to include the network multifailure states [24]. Ordinarily, if the source or destination node of the demand d fails in state S, it cannot in any way supply the demand in which case the network is set as V_d^s = 0. There are bound to be some other reasons why a network operator may set $V_d^s \neq V_d^o$.Despite the general parameters and data of the arc-flow formulation, there are still some additional variables and constriants applicable to any particlar or model used in ensuring protection of the network. Such variables and constraints are as in TRP.

Additional Vatiables:

$X_{d(nm)}^{cs}\ \epsilon\ \ N_O$ $\quad flow\ of\ demand\ d\ on\ wavelength\ c\ along\ edge\ (nm) in\ state\ S$

$V_d^{cs}\ \epsilon\ \ R_+$ $\quad Volume\ of\ demand\ d\ carried\ on\ primary\ wavelength\ C\ in\ state\ S$

Constriants:

$\sum_c V_d^{cs}\ \ \geq\ V_d^s$ The total volume of demand d in each state must be supplied by lightpaths of various wavelengths.

σ {n, m} = 0 ⟹ $U_{\{n,m\}} = 0,$ without a duct there can be no fibres on link (n, m).

There is also the constraints of flow conservation for paths, what goes into node **n** on wavelength C in state S must come out again. There must also be right calculation of required number of fibres in any states S on any wavelength C.

Path Diversity Protection Network Design (PDP).

In the PDP design problem, X_{dm}^{cs} is used to keep track of the flow in every state S, and find the required capacity t_{dnm}^{c} as the maximum of the X_{dnm}^{cs} over all the states.

Its variables and constraints are the same with that of the TRP except that;

Variables

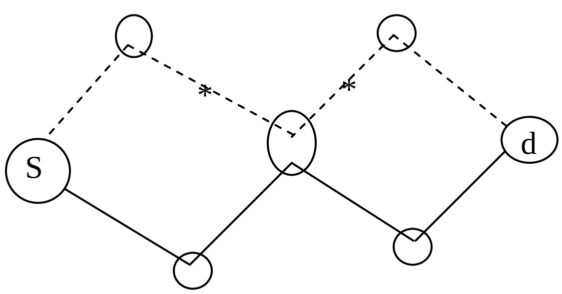
$t^{c}_{dnm} \in R_{+}$ Required capacity for demand d on wavelength C along edge (nm).

constraints

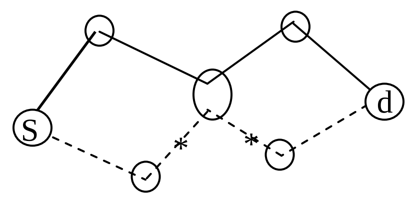
$X^{cs}_{dnm} \leq t^{c}_{dnm}$ calculating the required capacity for demand d on wavelength C along edge (n m).

Handling Multiple Link Failures Protection Using SHR

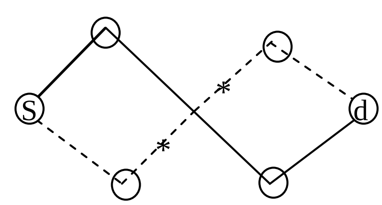
The formulations so far given are capable enough to handle multiple link/path failures, if it is all possibly set. This means that any given set of failed link ε_s, if the network connectivity is strong enough will handle itself to recover failed link/path within a reasonable short time frame if the ILP programs presented will be able to find a solution. Considering the network below, with just one demand from S to d, and three failure states such as; (1) one where two upper links fail, (2) one where two lower links fail, and (3) one where an upper andlower link fail alternatively. So both TRP and PDP are able to fix all situation in each case using the backup paths.



(a) Tow upper liknks failure



(b) Tow lower liknk failure



(c) An upp and lower liknk failure

Multiple link failures

This x- rays the characteristics of self-healing ring, shown and explanined diagramatically.It is called SONET SHR which is very useful technique for survivability of optical networks. Here networks are designed to have ring architecture [25]. SHR is more useful than other protection technique like APS (antomatic protection switching) because of its flexibility in handling both link and node failures. It uses add/drop multiplexing (ADM) techniques.

Unidirectional SHR (USHR) and bi-drectional (BSHR) are two types of SHRs. The difference between them is the direction of the traffic flow under normal condition. In USHR, the normal traffic flow goes around the ring in one direction as shown in the figure above(a-b). Any traffic routed to the protection ring because a failure is carried in the opposite direction [26]. But in BSHR, working traffic flows in both directions.However, a bidirectional logical-ring network employs OXC nodes which partitions the network into segments and then interconnects other segments at subchannel level to form logical ring structures [27] [28]. Every segment is independent, which includes a subset of (ADMs) nodes and two pairs of links, one working and the other for protection. The formation of the logical rings from the interconnection of independent segment subchannels preserves the self-healing advantages of conventional bidirectional ring networks and allows greater flexibility to effeciently accommodate bandwidth upgrate request and more robust traffic flow.

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