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Optic-Fibre Network Optimization

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ABSTRACT

In any good network, there should not for any cause be a noticeable downtime despite the numerous problems generally associated with telecommunication or optical networks. The network from the beginining needs proper and adequate planning which should include protective and restoration measures. This becomes necessary to first design a network plan, that is to precalculate or to see that failures do not take place indiscriminately. This means that any failure that occurs will automatically find a free alternative route without the notice of either the network operator or the end consumers. Since failures are bound to happen, it will only be automatically reflected on the system panel of the control room to show that there was a self healing implementation from the occured failure.

Keywords: Network, optimization, downtme, healing, implementation.

INTRDUCTION

For efficiency and durability of network services, there should not for any cause be a noticeable downtime despite the numerous problems generally associated with the networks. The network from the beginining needs proper and adequate planning which should include protective and restoration measures. This becomes necessary to first design a network plan, that is to precalculate or to see that failures do not take place indiscriminately [1]. This means that any failure that occurs will automatically find a free alternative route without the notice of either the network operator or the end consumers. Since failures are bound to happen, it will only be automatically reflected on the system panel of the control room to show that there was a self healing implementation from the occured failures [2].

Due to these, this work planned a greenfield events of perfect network where a telecommunication operator, has to determine where to locate or site some WDM network nodes [3]. The desire was on how to interconnect the nodes with links at least cost but with continous services assured even in the face of multilink or node failures. It was to forestall any architectural restrictions, and impositions against service demands. Hence, here is a well planned mesh network where every node is connected with an OXC without wavelength converters but still satisfy wavelength continuity constraints thereby optimizing the whole network system optically. The aims and objectives was to be actualized using matheuristic algorithm method called REACTIVE SEARCH OPTIMIZATION (RSO) [4]. It sequentially defined the network components and optimization tasks by methodically describing the algorithm for getting a set of “promising path” that can help to cut down the greenfield network cost by reducing both fibre and duct usage. The network linkpaths will subsequently be used for network optimization using integer linear programming (ILP) and two of the explain tools of the algorithm method known as simulated annealing (SAN) and Simulated allocation (SAL). The ILP program functions in two folds; Arc-flow and link-path formulations, both to produce optimal results based on the qualities of promising path sets [5].

The main features of the optimization tasks being used here are to see that duct costs, nodes and linkcosts are included and that wavelength assignment is integrated with path optimization and with duct and link placement [6].

The promising path generator (PPG) and the SAN + SAL (matheuristics) algorithm are the working tools here. Having mentioned earlier, this work used the RSO method to empirically evaluate the (PPG) algorithm by comparing its results with the best final results obtained from ILP programs using other networks as examples [7]. Finally, few graphs demonstrated that matheuristics comformed with their final solutions within a reasonably shorttime which draw a conclusion or verified the topic and objectives of this work.

WDM Network Planning of Greenfield Characteristics

There are many network design scenarios, characterised by what normal network parameters are known for, such as node positions, duct and link placements and also what parameters and to which extent they can be extended; (for example link equipment as in fibre). However, if the node positions are unknown, it is a greenfield network design scenario in which the operator must decide where to place the nodes based on the aim of where the end-users are densely located [8]. So here, the network is planned to always know the node locations and that some new volume of traffic demands are given which must be satisfied.

The network design plan is characterized as follows, where "+" sign means that the links or the nodes are extentable while the "-" sign means not extentable.

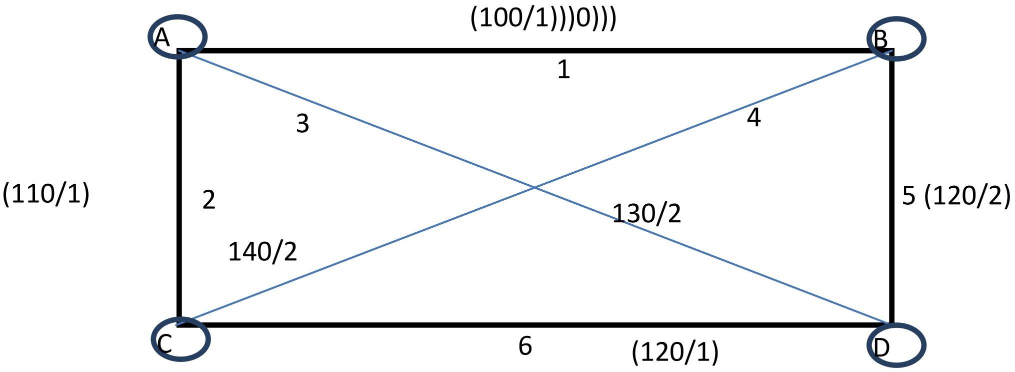
Classification of network design planning scenario.

Nodes		Links				Traffic	
Equipment deployed	New equip. Allowed	Ducts exist	New ducts allowed	Fibre deployed	New fibre allowed	Existing routes	Network design problem Types
-	+	-	+	-	+	-	(Node restricted) Greenfield
-	+	+	-	-	+	-	(Duct restricted) greenfield
+	-	+	-	+	-	-	Totally capacitated Routing
+	-	+	-	+	-	+	Totally capacitated Routing Extension
+	-	+	-	+	+	-	Node cap routing ext. & link deployment ext.
+	-	+	-	+	+	+	Node cap routing ext. & link deployment ext.
+	+	+	-	+	-	-	(link) capacitated routing
+	+	+	-	+	-	+	Link capacitated routing Extension
+	+	+	-	+	+	-	Duct resticted routing and Deploymentextension
+	+	+	-	+	+	+	duct restricted routing ext. and deployment extension
+	+	+	+	+	+	-	Routing and deployment Extension
+	+	+	+	+	+	+	(General) extension

The Plan shows that the most common scenarios are the greenfield, the duct restricted and the extension network design. Hence forth, the nodes and some traffic demands are considered with the goal to design their placement and capacities of the links [9].

Optimizing the Network for Link Costs

Every link comprises of one duct containing a number of fibre pairs which each carries M wavelengths in each direction. There is also a potential links which is a set of L as of yet non-existing links from which the actual network links must be chosen during the design process [10]. Below is an example of network with given nodes and potential links and traffic demand matrix with the fibre ducts.



WDM network planned on 6 links with a traffic demand matrix box containing 3 demand volume.

Decision box for the traffc matrix demand box.

L	Between	C_1^{duct}	C_1^{fibre}
1	A-B	100	1
2	A-C	110	1
3	A-D	130	2
4	B-C	140	2
5	B-D	120	2
6	C-D	120	1

	A	B	C	D
A	0	7	0	0
B	0	0	0	6
C	0	0	0	5
D	0	0	0	0

Each of the links is numbered and labelled with (duct/fibre) cost. The cost model used here is the cost of link L is $C_1^{link} = C_1^{duct} + F_1 C_1^{fibre}$, where; F_1, is the number of fibres deployed on link L. The cost of the whole network is the sum of all the link costs. This shows that the cost of nodes can be moddled.

Traffic Demand: The traffic is static and it is given as a set of D. Demand number d consist of a source node “n_d^{sc}” and a destination node “n_d^{dst}”.Each demand d has a traffic volume V_d, measured in numbers of wavelengths. For ease of simplicity, it is assumed that there is no set of any hop limit or length limit on the path which supplies demands [11].

Nodes: It is assumed that the OXCs in the nodes have unbounded switching capacities but no node is capable of wavelength conversion so the wavelength continuity constraint must be satisfied and gives the advantages of wavelength re-use in the network [12].

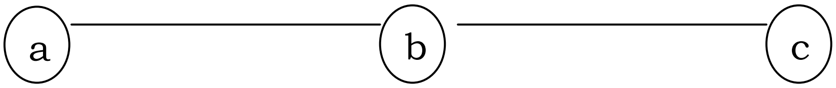
Dscussions/Network Protection Optimization

Considering the various ways of guiding the network traffic from failures. The links can be planned to be in the state of $S \in \{0, 1......S]$ showing that the state S = 0, denotes network normal state i.e: a fully stable network but network can exist in state S = L, such that state S>0 which is a failure state in which link S is broken or malfunctioning [13]. There can be single link failure and multiple link or node failures.

Given a set of paths all supplying the same demand, with identical source and destination nodes, it is said to be single link/node failure and it is resistant if it is such that no matter which single link/node failure occurs, there are still some working paths in the set [14]. But if for every pair of paths in the path set and every failure state at least one path is unaffected by the failure, it means that the set of paths is link/node failure disjointed. Hence, if there is existence of a failure resistant set of paths suppling a demand, there is also existence of a failure disjointed set of paths supplying the demand [16].

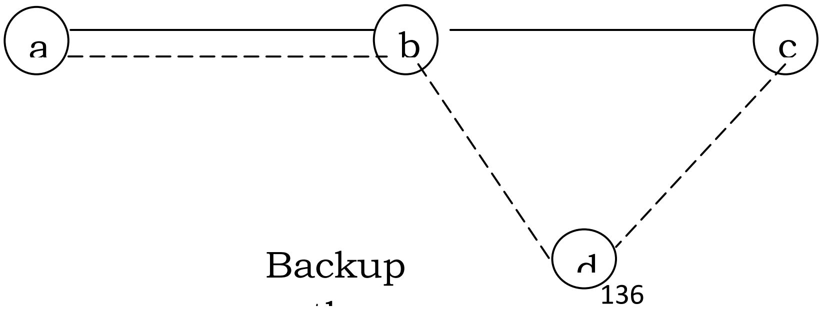
The paths used when there are no failures in the network are called the primary paths while the additional paths used in case of failures are called the backup paths.

Primary path: This is the path commonly used by network signal when the network system is stable and there are no failures. It is the shortest path of least cost.



Primary path

Backup path or Alternative root: This is used when failure or failures occur in the network system.



Backup

Traffic paths (a) primary path (b) backup path.

The workdesign is exclusively considered as m:n path protection of the optical network, protecting the traffic against failures in the following network procedures;

- Nominal design (ND)
- Total rerouting protection (TRP)
- Path diversity proection (PDP).

Shortest/Disjoint and Backup Paths.

Given a network as a set of nodes and a set of links, each link is annotated with a cost. The following can be considered for a given traffic demand between a source and destination node:

K_s(shortest paths): Find a set of K_s shortest paths from the source to the destination node with least cost. If fewer than K_s exist, find as many as possible.

K_d(disjoint paths): find a set of K_d link disjoint path such that the total cost of the used links is minimal. But fewer than K_d exist, find as many as possible.

K_b(backup paths): Removing temporarily from the links constituting the K_s shortest paths, find a set of K_b backup paths from the source to the destination node with least cost. If fewer than K_b paths exist, find as many as possible.

The shortest paths are useful for routing demands in the ND plan where no failure-disjointed backup paths are needed. The disjointed paths are useful for the protection scenarios [17]. The backup paths typically take the long way round from the source to the destination node and are useful when trying to design a network with ring structures as it is being done here, because each primary route usually uses one of the shortest paths and the alternateive route takes one of the backup paths.

Noteably, the disjionted paths cannot in any way be found simple by iteratively finding and removing the shortest path [18]. However, the disjointed paths constitute a set of edges P, which can be found in a directed network by a simple algorithm.

1. Let $i \leftarrow$ I and P ← { }
2. Find the shortest path P, if it does exist (if there is no path from source to destination). stop
3. Let P ← $p \uplus p$. that is for each edge/node in p. if it is already in P. remove it from P. otherwise add it to P.
4. Reverse the edge of the shortest path and negate the sign of the cost on the path links.
5. Let $i \leftarrow i + 1 : if\ i < kd\ go\ to\ step\ 2\ else\ stop$.

Let $P_n, b_n^1\ and\ b_n^2$ represent the primary path, the first backup route and the second backup route where "n" stands for the common request of the network.

Let,s assume that each common demand request requires a bandwidth of a particular wavelength channel providing 3 paths namely $P_o, P_1\ and\ P_2$ and all the nodes through which it transverse has full conversion capability. Each fibre link is on both way operations i.e bi-directional. The already defined paths; Kd, Ks and Kb have their associated wavelengths of w_o, w_1, w_2 as the case may be which are given below.

- Wavelength (w_o): The wavelength that is used by the primary request path P_o.
- Wavelength (w_1): The wavelength used by the backup path and shared with primary path.
- Wavelength (w_2): wavelength that are used and shared by both primary and backup path $b_1^2.W_2$ on link Kd needs to be assigned to backup path b_1^2 .i.e. second backup and the backup link on link Kd, w_1 needs to be assigned to backup path b_1^1 i.e first alternative route; the reason is that b_1^1 can share the primary wavelengthw_2 in the link (K_s) and also the path b_1^2 which has w_3 and can share the wavelength of w_o which transerve through the system.

It follows that wavelength w_2 and w_3 are nodes to be recognized and shared by b_1^2. For operational reasons under "ND" normal condition, w_2 and w_3 are redunant, simply because b_1^1can share the primary wavelength link w_1 on the link path of the first alternative route [19]. This arrangement is such that when there is a primary route failure for route b_1^1, the primary features and the wavelength of the alternative route which is b_1^2becomes operational in which the w_3 are converted to w_o and the $w_3$is saved. This is the application of the principle of frequency re-used.

In real life optical network system, the improvement and protection of the network using the described shared path self healing ring is achieved with use of WDM mesh network [20].

Rules of Sharing Mixed Wavelngth-Links

A Notations and Assumptions.

Assuming each connection request arrives at the network orderly, and there is only a connection request that arrives at a time. Assuming each connection requires the bandwidth of one wavelength channel, each fiber link is also bi-directional, and the network has the full wavelength conversion capacity [21]. The following notations are introduced.

- j: Fiber link in the network;
- fwj: The number of free wavelength-links on link j;
- pwj: The number of primary wavelength-links on link j.
- bwj: The number of backup wavelength-links on link j.
- mwj: The number of mixed wavelength-links on link j.
- Cr_n: Connection request n.
- $p_n: Primary\ path\ for\ cr_n$.
- $b_n^1\ and\ b_n^2: Backup\ paths\ for\ cr_n$.
- $mp_n^j: Takes\ value\ of\ 1\ if\ primary\ path\ p_n\ has\ used\ a\ mi$ $wavelength$ $-\ link\ on\ link\ j;\ 0\ otherwise$.
- $mb_n^{\alpha,j}$ ($\propto$ ϵ *1, 2:Takes value of 1 if backup path* b_n^α *has used a* mixed wavelength-link on link j; 0 otherwise.
- $s_j^{r,b}: Takes\ value\ of\ 1\ if\ backup\ path\ r\ and\ b\ can\ share\ t$ wavelength-links on link j based on the rules; 0 otherwise.
- $d_j^{p,q}: Takes\ value\ of\ 1\ if\ pathsp\ and\ q\ have\ the\ same\ dir$ $0\ otherwise$.
- $|\Omega|$: The number of elements in set Ω.

B. Mixing Primary Wavelength-Links

The mixed wavelength-links are this kind of wavelengths that can be released by failed primary paths and can be re-used by other backup paths. Assuming the connection request cr_narrives at the network. After finding $p_n, b_n^1\ and\ b_n^2, the\ following\ case\ was\ considered$:

Case 1: A primary wavelength-link on link j used by primary path p_n can be changed to a mixed wavelength-link and can be shared by previous backup path b_m^α $(\alpha \epsilon \{1,2\},\ \forall m\ \leq n-1)$.

$C.\ Sharing\ Mixed\ Wavelength-Links$

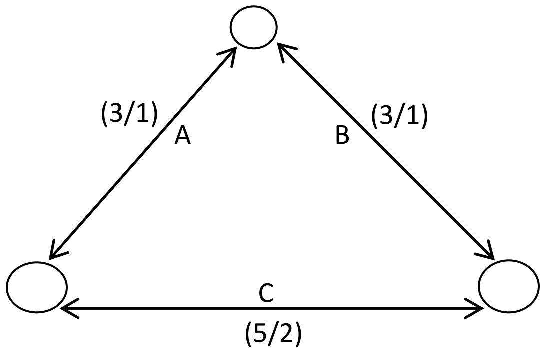
A mixed wavelength-link on link j used by previous primary path p_k and shared by backup-path $b_i^\alpha(\alpha \in \{1,2\}, \forall k, i\ \leq n-1)\ can\ be\ shared\ by\ backup\ path\ b_n^B(\beta \in \{1,2\})$.

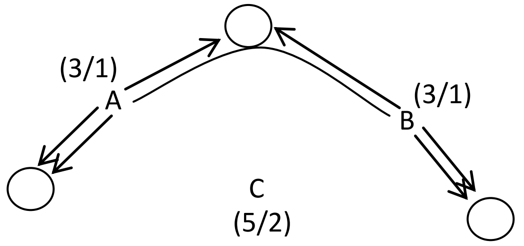
RESULTS/PROMISING PATH GENERATION

Planning a greenfield scenerio for protecting network provides opportunities for the network designer/planner to optimize the network by locating links wherever it seems best but it has its complexities of link selections to the optimization task. In many cases this added complexities that make the enhancement process prohibitively slow for realizing the set objectives [22]. Therefore, instead of optimizing both the placement of links and the reouting of traffic, an integrated optimazation approach is used. Meaning that the problem can be split into two stages, each of manageable complexity. In the first stage a set of primising links is exhtracted from the set of all potential links, based on rough estimates of their cost, and their usefulness for the traffic demands. In the same way, some promising paths i.e, cost efficient paths- for each demands are computed [23]. In the second stage, the network is optimized by only choosing paths from the set of promising paths.

The first stage is called the promising path generation (PPG). Given a set of traffic demands and the cost of constructing each link in the network, we must select a subset of the links [24]. At first attempt, one might compute the shortest path for each demand and then select the union of the used links. However, if there is an intial cost for constructing the duct of each link, too many long links might be selected. See the figure below where it is assumed that the traffic demands corresponding to 1 fibre between all nodes pairs. It showed that the best choice of paths and links demands not only on the cost of the ducts and fibres, but also on the traffic to be carried [25].

Union of shortest paths





Link A: 3 + 1 × 1 = 4 Link A: 3 + 2 × 1 = 5

Link B: 3 + 1 × 1 = 4 Link B: 3 + 2 × 1 = 5

Link C: 5 + 2 × 1 = 7 Link C: 0 + 0 × 1 = 0

Total cost: = 15Total cost: = 10

The union of the shortest paths including too many direct, long links, Duct/fibre cost are shown next to the links.

If there is a lot of traffic between two nodes, it may pay to design a direct link, rather than hopping through several distant internmediate links/nodes [26]. As the direct link is usually slightly shotter than the sum of the length of the intermediate links, the fibre cost will be smaller.

Thus, an algorithm is used for selecting links that strikes the right balance between the two extremes, using a lot of direct links producing a full connected mesh and sending all long-distant traffic through paths with many hops producing more or less minimum spanning tree.In all these, a balance has to be structed or reached by following an algorithm set up, which will initially sort the traffic demands ascendingly according to the cost of designing a direct link (meaning the pure duct cost) [27]. To each link it is assigned a traffic load and cost per traffic unit and then use an algorithm to iteratively update the values by routing the traffic demands one by one. Whenever, a traffic demand is routed along a path, the traffic load on each link is incremented accordingly and its cost per traffic unit is recalculated based on the new traffic load [28]. Finally it can use the cost per traffic values as link cost in a path finding algorithm. The whole algorithm design is put below as a promising path generation algorithm and the function route (d, cost-per-traffic, ks, kd, kb) is used to find paths for demands d.

Therefore, the promising path generation algorithm is designed as follows;

```
Promising paths (links, $cost^{duct}$, $cost^{fibr}$, demands, $K_s$, $K_d$, $K_b$) =
        For d ∈ demands do                          /* Intialize $cost^{direct}$    */
L {l ∈ links/ $Src_1$ = Srcd  ^ $dst_1$ = $dst_d$}/* find direct links*/
```

```
    If L ≠←{ } then
    $Cost_d^{direct}$ ← min {$cost_1^{duct}$/I∈ L}
    Else
        $Cost_d^{direct}$← ∞
    Sort demands according to $cost^{direct}$
    for I ∈links do $traffic_1$←0          /* initialize traffic          */
    for l ∈ links do $costpertraffic_1$← $cost^{duct}$/* initialize costpertraffic   */
    for d ∈demands do                                 /* main loop:          */
        Paths ←route (d, costpertraffic, 1,2..l)       /* Route traffic demand    */
         for P ∈ paths do
                for I ∈P do
    $Traffic_1$←$traffic_1$ + $volume_d$          /* update traffic        */
    $Costpertraffic_1$        ←cost (1, $traffic_1$) /traffic      /* update costpertraffic       */
for d ∈ demands do
    Rd ←route (d, costpertraffic, $K_s$, $K_d$, $K_b$)          /*perform final routing*/
    **Return** {Rd|d ∈demands}
```

The function route (d, cost-per-traffic, K_s, K_d, K_b) is used to find paths for demand "d" based on the link cost values in cost-per-traffic up to K_s, K_d, and K_b backup paths as discussed earlier. The cost of carrying $traffic_1$ wavelengths on link l is calculated by the function cost (1, $traffic_1$) based on the duct and fibre costs and then the number of wavelengths per fibre, w.One of the effects benefit of this algorithm that makes it work is that short links between neighbouring nodes tend to be loaded with the traffic before demands between more distant nodes that are routed, thereby enabling them to use some of the short links instead of creating long direct links [29]. Going through the algorithmic method, it was seen that it is important that there are traffic demands between neighbouring nodes so that short links between these nodes are created. This is assured by creating a dummy demand with volume zero for any node pair that does not have an explicit traffic demand [30]. A further slight improvement of the algorithm can be made by temporarily adjusting the cost-per-traffic values as if $volume_d$ wavelengths were added to every network link just before calling the route functions.

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