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DESIGN AND PERFORMANCE ANALYSIS OF A SURVIVABLE METROPOLITAN AREA FIBER OPTIC COMMUNICATION NETWORK

by

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(ABSTRACT)

The emergence of fiber optic communication technology as a viable alternative to the prevailing copper based network architectures has made it possible to capitalize on the inherent advantages of fiber which include high bandwidth,long regenerator distances and low cost.The focus of this project is to design a survivable and cost effective fiber optic communication network as a proposal for possible deployment in the city of Yaounde, Cameroon.The network comprises 100 nodes of which five are hubs,two gateways,and fourteen special central offices(COs).It also has 141 links,each of them a

candidate for possible fiber deployment.Computer analysis tools are used to generate an optimal topology that meets the specified route diversity constraints as well as the end-to-end DS3 demand requirements.Finally, several candidate architectures are investigated and a proposed model is selected based on how well it meets the design specifications as well as cost and survivability constraints.However, it should be noted that the final cost figures, derived from present US cost figures, will have to be adjusted to accommodate local reality and that the design methodology assumes a desert model (i.e. no pre-existing fiber conduits).

ACKNOWLEDGMENT

I would like to express my gratitude to Ms. Jeanette N. Chumfong for her support during the research and writing of this project. I would also like to thank Mr. R.H.Cardwell and Mr. C.L.Monma of Bell Communications Research, Red Bank,New Jersey, for their useful comments and contributions to this work.Finally, my sincere appreciation goes to Drs. F.J.Ricci, E.K. Haddad, and S.Lakeou , who graciously accepted to serve on my committee.This work is dedicated to my family,in recognition of their unwavering support.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

Recent maturation of fiber optic technology has created a wealth of opportunities in the domain of telecommunications. Besides their increasing deployment in telephony networks, fiber optic systems are being used to interconnect office computer peripherals and terminals,PBX switches,cable television and a host of metropolitan area communications applications.This is a radical departure from fiber's heretofore almost exclusive use in long distance telephone networks.However, to capitalize on the many advantages of broadband fiber optic systems which include the availability of an extensive shared base of vital resources,high bandwidth,long regenerator distances and low fiber cost,it is of vital importance that besides meeting specific design requirements,the network architecture be survivable and cost effective.

The element of survivability is crucial in fiber optic network design because of the relatively high information carrying capacity of fiber optic cables.The desire to design optimal and cost effective networks could lead to sparse tree-like network designs thus creating the potential for a large percentage of traffic being lost in case a link is severed without the capability of rerouting.Failures of this type have been known to occur due to fire,storm,flooding or construction damages.The paralyzing loss of traffic that occurs due to such failures has underscored the need to design fiber based communication systems with the inherent ability to recover from node or link failure by rerouting traffic through designated protection paths for restoration.The survivability of a network is a measure of its ability to recover from singly occurring failures.More precisely,link survivability is defined as the portion of demand that is still intact when the fiber cable of that link is cut and the restoration strategy is enforced.The focus of this project is to design a fiber based communication network that meets certain connectivity and availability constraints without incurring prohibitive costs.

Specifically,the salient features of this project include:

(i) The use of protection optical switches to decrease the terminal electronics cost without jeopardizing network survivability [5];

(ii) The extensive use of simulation techniques at alternate fiber transmission rates to model the performance of a slew of survivable network architectures;

(iii) The ability to include cost figures at various phasHx of the design,thereby providing valuable insight into the possible tradeoffs between cost and survivability.

2.0 <u>NETWORK DESIGN OBJECTIVE AND SPECIFICATIONS</u>

2.1 DESIGN OBJECTIVE

The objective of this design is to develop a model for a 100 node,141 link fiber based communication system as a proposal for deployment in the city of Yaounde,CAMEROON.Of these 100 nodes,7 are hubs,14 special COs,and 79 non-special COs.(Special COs are so designated because they are terminating points of high priority circuits and are therefore deserving of dual connectivity).

Given:

1. A candidate link location and link distance list
2. End to End circuit and DS3 requirements.
3. Fiber and Opto-electronic component cost.
4. Alternate fiber transmission rates.

OBJECTIVE:

Design a cost effective fiber-hubbed network architecture that would meet specified end-to-end circuit demand requirements and satisfy clearly defined connectivity and survivability constraints.It is also desired that the network architecture have the inherent capability of accommodating projected growth.The latter constraint in the formulation of the design objective is the result of economic considerations since the selection of special COs is contingent on cost/benefit factors.

2.2 NETWORK SPECIFICATIONS

The specifications for this design are delineated in two main files:

1:A problem file.

2:A traffic file.

(See appendices A and B for both files)

The problem file contains information about the number of buildings in the network,the connectivity type,the building coordinates as well as the link distances.Also included in this file are the hierarchy levels of each building along with its connectivity,the number of hubs and the sectors to which they belong as well as the traffic type.

The traffic file comprises a set of two files:

(A).A message traffic file

(B).A special traffic file.

These two traffic files have the same format.However,the special traffic file contains special circuit demand pairs terminating on D channel banks for administrative purposes. (D channel banks aggregate DS0s; 64 kbps, into DS1s; 1.544Mbps).

It is desired that the network be cost-effective and that it be highly survivable.Specifically,it should have a minimum worst case link survivability of 90% and a minimum worst case hub survivability of 75%.

2.3 DESIGN CONSIDERATIONS

It has been reported that structural availability of fiber cable in real networks is as low as 96.5% which translates into 300 hours per year downtime at a cost of $75,000 per minute of outage[7].This makes proven methods of restoration essential adjuncts to the deployment of fiber optic networks.

The design of an optimally survivable fiber based communication network is therefore largely dependent on the constraints of cost and restorative capability.A realistic approach to this design would be to quantitatively examine the trade_off between cost and survivability between several candidate architectures.

The conception of a fault tolerant network usually involves either of the following approaches or some combination thereof:

(i)To design a network with inherent restorative capabilities so that traffic on circuits in which a network component has failed can be switched to a protection system.

(ii)To employ intelligent network elements to re-route traffic through alternate transmission paths if a network component fails [10].

The fact that the cost of fiber material relative to distance is very low while the information carrying capacity of fiber transmission systems is very large compared to building to building circuit quantities lends itself to the use of facility hubbing and facility hierarchy in the design of fiber systems.The underlying premise that justifies the use of a three level fiber hubbing architecture in this design is that the aforementioned architecture prevents underutilization of bandwidth and, a fortiori, a ruinous use of resources.

The three levels of this architecture are : COs, hubs, and gateways.A group of COs served by the same hub is called a cluster.A group of clusters served by the same gateway is called a sector.Gateways are fully connected to each other by fiber systems.It is worthwhile to note that a gateway is also a hub which is designated to handle inter-sector demands.This hierarchy is illustrated in Figure 1.

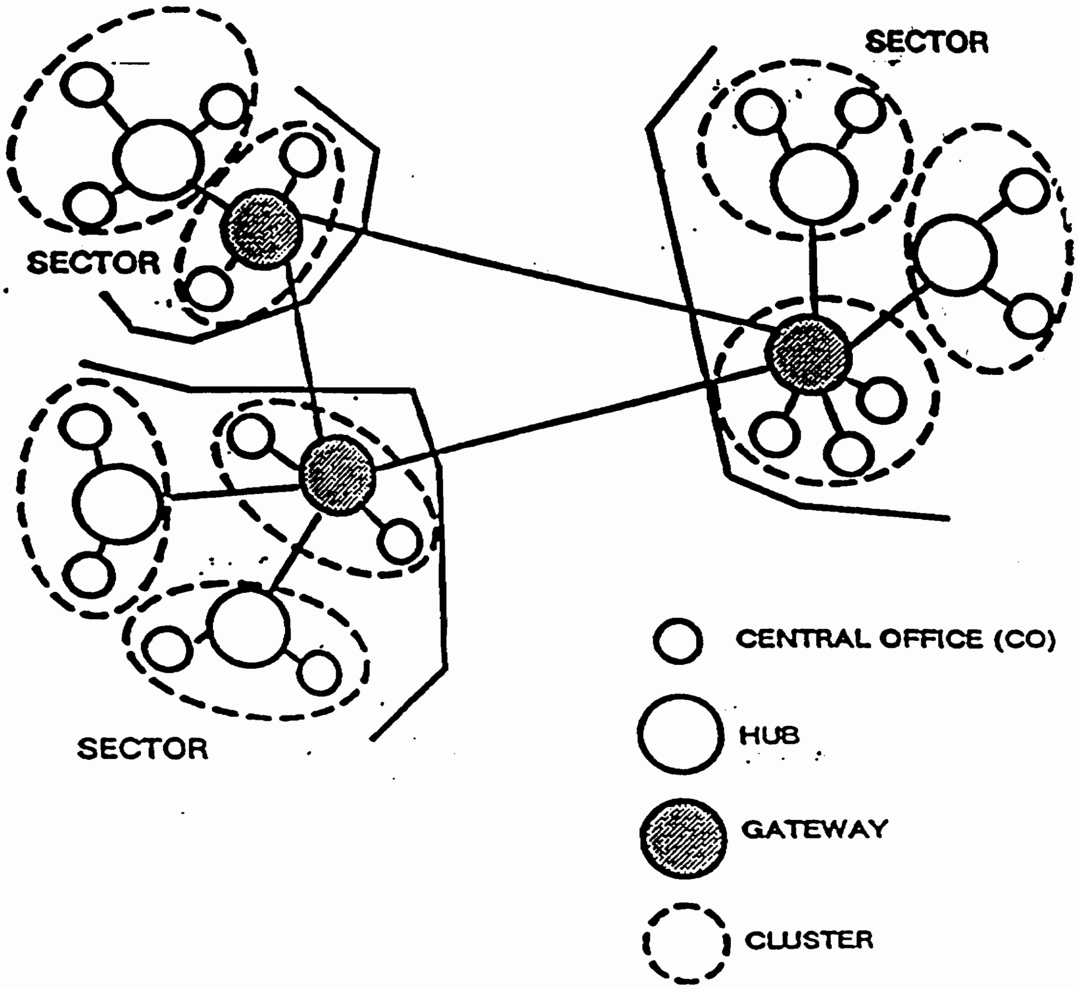


Figure 1. Three level Hubbing Architecture

The design methodology is depicted by the following flowchart.

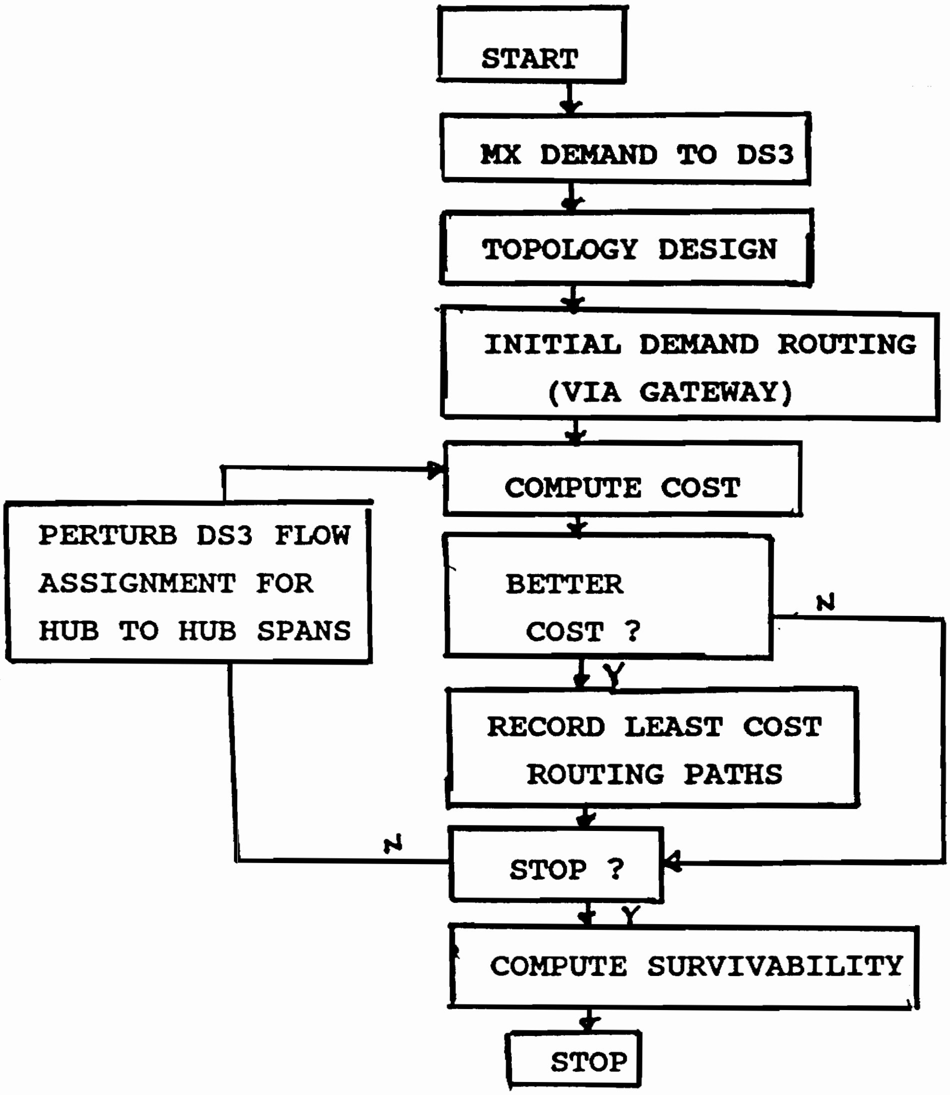


Figure 2. Flow chart of modelling.

The first stage of the design methodology involves the generation of an appropriate topology which constitutes the physical fiber layout based on the imposed connectivity requirements of the candidate links.After several iterations and a subsequent elinination of expendable candidate links,an optimal topology is retained as the basis for demand multiplexing.Demand multiplexing is essentially an upwardly mobile process in the hierarchy whereby demand fron COs is aggrgated by non-programmable multiplexers (M13s) to the DS3 signal level (44.737Mbps).Fiber spans are then built and demand is initially routed through gateways with the associated network cost recorded.The DS3 flow assignment is perturbed by the creation of DS3 cross-connects wheneverwhe existing demand in any pair of buildings exceeds a given threshold (28 DS1s). A comparative assessment of the network cost is made relative to the recorded cost to determine the lowest cost possible. After several iterations at alternate fiber transmission rates, the least cost routing path is selected.The survivabiblity of the network is then computed empirically by failing links and nodes sequentially and evaluating the volume of surviving traffic.

To maximize fiber utilization,the total demand from each CO is multiplexed on a fiber span having terminals at the CO and at its hub with each span passing through one or more links in the network topology.Aggregating inter-office demand into a single fiber pair significantly reduces the penalty for small COs requiring transport to other destinations.

The preceding considerations are the guidelines that have determined the methodology of this design.

3. MATERIALS AND METHODS

A significant research effort at Bell Communications Research by Cardwell et al. has recently yielded an appropriate PC based software package called Fiber Options intended for the state of the art design and analysis of fiber based communication systems [2]. This package is used extensively in this design because it provides flexibility both in generating topologies for the fiber layout as well as a variety of survivable network architectures based on the design specifications.The package also allows for the incorporation of associated cost factors into the design thereby providing crucial insight into the cost/survivability tradeoffs that determine an optimal or near optimal design.The package consists of three modules:

1. A topology generator;
2. A circuit to DS3 bundler;
3. A multiplex layout system.

Figure 3 outlines the structure of this software package.

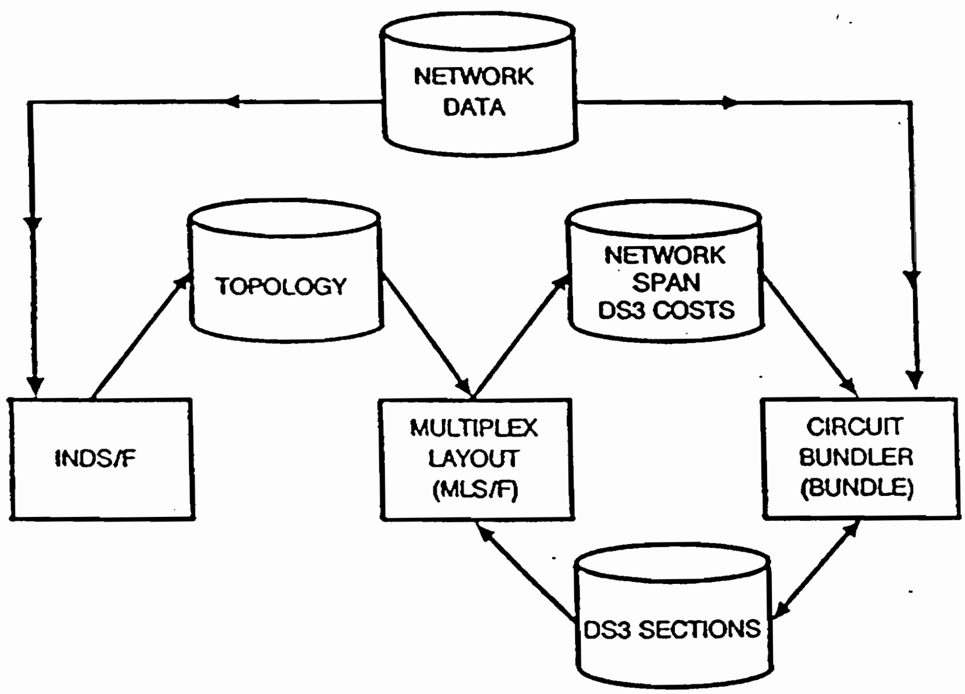


Figure 3. Fiber Options Software

4.0 TOPOLOGY DESIGN

4.1 INPUT

The preceding datafile contains the requisite information to generate ,from scratch,a fiber layout which minimizes installation costs subject to the prescribed connectivity requirements.The nodes are identified by the (x,y) coordinates representing their geographical locations.These buildings are CO switch locations and the potential links correspond to pairs of offices between which fiber could be placed.Each link has an associated cost of fiber placement proportional to the length of the fiber facility along the route represented by the link.

4.2 CONSTRUCTION HEURISTICS.

Given this undirected graph G=(V,E),where V represents the set of nodes or building locations and E represents the set of edges or potential links,a two-connected part of the fiber layout is constructed.This embryonic topology consists of all special nodes,with each pair of nodes having at least two node-disjoint paths between them.The remaining nodes are then linked to the two connected part by spanning trees as depicted by broken lines in Figure 4 [12].

The two-connected network is generated by starting with an initial cycle C, and iteratively adding edges to the existing partial solution.The 'greedy' heuristic which is adopted in

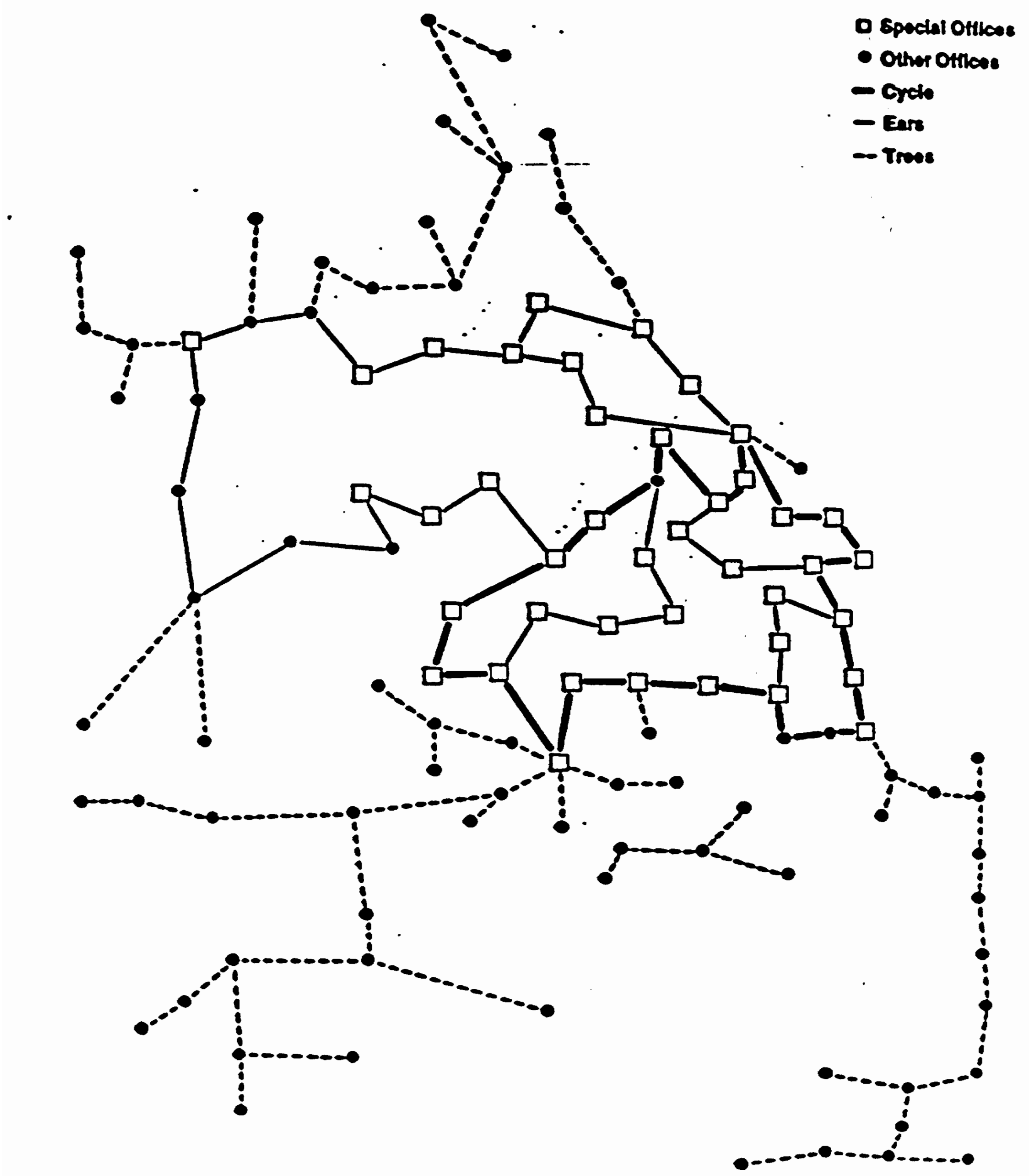


Figure 4. Topology Construction

this design randomly selects a special node v,and then selects another special node w whose shortest path P to v is the longest among all special nodes[11]. Using node u which is adjacent to w on the path P,the shortest path from u to w is found not using edge(u,w).It should be noted that such a path must be found inorder to satisfy the two-connectivity requirement for special nodes.This construction heuristic greedily generates cycles and paths while minimizing fiber placement and regenerator costs.

4.3 FIBER LAYOUT COST FIGURES.

Using present technology, the cost figures used are:

1. Fiber material $1,700
(per pair per mile)

2. Fiber placement $5,000
(per route mile)

3. 1*2 mechanical optical switch $1,000

4. Distance requiring a generator = 30 miles.

5. Fiber line rates,maximum N for 1:N system and regenerator cost.

line rate#	line rate (Mbps)	max N	repeater cost($K)
1	45	1	6.88
2	90	11	10.83
3	135	15	13.83
4	405	15	19.20
5	565	15	29.64
6	1200	15	49.10

6. Automatic protection switching(APS) cost (base unit=$1,000)

$$\text{Cost APS}(i,j,k)=\begin{cases} 0 & \text{if } (k<2) \text{ or } (i=1 \text{ and } k>=2) \\ 7.525+(j-2)0.36 & \text{if } i=2 \text{ and } j>=2 \text{ and } k<=2 \\ 12.155 & \text{if } i>=2 \text{ and } k>=2 \end{cases}$$

where i=line rate #

j=number of DS3s carried by the span

k=number of working fiber systems in the span

Note: A DS1(1.544Mbps) contains 24 circuits(DS0s,64Kbps) and a DS3(44.737Mbps) contains 28 DS1s for a total of 672 circuits. (See Ref 14 for cost data)

4.4 FIBER LAYOUT COST FIGURES.

Topology statistics obtained after implementation of the 'greedy' algorithm to build an initial solution for this project were as follows:

1. Fiber placement cost	$36,100
2. Number of regenerators	50
3. Fiber and regenerator cost	$77,556
4. Route miles	7720
5. Working fiber miles	19235
6. Protection fiber miles	20510

The route diversity of the network,defined as the percentage of point-to-point traffic which has at least two node disjoint paths in the network is 82% one-connected and 18% two-connected.The latter figure represents the fraction of traffic volume that would never be disrupted by any single link or node failure.The network survivability figures derived from this topology are as follows:

Link failure

worst case : 76.2%

average : 97.3%

Node failure

worst case : 26.8%

average :97.2%

These figures represent the percentages of point-to-point traffic which can still be carried after a single link or node failure respectively.They are computed by removing each link turn and computing the percentage of traffic which can still be carried by the network.

Obviously, the node failure figures do not meet design specifications.They would have to be improved using demand multiplexing and an appropriate choice of a survivable network architecture.

4.5 IMPROVEMENT HEURISTICS

Optimization of the feasible network involves making some local transformations in order to reduce the total cost of placement, fiber material,and regenerators without altering network connectivity.Improvement methods used in this design include pretzel formation/removal, optimal interchanges,and chord removal.

4.5.1 PRETZEL FORMATION/REMOVAL

As illustrated in Figure 5,this improvement method involves replacing a link (u,v) in a randomly chosen cycle with two crossing links (v,x) and (u,y) to form a pretzel of lower overall cost.Several iterations of this heuristic are done until there are no changes in cost.

Pretzel removal involves the replacement of pretzels formed in the initial solution by cycles of a lower overall cost.This also requires several iterations to bring about a reduction in cost.

4.5.2 OPTIMAL INTERCHANGES.

These improvement methods involve the removal of

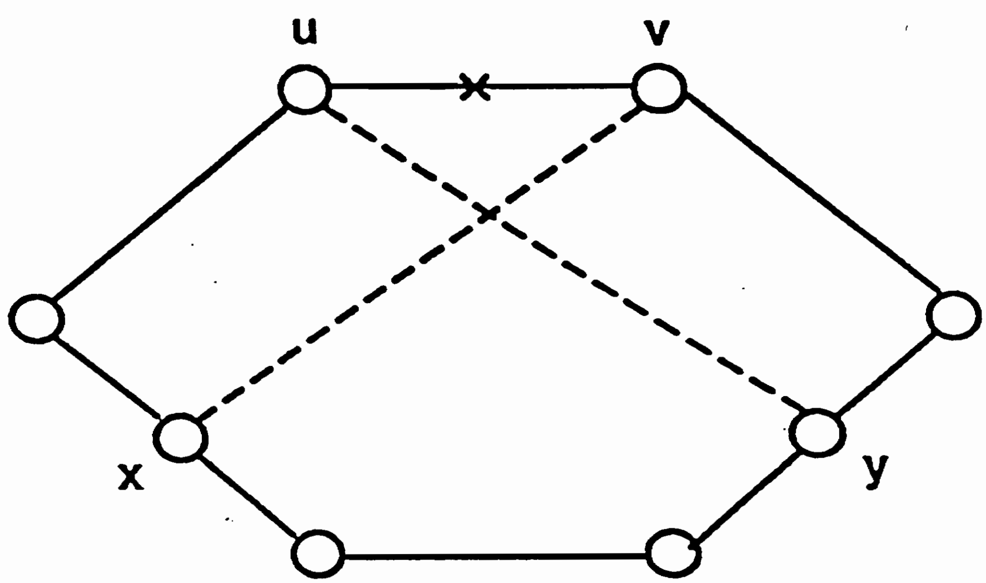


Figure 5. Pretzel Formation

one,two,or three links from a cycle and their subsequent replacement with an equal number of links that are not in the current solution.

Figures 6,7,8 illustrate these methods.For better results, the maximum window size (100) is chosen to permit links to be moved further away hence reducing overall cost.

4.5.3. CHORD REMOVAL

This procedure,illustrated in Figure 9,involves the removal of a chord or link from a local cycle without altering the connectivity of any of the buildings on which it terminates.It is an iterative procedure and therefore has to be done repeatedly to obtain a significant reduction in overall cost.

4.6 IMPROVED FIBER LAYOUT STATISTICS.

After several iterations of the improvement heuristics described above,the ensuing topology had the statistical profile delineated in Table 1.

TABLE 1. IMPROVED FIBER LAYOUT STATISTICS.

		Improvement
1. Fiber placement cost	$35,085	2.8%
2. Fiber & regenerator cost	$74,752	3.6%
3. Number of repeaters	45	10%
4. Route miles	7017	2.8%
5. Working fiber miles	18,397	4.3%
6. Protection fiber miles	20281	1.1%

The statistics indicate a significant decrease in cost thereby

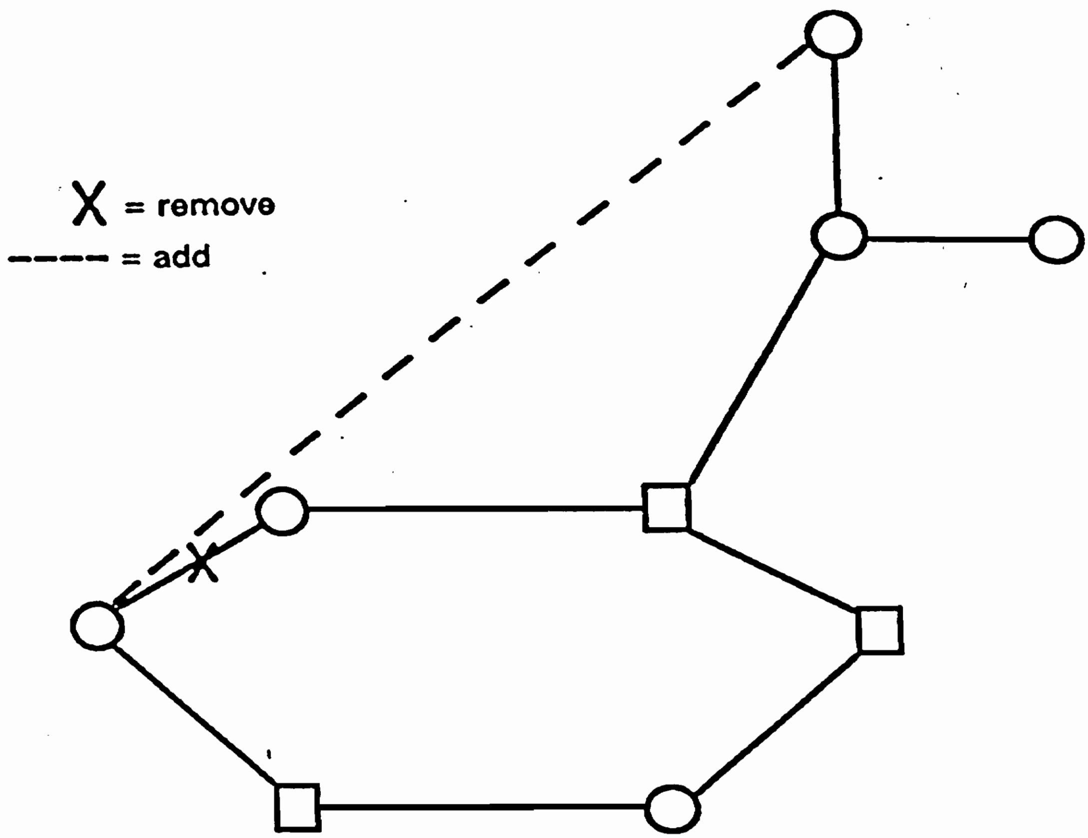


Figure 6. One Optimal Interchange

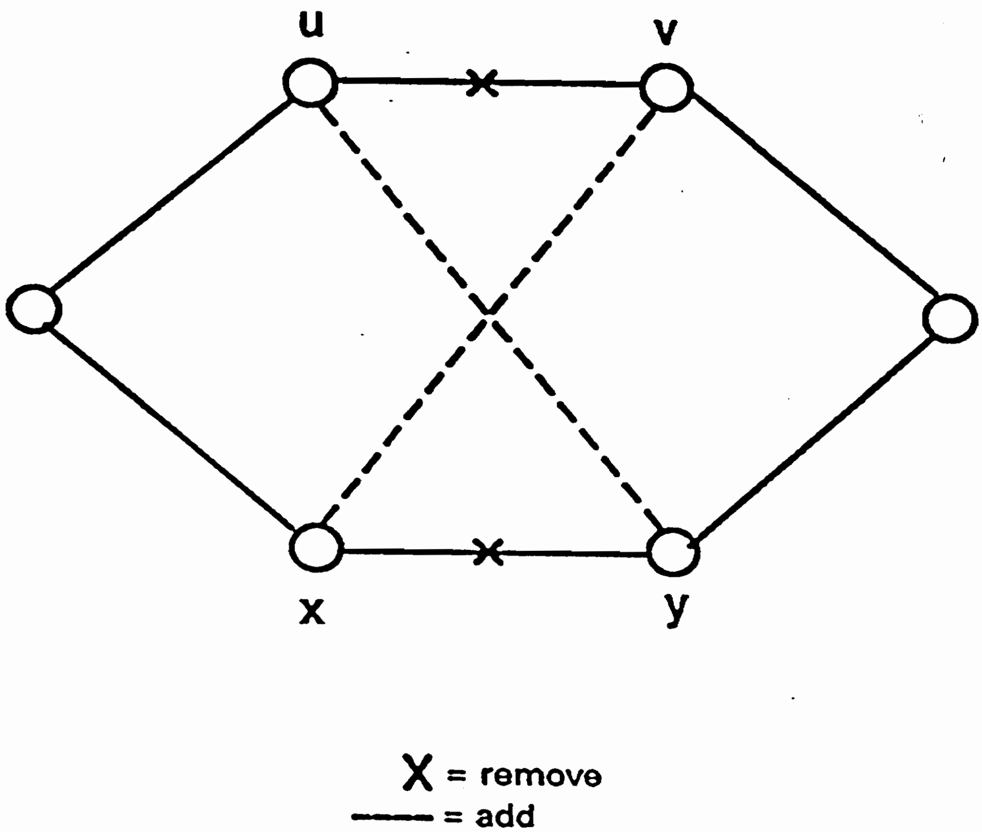


Figure 7. Two Optimal Interchange

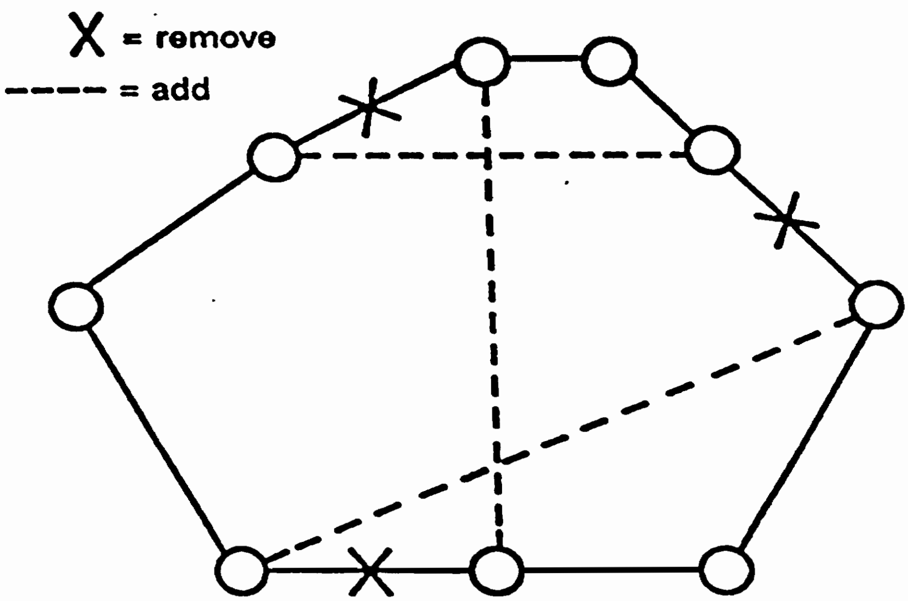


Figure 8. Three Optimal Interchange

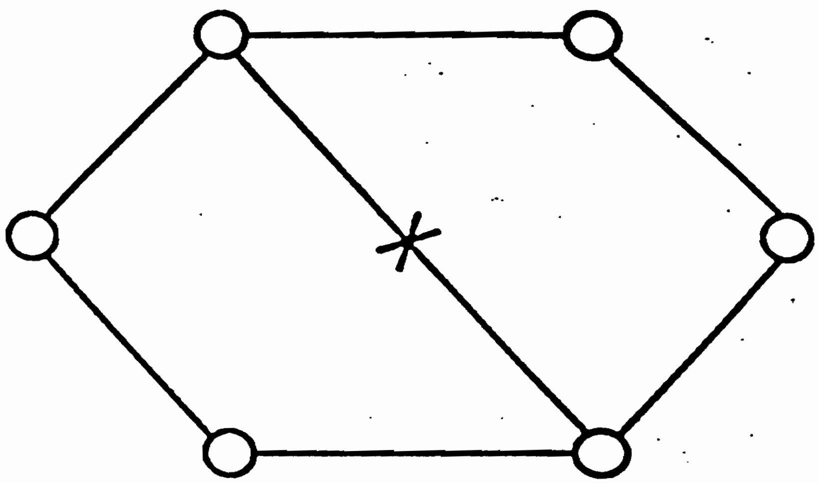


Figure 9. Chord Removal

justifying the use of improvement heuristics.However,the survivability and route diversity statistics remain unchanged due to the fact that the improvement methods did not alter the connectivity constraints.

5. CIRCUIT TO DS3 BUNDLING

The most attractive aspect of fiber based communication networks is their inherently large bandwidth.To capitalize on this important attribute and in conformity with the adopted facility hierarchy,all demand from a CO is multiplexed on a fiber span terminating at the CO and its hub.A span is an ordered set of consecutive links with no terminations at intermediate nodes.Figure 10 illustrates a span multiplexing layout wherein hubs are equipped with digital cross connect systems(DCS).

5.1 DCS SORTING

As opposed to an M13 which is a non-programmable multiplexer, a hub DCS,schematically depicted in figure 11(a), accepts DS3 signals as input and rearranges the constituent DS1s so that each DS1 is placed into the DS3 destined for the right building.The M13 multiplexes DS1 rate signals up to the DS3 level.One or more DS3 rate signals may be multiplexed together by an optical line terminating multiplexer(OLTM) which combines electrical DS3 signals and then modulates a laser to transmit the signal to the hub DCS.At the hub,this optical signal terminates in a matching OLTM where it is reconverted into electrical DS3s.This is depicted in Figure

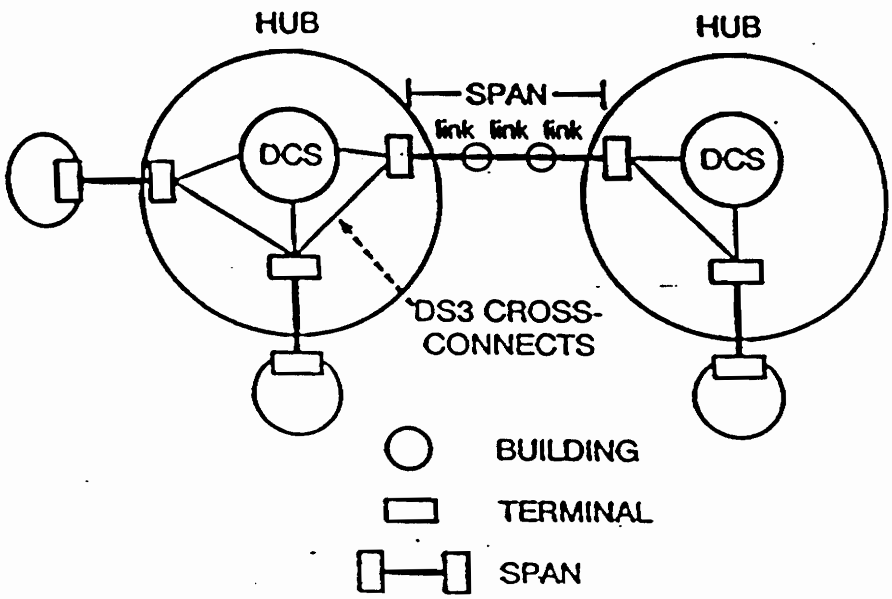


Figure 10. Fiber Span Layout

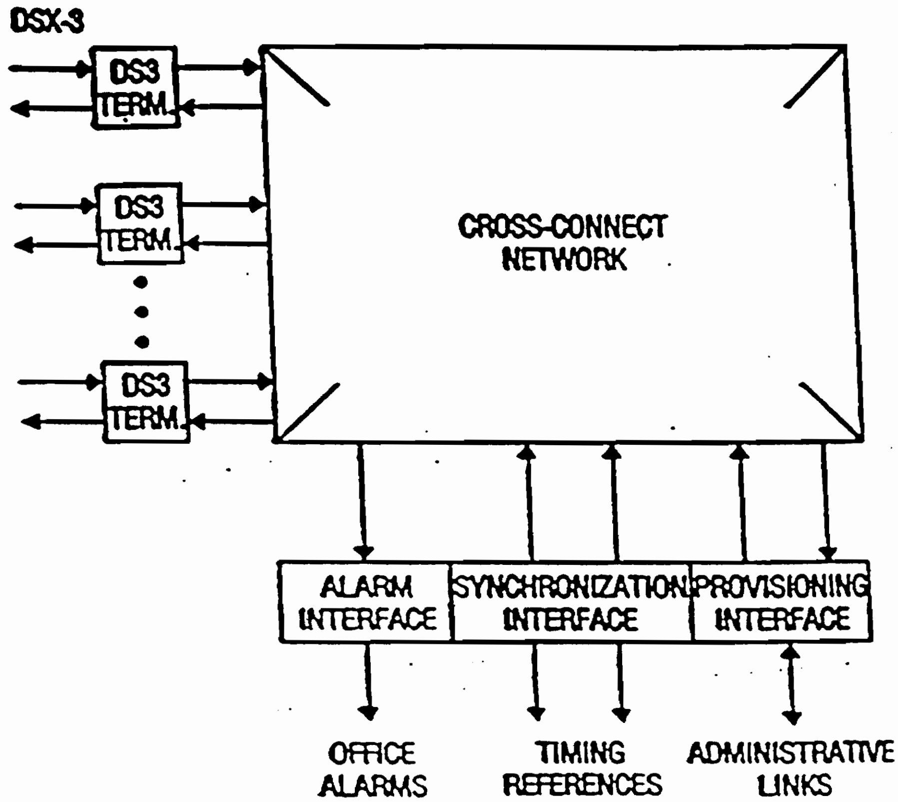


Figure 11a. Schematic Representation of a DCS

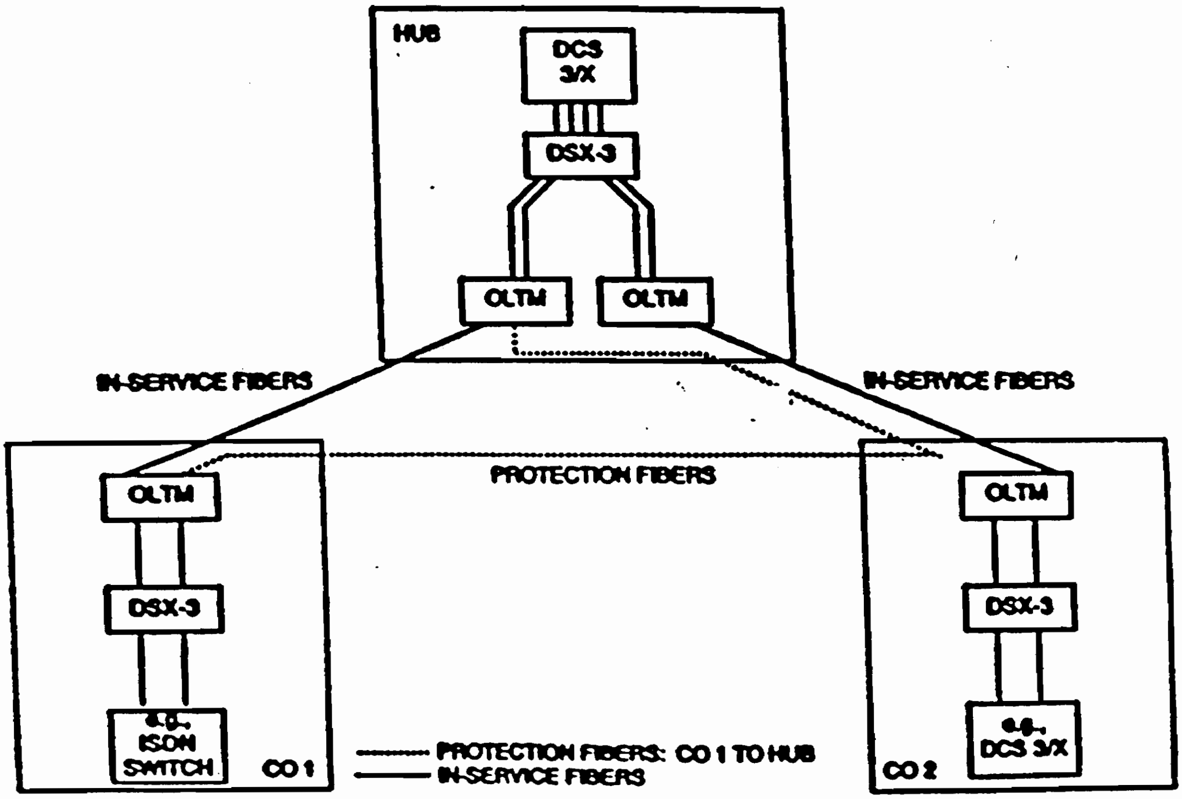


Figure 11 b. Automatic Protection Switching with Diverse Routing via OLTMs (Hub to CO1)

11(b).

The switching information for reconfiguration at the hub DCS is provided in a programmable cross-connect matrix[11]. In this sense,the hub serves as the point where all demand is aggregated.Taking this one step further in the hierarchy, hubs are combined into sectors, with each sector being served by a gateway.

5.2 CIRCUIT BUNDLING COST DATA.

Termination equipment cost for circuit bundling are as follows:

Hub DS3 Termination	$7,000
Hub DS1 Termination	$1,500
M13 multiplex common equipment	$7,650
M13 Plug_in for 4 DS1s	$540

5.3 PARCEL ROUTING

The stated objective of circuit bundling is to form DS3s with high occupancy.The constituent 'parcels' in these DS3s are then routed between hub DCSs.A parcel is a demand of one or more DS1s and the two endpoints of the circuits in those DS1s.The parcel routing process is guided by the following principles:

1. Demand is always carried between buildings on a DS3 level.

2. DS3s are formed as soon as possible to minimize the number of hub DCSs used, and to carry demand as low as possible in the hierarchy.

3. To avoid bandwidth underutilization, leftover demand between two buildings is combined with demand from other COs and sent to the next facility hierarchy level where another attempt to generate a DS3 is made.

4. The gateway level is fully interconnected at the DS3 level[14].

5.4 DS3 SYNTRAN FORMAT

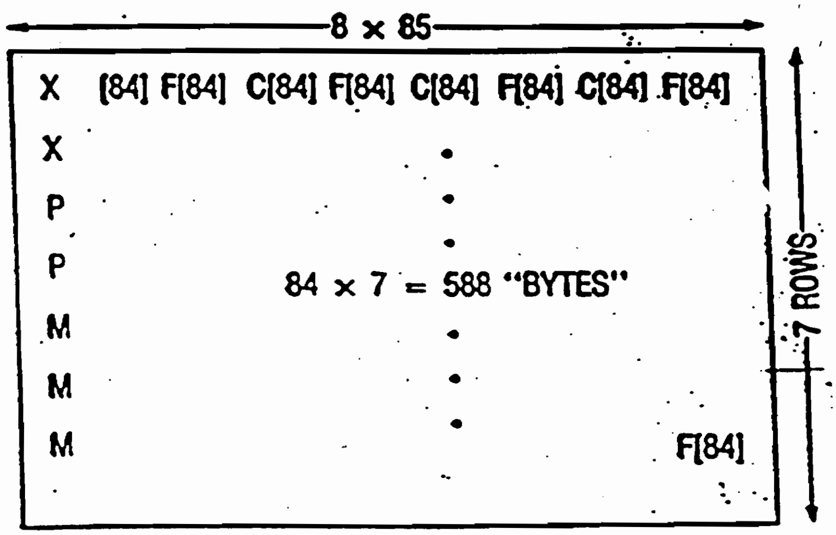
To allow efficient access to the constituent DS1 and DS0 signals of the DS3 data stream and a means of providing direct DS3 interfaces to the digital central office and cross-connect systems ,the SYNTRAN(synchronous transmission) DS3 frame format is used. As shown in figure 12, each frame is organized as seven rows of 8*85 bit blocks .Each of the 85 bit blocks contains 84 information bits and one bit for framing.

5.4 DS3 TYPES

The economics of parcel routing allows for the formation of four main DS3 types: building to building, building to home hub, building to foreign hub, and hub to hub. These various DS3 types are depicted in Figure 13.

1. Building to building DS3s

The formation of this DS3 type depends on whether the existing traffic between the two buildings exceeds 672



LENGTH OF DS3 MULTIFRAME:

$8 \times 7 \times 85/44.736 \times 10^6 = 106.402\mu s$

NOTE: $699 \times 106.402\mu s \triangleq 595 \times 125\mu s$

Figure 12. DCS FRAME FORMAT

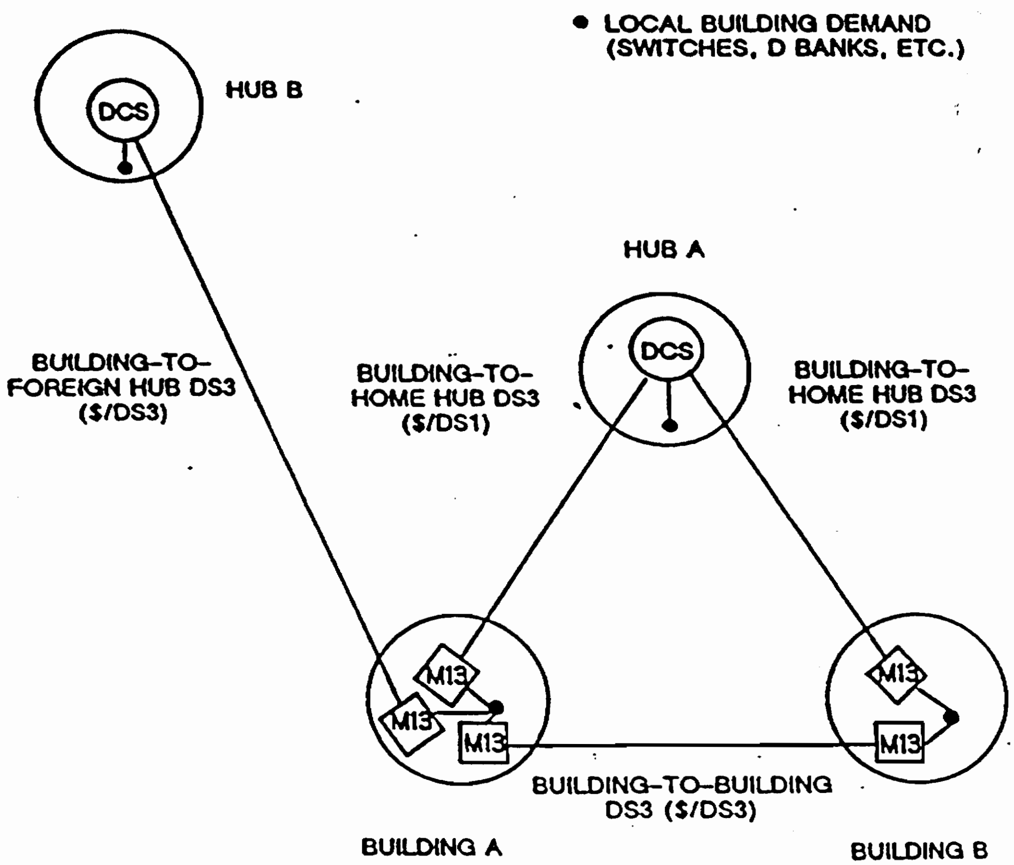


Figure 13. DS3 Types

circuits(1 DS3),thereby making the cost of a direct DS3 less expensive than the cost of the alternate hub DCS route.Once the threshold is exceeded,the residual unrouted DS1s are assigned equally to the home hub DCSs of the two buildings.

2. Building to home hub DS3s

These involve local demand emanating from a building and terminating on the home hub.

3. Building to foreign hub DS3s

This DS3 type originates from a source in a building and terminate on a hub other than the home hub of the source building.

4. Hub to Hub DS3s

This DS3 type involves traffic that terminates on a hub DCS3/1 at either end.

In order to improve DS3 occupancy and provide better network DCS survivability,parcels are spread over more hub DCSs.

5.5 CIRCUIT BUNDLING STATISTICS.

5.5.1 DS3 TYPE(as determined by multiplexing)

	Volume
Building to building	205
Building to home hub	193
Building to foreign hub	67
Hub to Hub	20
TOTAL	485

5.5.2 DS3 DESTINATION TYPES

	Volume
Building to building	56
Building to home hub	293
Building to foreign hub	70
Hub to Hub	66

These DS3s are so designated because of the type of building on which they terminate.

5.5.3 NETWORK OCCUPANCY

DS3 TYPE	DS0/DS1	DS0/DS3	DS1/DS3
BLDG-BLDG	99.3	88.9	89.5
BLDG-HHUB	80.2	62.5	77.9
BLDG-FHUB	79.5	63.9	80.3
HUB-HUB	56.1	46.1	82.1
TOTALS	87.8	73.2	83.3

5.5.4 HUB LOADING INFORMATION

EXT refers to external DS3 that leave a hub building location and terminate in other buildings,whereas INTERNAL refers to the traffic accessing the hub DCS within the same cluster.

	EXT	INTERNAL		TOTAL
HUB	DS3	DS1	DS3	DS3
AZNBCD	15	93	4	19
ESCRGB	22	103	4	26
EUSTCM	81	114	5	86
GMOUNN	48	139	5	53
NUDMMO	25	131	5	30
RMNPMO	82	231	9	91
ROUDNN	27	98	4	31

5.5.5 NETWORK COST(*)

Cost component	Cost
Transmission	16655220
Hubbing	5143500
Mux 1/3	4772340
TOTAL	26571060.0

* It is worthwhile noting that the network is not protected against failures at this stage and does not benefit from the use of adequate multiplexing strategies.This explains the relatively higher cost.

6.0 MULTIPLEX SPAN LAYOUT AND SURVIVABILITY

6.1 MULTIPLEX SPAN LAYOUT

To optimize the use of fiber in this design,a working multiplex span layout is built based on the topology by constructing the shortest span between each CO and its hub for CO to hub routing;each special CO and its foreign hub physically diverse from the span terminating at its home hub for dual homing when necessary;each hub and an associated hub for intrasector routing;each gateway and an associated gateway for intersector routing.Figure 14 depicts this strategy.

Each fiber path may use one or more multiplex spans and each span may pass through one or more links without intermediate nodes.Any point-to-point demand large enough to justify a DS3 is cross-connected on a DS3 basis to the multiplex span destined for the proper building since the DS3 signal level is considered the basic routing block.

6.2 DEDICATED/MIXED MULTIPLEXING

Inorder to optimize the use of fiber capacity and to reduce the amount of termination equipment, two multiplexing strategies are used in this network design;viz: dedicated and mixed strategies.

6.2.1 DEDICATED MULTIPLEXING

This multiplexing strategy involves the use of a direct span between any building and its hub or between any pair of hubs.This is illustrated in Figure 15(a).

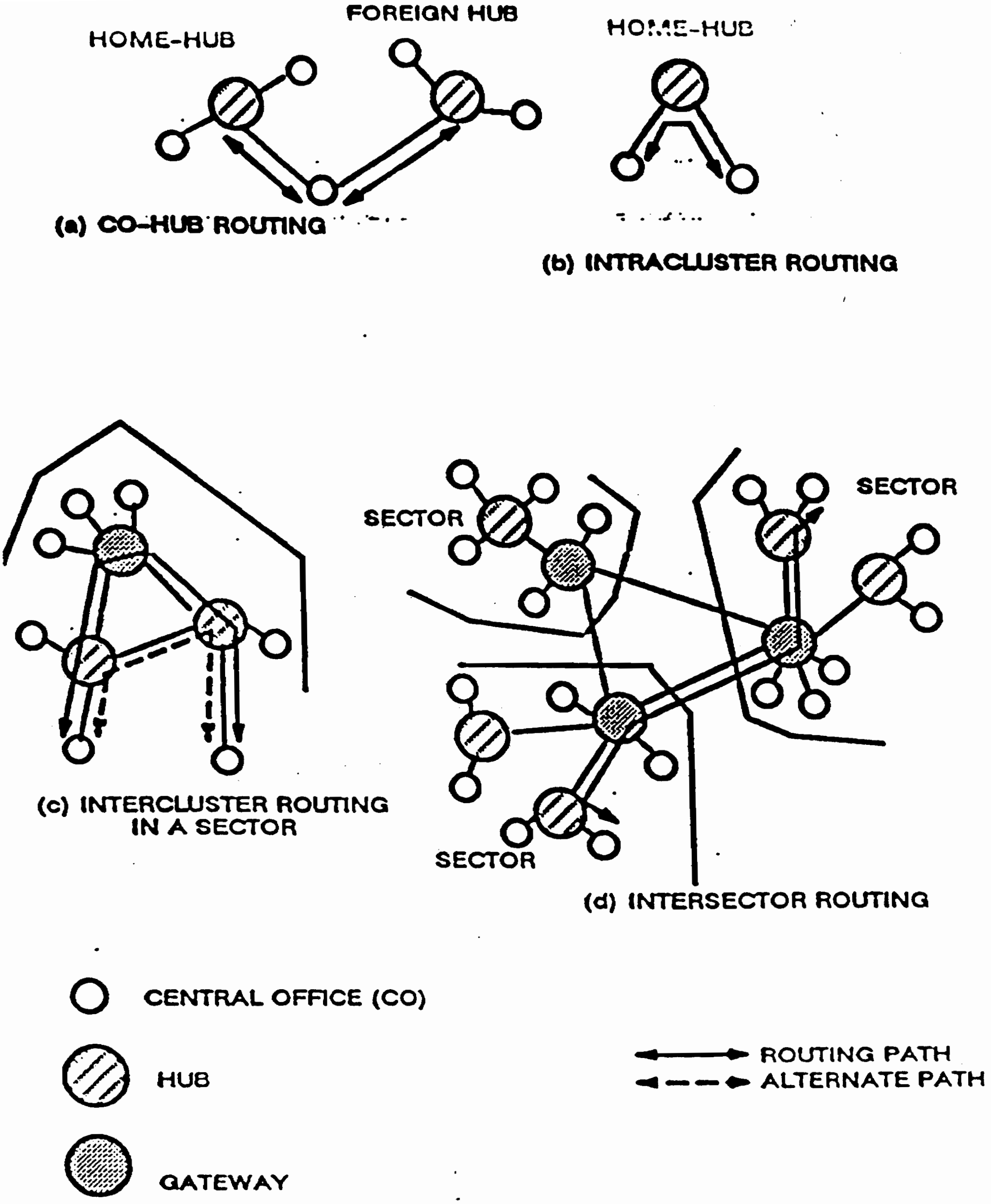


Figure 14. Hub Routing

6.2.1 MIXED MULTIPLEXING

This multiplexing strategy allows for demultiplexing and remultiplexing of traffic at intermediate buildings.The advantage of using this strategy lies in the reduced cost of working terminals and regenerators.Figure 15(b) illustrates this strategy.

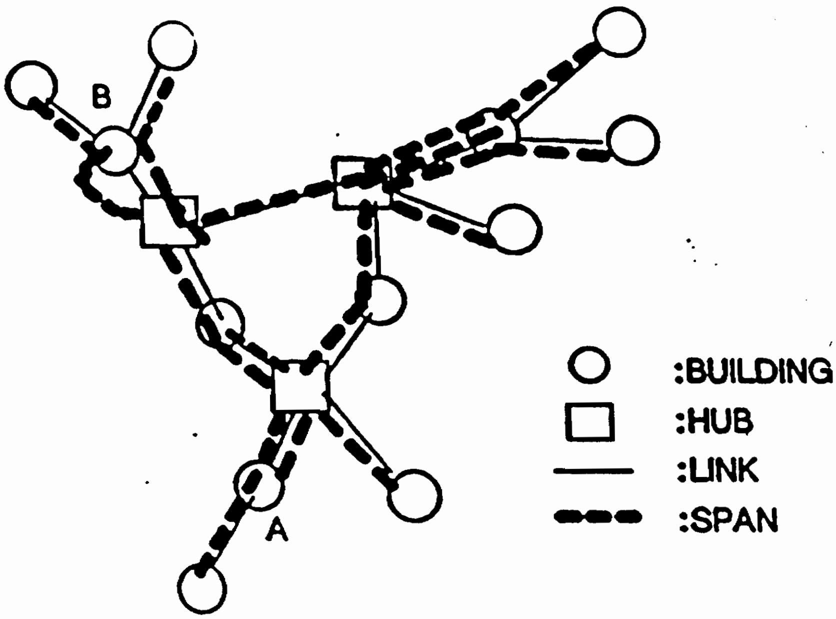
6.3 SURVIVABILITY

The relatively large bandwidth involved in fiber based communication networks makes their survivability a very important factor in any design.This design is no exception to that consideration. The design methodology for the candidate network architectures includes three notable plans to accommodate the contingency of network failure.They include the use of protection switching,dual homing,and the use of standby DS3s.

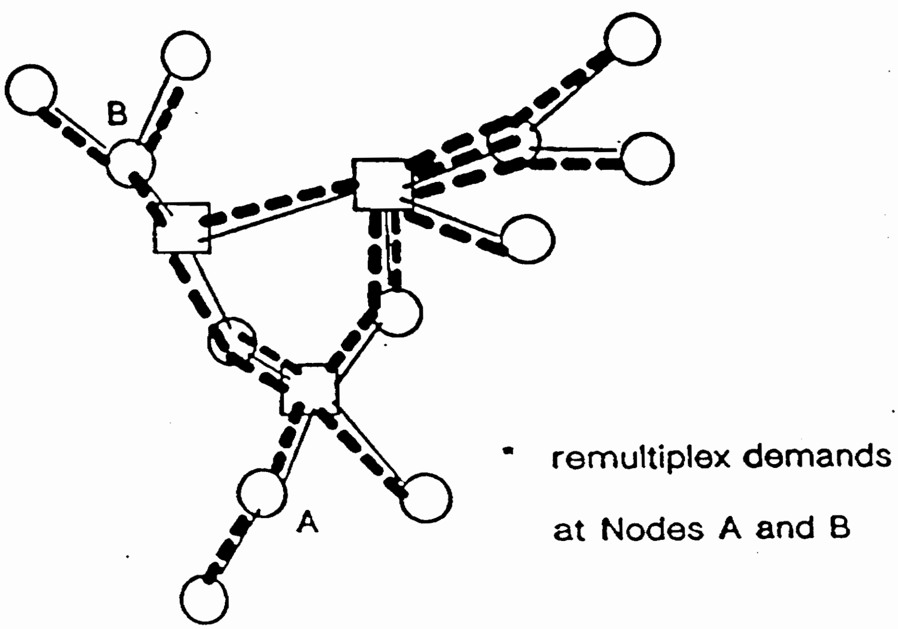
6.3.1 PROTECTION SWITCHING

This involves the allocation of a protection path through which traffic is routed in case of failure.As depicted in Figure 16,the difference between the base 1:N strategy and the 1:N with diverse protection(DP) strategy is in the location of the protection path ; the latter being placed in a physically diverse route.

Justification for the use of the diverse protection scheme lies in the fact that electronics cost dominates total transport cost and does not have to increase to achieve survivability.Other factors that enhance its attractiveness

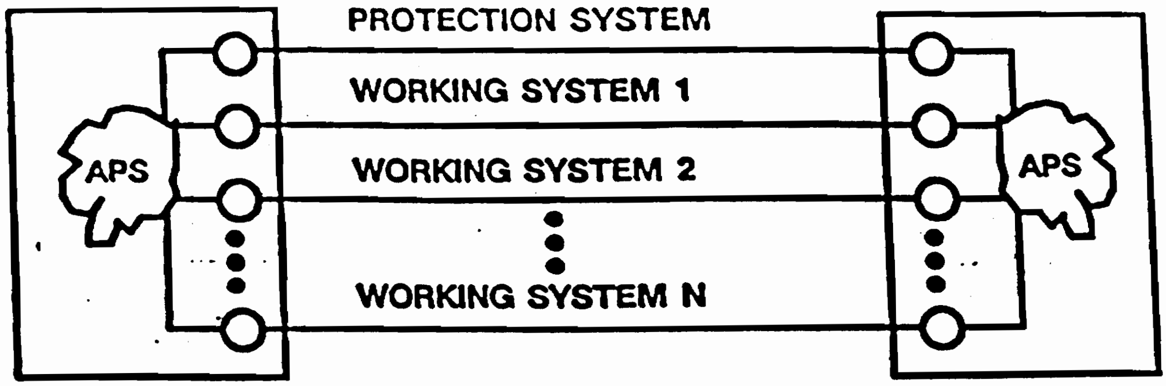


(a) Hubbing Configuration Using Dedicated Multiplexing

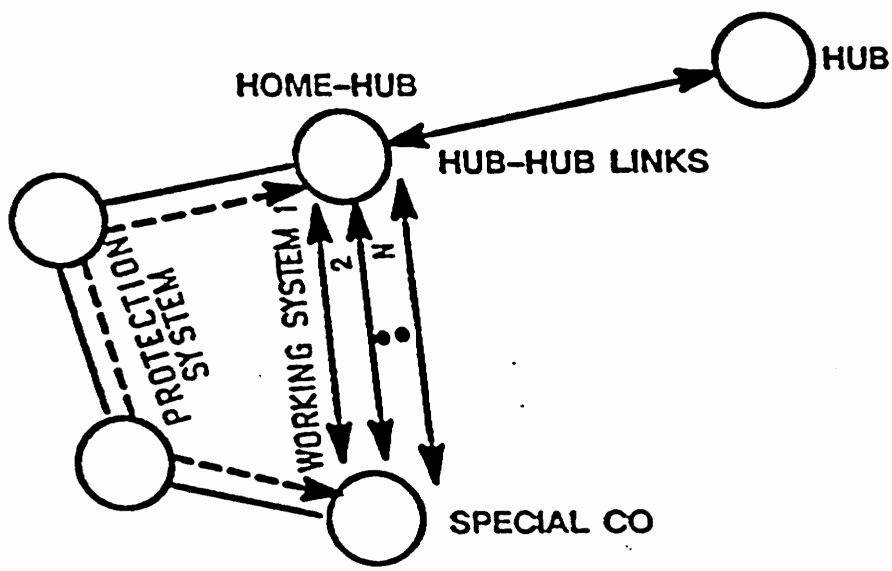


(b) Hubbing Configuration Using Mixed Multiplexing

Figure 15. Hubbing Configuration using dedicated (a) and mixed (b) Multiplexing.



(a) 1:N PROTECTION



(b) 1:N PROTECTION WITH DIVERSE ROUTING

Figure 16. 1:N Protection using APS and 1:N Diverse Protection.

include its use for maintenance and the availability of totally automated protection switches(APS) which allow for detection of fiber cuts and near instantaneous re-routing via the protection path.Figure 16(a) illustrates the use of such a device.It should be noted that a 1:1 diverse protection scheme provides 100% survivability for fiber placement cuts,whereas a 1:N diverse protection scheme would be less survivable due to the fact that only one of the N working systems can be rerouted.

6.3.2 DUAL HOMING

As opposed to the single homing approach for demand distribution which uses an associated home hub to aggregate demands from any building to their destinations, dual homing is a concept of demand balancing that partitions demand emanating from a special CO between a home hub and a designated foreign hub as is indicated in Figure 17.
This form of service protection which has to used in conjunction with path rearrangement guarantees surviving connectivity during hub and DCS failures.However,it takes time to restore priority circuits and this,coupled with the additional transport cost, decreases its appeal in most cases.

6.3.3 STANDBY DS3 PATHS

The protection mechanisms mentioned heretofore have envisioned the contingency of fiber cable cuts and other fiber system failures.To protect against DS3 and DS1 level failures in COs and hubs, one and two standby paths are allocated for

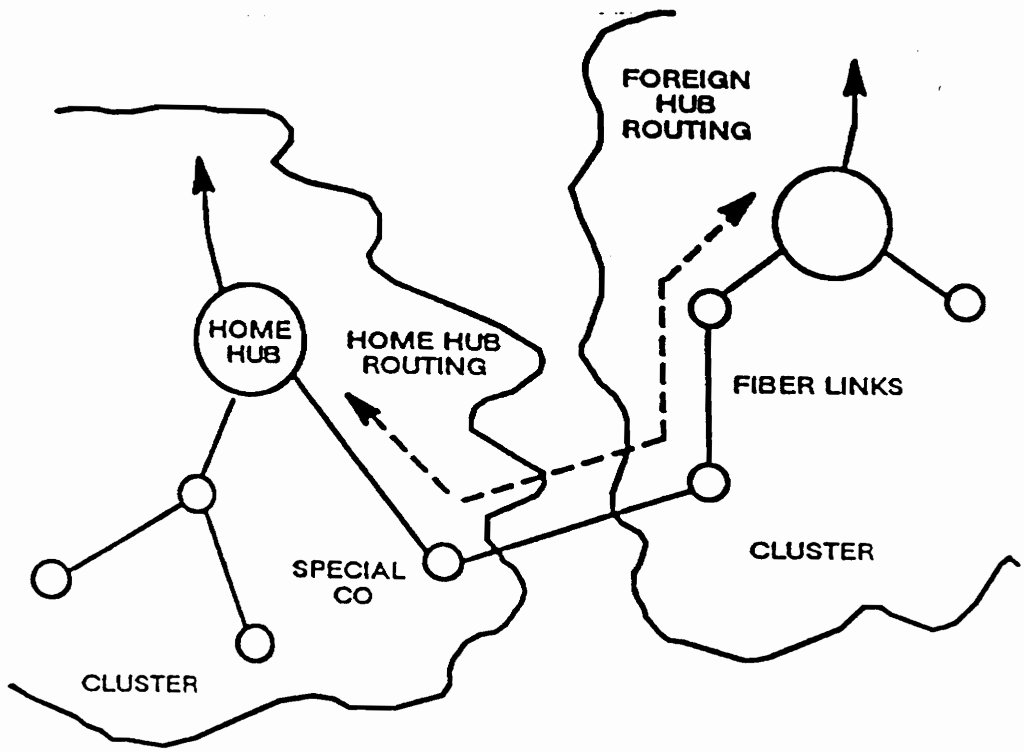


Figure 17. Dual Homing Architecture

each special CO-hub and hub to hub pair respectively.As indicated earlier,these paths could also be used for dual homing purposes.

6.4 NETWORK SURVIVABILITY

The survivability of a network depends on the chosen architecture and the inherent protection mechanism.The two important aspects of network survivability considered are: link survivability and hub survivability,both in their average and worst cases.In each case,survivability is defined as the portion of traffic in the entire network that is still intact after a link(or hub) failure and the subsequent enforcement of the restoration scheme.The methodology used is to sequentially fail each link or hub and compute the surviving traffic. (APPENDIX C)

6.5 CANDIDATE NETWORK ARCHITECTURES.

To evaluate the trade-offs between cost and survivability,the following network architectures for restoration are used:

1. Single homing 1:N (SH/1:N;base case)
2. Single homing 1:N with diverse protection (SH/1:N/DP)
3. Single homing 1:1 with diverse protection (SH/1:1/DP)
4. Dual homing 1:N with diverse protection (DH/1:N/DP)
5. Single homing with 1:1 diverse protection for special COs and hubs and 1:N protection is applied to regular COs (SH/1:1+1:N/DP)
6. Single homing with 1:N electronic protection and 1:1 fiber

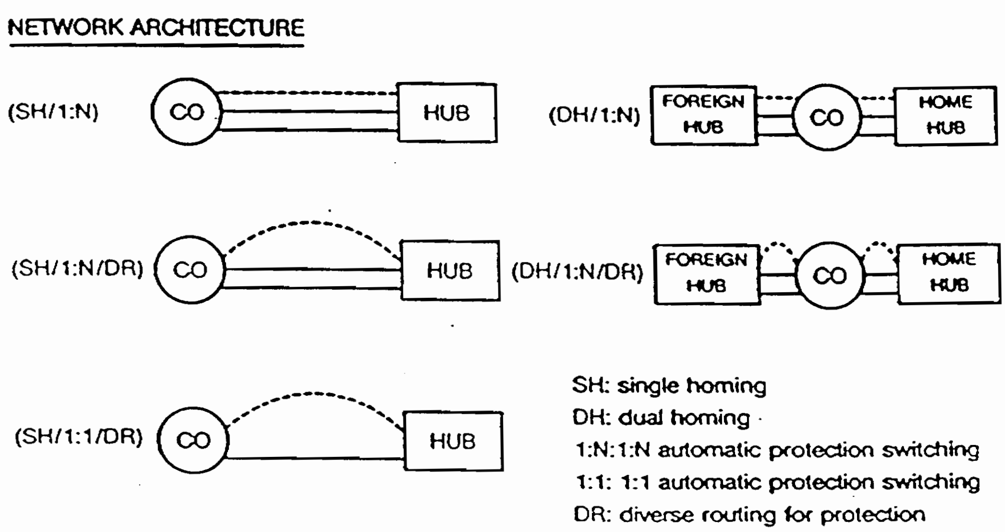
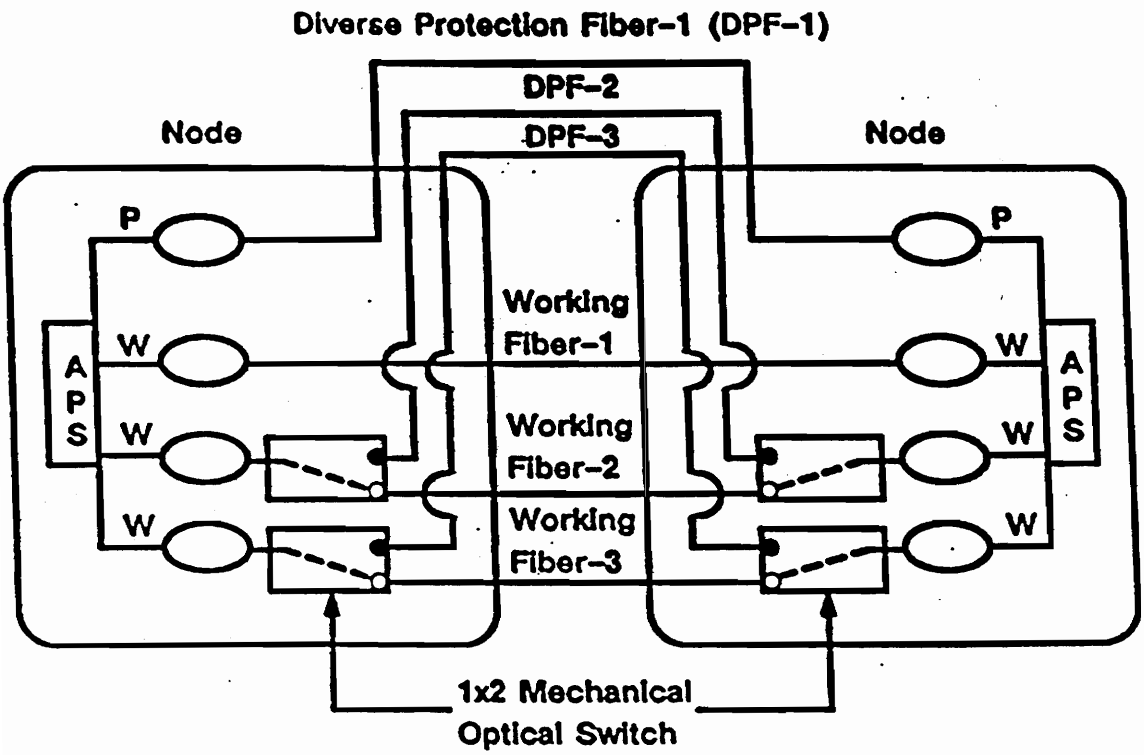


Figure 18. Survivable Network Architecture.

protection (SH/1:N EP/1:1/OP)

Figure 18 depicts the survivable architectures derived from the described protection mechanisms Architecture #6 is a hybrid architecture which combines the high survivability of the SH/1:1/DP architecture with the relatively lower cost of the SH/1:N/DP architecture.As illustrated in figure 19, 1*2 mechanical optical switches are used as protection switches[5]. The terminal electronics cost remains similar to that of the 1:N protection scheme,with the added advantage that the survivability mirrors that of the 1:1 protection scheme.In this situation the APS is modified to monitor the working systems and control the 1*2 mechanical optical switches, thus requiring no manual intervention.It should be noted that diverse protection applies to special buildings and hubs and, when used, dual homing applies only to selected special buildings. Also, spans with 1:N protection can only use one transmission rate whereas multirate spans are allowed for 1:1 systems.



DPF=Diverse Protection Fibers
W=Working P=Protection
APS=Automatic Protection Switch

Figure 19. Hybrid Architecture using Protection Optical Switches.

7.NETWORK COST CALCULATION

The total network cost comprises facility and equipment cost.These include:

1. Working terminal cost
2. Protection terminal cost
3. APS cost
4. Fiber placement cost
5. Regenerator cost
6. Fiber material cost
7. 1*2 mechanical optical switches.

The terminal cost includes the cost of termination equipment and optical line terminating multiplexers (OLTMs)
The cost figures obtained from traffic multiplexing are more accurate than those derived simply from circuit to DS3 bundling and transmission in 5.5.5 The major criterion for cost analysis is to minimize the total network cost using alternate transmission rates.

An important barometer used to gauge the tradeoff between cost and survivability is the cost_to_survivability ratio (CSR) computed as follows:

$$CSR = \frac{\text{total network design cost}}{\text{network surv.(\%) * total number of circuits}}$$

The CSR is inversely proportional to the network survivability and therefore a relatively low CSR value is desirable because it either represents a cost_effective design or high network survivability.

8.0 RESULTS AND PERFORMANCE ANALYSIS

8.1 RESULTS.

Using six different fiber transmission rates reflecting prevailing fiber technology,viz

45 Mbps (1 DS3)

90 Mbps (2 DS3s)

135 Mbps (3 DS3s)

405 Mbps (9 DS3s)

565 Mbps (12 DS3s)

1.2 Gbps (24 DS3s)

and six survivable candidate network architectures,the following results were obtained.

TABLE 2. CANDIDATE NETWORK COSTS

Architecture	Cost ($K)	Cost Penalty
SH 1:N	21009	-
SH 1:N/DP	23004	9.4%
SH 1:1/DP	23389	11.3%
SH 1:1+1:N/DP	22778	8.4%
SH 1:N/EP/1:1/OP	21417	1.9%
DH 1:N/DP	24471	16.4%

TABLE 3. NETWORK SURVIVABILITY

ARCHITECTURE	WLS(%)	ALS(%)	WHS(%)	AHS(%)
SH 1:N	73.1	96.4	39.2	82.6
SH 1:N/DP	78.5	97.9	36.1	82.3
SH 1:1/DP	78.5	99.0	39.1	82.6
SH 1:1+1:N/DP	78.0	98.7	39.1	87.9
SH 1:N/EP/1:N/OP	95.9	99.8	79.0	93.8
DH 1:N/DP	95.0	99.8	81.2	94.0

WLS worst case link survivability

ALS average link survivability

WHS worst case hub survivability

AHS average hub survivability

TABLE 4. NETWORK COST TO SURVIVABILITY RATIO

ARCHITECTURE	CSR(WLS)	CSR(ALS)	CSR(WHS)	CSR(AHS)
SH 1:N	160.3	121.5	289.78	141.6
SH 1:N/DP	157.9	126.6	343.3	150.7
SH 1:1/DP	168.2	133.5	338.0	159.8
SH 1:1+1:N/DP	156.4	124.0	314.0	148.0
SH 1:N/EP/1:1/OP	123.7	118.9	146.9	126.1
DH 1:N/DP	137.2	131.8	162.1	140.1

CSR(WLS) cost-to-survivability ratio for worst case link survivability.

CSR(ALS) cost-to-survivability ratio for average case link survivability.

CSR(WHS) cost-to-survivability ratio for worst case hub survivability

CSR(AHS) cost-to-survivability for average case hub survivability

8.2 PERFORMANCE ANALYSIS

Network analysis for the different candidate architectures is made relative to the base case SH 1:N architecture since this is widely used.The survivability statistics critical to the selection of a suitable architecture for deployment are those referring to the worst case survivability(i.e.,the lowest percentage of circuits surviving over all possible singly occurring failures) including :

1. Fiber cable cuts affecting all systems within a link.
2. Total failure of all equipment within a hub office

Furthermore,the CSR which represents the cost in dollars per survivable circuit is used to evaluate the cost versus survivability tradeoffs.It is therefore a crucial factor which determines the selection of a particular architecture. Bearing in mind that the design objective is to produce a minimum cost fiber optic communication network with the following survivability figures;

1. minimum worst case link survivability 90%
2. minimum worst case hub survivability 75%

it is evident from Table 3 that architectures SH 1:N, SH 1:N/DP,SH 1:1/DP and SH 1:1+1:N/DP do not meet the criteria.

The hybrid SH 1:N/EP/1:1/OP has a slightly better link survivability figure than does the DH 1:N/DP. Though the DH 1:N/DP performs better in case of hub failures(81.2%),the cost penalty is higher(16.4%,from Table 2)

Justification for the selection of the compromise SH 1:N/EP/1:1/OP lies in its relatively low cost(1.9% cost penalty over the base case),its high link survivability (95.9%),and a reasonable WHS figure(79%).More often than not,fiber cable cuts are the prevalent sources of failure thereby making the link survivability figures more important than the less occurring hub or DCS failures.Moreover,the CSR figures which allow numerical comparison of cost versus survivability tradeoffs are smaller for the chosen SH 1:N/EP/1:1/OP architecture than they are for the rival DH 1:N/DP architecture.Finally, another factor favoring the selection of the SH I:N/EP/1:1/OP architecture is that single homing architectures are generally easier to plan and administer than dual homing architectures.The tradeoffs would have have to be overwhelmingly in favor of the dual homing architecture to overcome the relative difficulties encountered in their planning and administration,and to justify their selection over comparable single homing structures.

9.0 SUMMARY AND CONCLUSION

This design proposes a minimum cost topology for fiber layout, an optimal end-to-end circuit demand routing scheme,and a survivable multiplexing architecture for a fiber-based communication network as a candidate for possible deployment in the city of Yaounde,Cameroon.The network contains 100 nodes of which 2 are gateways,5 hubs,and 14 special buildings.The designation of a building as a special building is contingent upon the cost/benefit factors involved,thereby mandating extra-survivability and a connectivity of two in the network topology.The general connectivity and survivability requirements as obtained from the Ministry of Post and Telecommunications,Yaoúnde are specified in the problem and traffic files.They also contain the end-to-end circuit demand requirement and the overall link and hub survivability figures that must be met.The cost figures used are based on local BELLCORE figures and would be subject to variation to suit the local reality in Cameroon.

Based on the minimum cost topology for fiber layout,six survivable multiplex architectures are modeled and a hybrid architecture,the SH 1:N/EP/1:1/OP is selected based on:

(i) Its low cost penalty relative to the base architecture (1.9%),

(ii) Its high worst case link survivability (95.9%) which more than meets the specified design requirements,

(iii) Its relatively low cost_to_survivability(CSR) figures (WLS,123.7) and (WHS,146.1)

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EDNCUN  156  133    7    1    0    1    1
EYUSDX  164  131    7    1    0    1    1
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NGASSA  187  151    7    1    0    1    1
CHUMFO  156  147    7    1    0    1    1
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MOENYH	167	63	3	1	0	1	1
MOPNYJ	156	48	3	1	0	1	1
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APPENDIX B. Traffic File

182

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1002

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APPENDIX C

This appendix summarizes the method used to compute network survivability due to fiber cable cuts for architecture SH/1:N/DP.

LS_k Link survivability

LS Network survivability due to cable cuts which is defined as the minimum one of $\{LS_k\}$

f_i Demand requirement for DS3 demand pair i that will be lost when link k fails

f_i, if the routing path for demand pair i passes through link k,

0, otherwise

g_{ik} Demand that can be restored for DS3 demand pair i passing through link k when link k fails

$n_k(i)$ number of spans in the routing path for demand pair i that passes through link k

S^j_{ik} the jth span in the routing path for demand pair i that passes through link $k, j=1,...,n_k(i)$

C^j_{ik} fiber capacity for span S^j_{ik},

R^J_{IK} Remaining capacity that can be used to restore demand for S^J_{IK} when link k fails.

Then LS_k and LS for architectures with 1:N diverse protection can be computed as follows:

$$LS_k = \frac{\sum_i f_i - \{\sum_i (f_{ik} - g_{ik})\}}{\sum_i f_i}$$

and

$$LS = \min_K \{LS_K\}$$

where g_{ik} is computed by the following procedure:

1.For each S^J_{IK} $(J=1,...,n_k(i))$ set initial

$$R^J_{IK} = \begin{cases} C^J_{IK}, & \text{if two ends of } S^j_{ik} \text{ are special COs or hubs} \\ 0, & \text{otherwise} \end{cases}$$

2. For each demand pair i, compute g_{ik} as follows until all demand pairs have been processed:

a) compute $g_{ik} = \min \{ f_{ik}, R^{j}_{ik}, \ldots, R^{nk}(i_{ik}) \}$

b) update R^{j}_{ik} -- $R^{j}_{ik} - g_{ik}$.

[1]

APPENDIX D

********* ENTIRE NETWORK DATA *********

The network has 2 sectors whose gateways are:
gateway(1) = 15
gateway(2) = 94

*** hub(i,j) means the j-th hub of the i-th sector ***
hub(1, 1) = 1
hub(1, 2) = 11
hub(1, 3) = 15
hub(1, 4) = 34
hub(2, 1) = 57
hub(2, 2) = 84
hub(2, 3) = 94

total number of nodes = 100

**** building = 2 : special building or hub which requires 2-connectivity ;
**** building = 1 : building which requires 1-connectivity ;
**** building = 0 : building which requires 0-connectivity ;

node#	sector#	cluster#	local node#	building	home_hub	for_hub	name
1	1	1	1	1	1	0	AZNBCD
2	1	1	2	1	1	0	YOMANE
3	1	1	3	1	1	0	EDNCUN
4	1	1	4	1	1	0	EYUSDX
5	1	1	5	1	1	0	HSGRYJ
6	1	1	6	1	1	0	NGASSA
7	1	1	7	1	1	0	CHUMFO
8	1	1	8	1	1	0	RODNNN
9	1	1	9	1	1	0	TBMOYH
10	1	1	10	1	1	0	XSMLNO
11	1	2	1	2	11	0	ESCRGB
12	1	2	2	1	11	0	ESCRDB
13	1	2	3	2	11	0	ESCRPR
14	1	2	4	2	11	0	UBZMXL
15	1	3	1	2	15	0	EUSTCM
16	1	3	2	1	15	0	EUSTDM
17	1	3	3	1	15	0	EUSTIH
18	1	3	4	1	15	0	EUSTMY
19	1	3	5	1	15	0	EUSTND
20	1	3	6	1	15	0	EUSTOJ
21	1	3	7	1	15	0	EUSTRF
22	1	3	8	2	15	0	EUSTRH
23	1	3	9	1	15	0	EUSTRW
24	1	3	10	2	15	0	EUSTTF
25	1	3	11	2	15	0	EUSTTX
26	1	3	12	1	15	0	EUSTVW
27	1	3	13	2	15	0	EUSTWT
28	1	3	14	1	15	0	EUSTWX
29	1	3	15	1	15	0	IHRLUT
30	1	3	16	2	15	0	MORLBU
31	1	3	17	1	15	0	SLXERW
32	1	3	18	1	15	0	USFONN
33	1	3	19	1	15	0	XZOENN
34	1	4	1	2	34	0	RMNPMO
35	1	4	2	1	34	0	CJUOFT
36	1	4	3	1	34	0	CMWMBV
37	1	4	4	1	34	0	DBUOCT
38	1	4	5	1	34	0	FSJEYH
39	1	4	6	1	34	0	GMSLFR
40	1	4	7	1	34	0	INCHMO
41	1	4	8	1	34	0	IPXMNO

42	1	4	9	1	34	0	ISMEHR
43	1	4	10	2	34	0	MJWONN
44	1	4	11	1	34	0	MJWONX
45	1	4	12	1	34	0	NPOSMN
46	1	4	13	1	34	0	NPOSNF
47	1	4	14	1	34	0	OCUNNN
48	1	4	15	1	34	0	OSWMNN
49	1	4	16	1	34	0	OXRUYJ
50	1	4	17	1	34	0	SNMTMO
51	1	4	18	1	34	0	TMZONN
52	1	4	19	1	34	0	UNRSYH
53	1	4	20	2	34	0	XBZONN
54	1	4	21	2	34	0	XBZONW
55	1	4	22	1	34	0	XJMTWM
56	1	4	23	1	34	0	ZRTMNO
57	2	1	1	1	57	0	GMOUNN
58	2	1	2	1	57	0	BMNUYH
59	2	1	3	1	57	0	CUOHRG
60	2	1	4	1	57	0	CZSOBY
61	2	1	5	1	57	0	DCWMYH
62	2	1	6	1	57	0	DMJPNO
63	2	1	7	1	57	0	ESZDYH
64	2	1	8	1	57	0	EWTOYH
65	2	1	9	1	57	0	GMOUNF
66	2	1	10	1	57	0	GMOUNS
67	2	1	11	1	57	0	GMOUNX
68	2	1	12	1	57	0	GMTIFS
69	2	1	13	1	57	0	GOUNNN
70	2	1	14	1	57	0	HESDYK
71	2	1	15	1	57	0	HSCMNO
72	2	1	16	1	57	0	IEMZYJ
73	2	1	17	1	57	0	IMMZHY
74	2	1	18	1	57	0	JNDZYI
75	2	1	19	1	57	0	MOENYH
76	2	1	20	1	57	0	MOPNYJ
77	2	1	21	1	57	0	MRFSMQ
78	2	1	22	1	57	0	NUSTYJ
79	2	1	23	1	57	0	OCSNYH
80	2	1	24	1	57	0	OMUIYK
81	2	1	25	1	57	0	PUWMYH
82	2	1	26	1	57	0	SOLNYH
83	2	1	27	1	57	0	TXDSYH
84	2	2	1	1	84	0	NUDMMO
85	2	2	2	1	84	0	BMHONN
86	2	2	3	1	84	0	ISJTNO
87	2	2	4	1	84	0	NSDZMO
88	2	2	5	1	84	0	NUDMCM
89	2	2	6	1	84	0	NUDMOS
90	2	2	7	1	84	0	OCNSMN
91	2	2	8	1	84	0	OXINNN
92	2	2	9	1	84	0	STWMNO
93	2	2	10	1	84	0	STWMOR
94	2	3	1	2	94	0	ROUDNN
95	2	3	2	1	94	0	BCIHNO
96	2	3	3	1	94	0	BSNEMO
97	2	3	4	1	94	0	DLUONN
98	2	3	5	1	94	0	DNSCCM
99	2	3	6	1	94	0	DNSCOR
100	2	3	7	1	94	0	ESRMNO

total number of links = 105

link #	link	link length (miles)
1	(1, 2)	4.7
2	(1, 4)	9.7
3	(1, 9)	15.4
4	(1,10)	11.9

5	(2,56)	4.9
6	(2, 6)	12.0
7	(3, 4)	7.7
8	(3, 7)	12.5
9	(4, 8)	10.7
10	(5, 8)	8.1
11	(11,13)	2.4
12	(11,12)	2.8
13	(12,53)	6.2
14	(12,14)	4.8
15	(13,15)	5.6
16	(14,30)	5.0
17	(15,24)	2.9
18	(15,23)	1.7
19	(15,28)	4.1
20	(15,18)	6.1
21	(15,21)	4.4
22	(15,16)	1.4
23	(16,19)	2.1
24	(17,24)	2.9
25	(17,27)	2.7
26	(18,20)	3.3
27	(19,29)	2.4
28	(19,24)	2.7
29	(21,22)	4.2
30	(22,25)	5.3
31	(25,29)	3.7
32	(25,94)	7.5
33	(26,29)	3.7
34	(27,94)	7.0
35	(28,30)	5.5
36	(30,33)	3.4
37	(31,32)	6.3
38	(32,33)	5.5
39	(57,59)	4.5
40	(57,66)	4.2
41	(57,67)	4.5
42	(58,74)	5.7
43	(59,64)	10.0
44	(59,71)	4.8
45	(59,77)	19.3
46	(60,75)	16.0
47	(61,77)	10.6
48	(61,79)	13.2
49	(61,81)	5.5
50	(62,66)	5.6
51	(63,74)	9.1
52	(65,66)	4.2
53	(67,68)	7.1
54	(67,76)	6.7
55	(67,83)	7.9
56	(68,78)	9.8
57	(68,80)	9.7
58	(69,73)	4.8
59	(69,75)	4.5
60	(42,69)	0.5
61	(70,71)	8.9
62	(71,73)	7.5
63	(71,82)	5.4
64	(72,77)	11.6
65	(73,97)	0.4
66	(74,77)	13.3
67	(84,88)	5.5
68	(84,89)	5.8
69	(84,93)	3.4
70	(85,86)	4.8
71	(85,87)	10.0
72	(87,90)	15.6

73	(89,90)	6.7
74	(89,91)	6.0
75	(91,96)	0.7
76	(92,93)	4.4
77	(34,48)	6.1
78	(34,54)	4.0
79	(34,43)	6.8
80	(34,44)	6.0
81	(35,40)	6.3
82	(35,51)	10.4
83	(35,41)	9.8
84	(36,50)	8.1
85	(36,55)	7.1
86	(36,54)	8.8
87	(37,39)	6.8
88	(38,52)	4.7
89	(38,45)	10.5
90	(39,49)	13.7
91	(39,50)	10.0
92	(39,45)	12.5
93	(43,53)	8.3
94	(45,46)	6.6
95	(47,50)	5.6
96	(48,94)	6.0
97	(48,51)	10.3
98	(53,54)	8.0
99	(54,56)	8.9
100	(94,100)	5.6
101	(94,95)	7.3
102	(94,96)	9.5
103	(97,99)	0.4
104	(97,100)	3.4
105	(98,99)	5.2

Total number of demand pairs = 205

pair#	demand pair	DS3 demands
1	(1, 2)	4
2	(1, 15)	5
3	(1, 34)	9
4	(1, 56)	2
5	(2, 15)	2
6	(2, 34)	2
7	(2, 56)	1
8	(11, 12)	5
9	(11, 13)	5
10	(11, 15)	8
11	(11, 23)	1
12	(11, 30)	3
13	(11, 43)	1
14	(12, 13)	1
15	(12, 14)	1
16	(12, 15)	4
17	(12, 30)	1
18	(12, 43)	1
19	(12, 53)	1
20	(13, 15)	3
21	(13, 28)	1
22	(14, 15)	1
23	(14, 30)	1
24	(14, 33)	1
25	(14, 34)	2
26	(14, 50)	1
27	(15, 16)	8
28	(15, 17)	6
29	(15, 18)	6

30	(15, 19)	15
31	(15, 20)	5
32	(15, 21)	7
33	(15, 22)	6
34	(15, 23)	12
35	(15, 24)	5
36	(15, 25)	5
37	(15, 26)	9
38	(15, 27)	7
39	(15, 28)	6
40	(15, 29)	7
41	(15, 30)	5
42	(15, 32)	4
43	(15, 33)	6
44	(15, 57)	2
45	(15, 84)	3
46	(15, 88)	1
47	(15, 89)	1
48	(15, 92)	3
49	(15, 93)	3
50	(15, 34)	8
51	(15, 43)	2
52	(15, 48)	1
53	(15, 50)	1
54	(15, 53)	2
55	(15, 94)	7
56	(15, 95)	2
57	(16, 19)	2
58	(16, 24)	1
59	(16, 26)	1
60	(17, 24)	1
61	(17, 26)	2
62	(17, 27)	2
63	(17, 29)	1
64	(18, 20)	1
65	(18, 21)	1
66	(18, 22)	1
67	(18, 26)	1
68	(19, 21)	1
69	(19, 23)	1
70	(19, 24)	1
71	(19, 25)	1
72	(19, 26)	1
73	(19, 29)	1
74	(20, 22)	1
75	(20, 92)	1
76	(21, 22)	1
77	(21, 25)	1
78	(21, 26)	1
79	(21, 29)	1
80	(22, 25)	1
81	(22, 92)	1
82	(24, 26)	1
83	(24, 27)	1
84	(24, 29)	1
85	(25, 26)	1
86	(25, 29)	1
87	(26, 27)	3
88	(26, 29)	1
89	(27, 29)	1
90	(28, 30)	2
91	(30, 33)	1
92	(30, 34)	2
93	(32, 33)	1
94	(57, 59)	6
95	(57, 62)	3
96	(57, 65)	3
97	(57, 66)	6

98	(57, 67)	6
99	(57, 68)	2
100	(57, 69)	3
101	(57, 71)	4
102	(57, 83)	2
103	(57, 94)	9
104	(83, 94)	1
105	(84, 88)	3
106	(84, 92)	4
107	(84, 93)	4
108	(92, 93)	2
109	(34, 35)	3
110	(34, 43)	9
111	(34, 44)	4
112	(34, 45)	4
113	(34, 48)	5
114	(34, 50)	4
115	(34, 53)	6
116	(34, 54)	4
117	(34, 56)	6
118	(43, 44)	1
119	(43, 53)	1
120	(94, 95)	3
121	(94, 97)	2
122	(94, 98)	2
123	(94, 99)	2
124	(1, 94)	1
125	(4, 34)	1
126	(6, 34)	1
127	(8, 34)	1
128	(9, 34)	1
129	(11, 34)	3
130	(11, 94)	1
131	(12, 34)	1
132	(13, 34)	1
133	(11, 17)	1
134	(17, 34)	1
135	(11, 19)	1
136	(19, 34)	1
137	(84, 94)	7
138	(19, 94)	1
139	(20, 94)	1
140	(22, 84)	1
141	(23, 94)	1
142	(11, 24)	1
143	(25, 94)	1
144	(11, 26)	1
145	(26, 34)	1
146	(26, 94)	1
147	(11, 27)	1
148	(27, 34)	1
149	(11, 28)	1
150	(28, 34)	1
151	(29, 94)	1
152	(11, 32)	1
153	(34, 39)	3
154	(32, 34)	2
155	(33, 34)	1
156	(34, 94)	2
157	(41, 94)	1
158	(43, 94)	1
159	(11, 14)	3
160	(1, 11)	1
161	(57, 77)	2
162	(57, 64)	2
163	(84, 89)	2
164	(84, 90)	2
165	(34, 36)	3

166	(34, 41)	2
167	(34, 51)	2
168	(1, 3)	2
169	(1, 9)	1
170	(34, 37)	1
171	(15, 31)	1
172	(1, 4)	1
173	(1, 5)	1
174	(1, 6)	1
175	(1, 7)	1
176	(1, 8)	1
177	(1, 10)	1
178	(57, 58)	1
179	(57, 60)	1
180	(57, 61)	1
181	(57, 63)	1
182	(57, 70)	1
183	(57, 72)	1
184	(57, 73)	1
185	(57, 74)	1
186	(57, 75)	1
187	(57, 76)	1
188	(57, 78)	1
189	(57, 79)	1
190	(57, 80)	1
191	(57, 81)	1
192	(57, 82)	1
193	(84, 85)	1
194	(84, 86)	1
195	(84, 87)	1
196	(84, 91)	1
197	(34, 38)	1
198	(34, 40)	1
199	(34, 42)	1
200	(34, 46)	1
201	(34, 47)	1
202	(34, 49)	1
203	(34, 52)	1
204	(34, 55)	1
205	(94, 96)	1

Total number of DS3s in the entire network = 485

***** Cost Function ****

Fiber material cost = $ 1700.00 per mile per fiber pair
Fiber placement cost = $ 5000.00 per route mile
1 x 2 mechanical optical switch cost = $ 1000.00 (for each)
Distance threshold required for a regenerator = 30.00 miles

Total number of transmission systems = 6

system#	DS3 rate	max_N (for 1:N)	regenerator cost ($k)
1	1	1	6.88
2	2	11	10.83
3	3	15	13.83
4	9	15	19.42
5	12	15	27.64
6	24	15	49.10

------ Terminal Cost -----

** NOTE : THE COST UNIT IS $1,000

system#	DS3= 1	DS3= 2	DS3= 3	DS3= 4	DS3= 5	DS3= 6
1	7.11	*	*	*	*	*
2	9.30	10.40	*	*	*	*
3	10.56	11.61	12.66	*	*	*
4	22.14	22.14	22.14	26.60	26.60	26.60
5	34.18	34.18	34.18	37.24	37.24	37.24
6	70.44	70.44	70.44	73.50	73.50	73.50

system#	DS3= 7	DS3= 8	DS3= 9	DS3= 10	DS3= 11	DS3= 12
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	31.07	31.07	31.07	*	*	*
5	42.80	42.80	42.80	45.86	45.86	45.86
6	79.06	79.06	79.06	82.12	82.12	82.12

system#	DS3= 13	DS3= 14	DS3= 15	DS3= 16	DS3= 17	DS3= 18
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	*	*	*	*	*	*
5	*	*	*	*	*	*
6	87.68	87.68	87.68	90.74	90.74	90.74

system#	DS3= 19	DS3= 20	DS3= 21	DS3= 22	DS3= 23	DS3= 24
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	*	*	*	*	*	*
5	*	*	*	*	*	*
6	96.30	96.30	96.30	99.36	99.36	99.36

----- Bay Cost -----

system#	N= 1	N= 2	N= 3	N= 4	N= 5	N= 6	N= 7	N= 8
1	0.00	*	*	*	*	*	*	*
2	0.40	0.40	0.40	0.40	0.88	0.88	0.88	0.88
3	3.39	3.39	6.79	6.79	6.79	10.19	10.19	10.19
4	6.26	9.39	12.52	15.65	18.78	21.91	25.04	28.17
5	0.22	0.22	0.44	0.44	0.66	0.66	0.88	0.88
6	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60

system#	N= 9	N=10	N=11	N=12	N=13	N=14	N=15
1	*	*	*	*	*	*	*
2	0.88	0.88	0.88	*	*	*	*
3	13.58	13.58	13.58	16.98	16.98	16.98	20.37
4	31.30	34.43	37.56	40.69	43.82	46.95	50.08
5	1.01	1.01	1.32	1.32	1.54	1.54	1.76
6	1.80	2.00	2.20	2.40	2.60	2.80	3.00

*** Network Design Process for Sector 1 ***

The gateway = 15
hub(1) = 1
hub(2) = 11
hub(3) = 15
hub(4) = 34

total number of nodes = 56

**** building = 2 : special building or hub which requires 2-connectivity ;
**** building = 1 : building which requires 1-connectivity ;
**** building = 0 : building which requires 0-connectivity ;

node#	sector#	cluster#	local node#	building	home_hub	for_hub	name
1	1	1	1	1	1	0	AZNBCD
2	1	1	2	1	1	0	YOMANE
3	1	1	3	1	1	0	EDNCUN
4	1	1	4	1	1	0	EYUSDX
5	1	1	5	1	1	0	HSGRYJ
6	1	1	6	1	1	0	NGASSA
7	1	1	7	1	1	0	CHUMFO
8	1	1	8	1	1	0	RODNNN
9	1	1	9	1	1	0	TBMOYH
10	1	1	10	1	1	0	XSMLNO
11	1	2	1	2	11	0	ESCRGB
12	1	2	2	1	11	0	ESCRDB
13	1	2	3	2	11	0	ESCRPR
14	1	2	4	2	11	0	UBZMXL
15	1	3	1	2	15	0	EUSTCM
16	1	3	2	1	15	0	EUSTDM
17	1	3	3	1	15	0	EUSTIH
18	1	3	4	1	15	0	EUSTMY
19	1	3	5	1	15	0	EUSTND
20	1	3	6	1	15	0	EUSTOJ
21	1	3	7	1	15	0	EUSTRF
22	1	3	8	2	15	0	EUSTRH
23	1	3	9	1	15	0	EUSTRW
24	1	3	10	2	15	0	EUSTTF
25	1	3	11	2	15	0	EUSTTX
26	1	3	12	1	15	0	EUSTVW
27	1	3	13	2	15	0	EUSTWT
28	1	3	14	1	15	0	EUSTWX
29	1	3	15	1	15	0	IHRLUT
30	1	3	16	2	15	0	MORLBU
31	1	3	17	1	15	0	SLXERW
32	1	3	18	1	15	0	USFONN
33	1	3	19	1	15	0	XZOENN
34	1	4	1	2	34	0	RMNPMO
35	1	4	2	1	34	0	CJUOFT
36	1	4	3	1	34	0	CMWMBV
37	1	4	4	1	34	0	DBUOCT
38	1	4	5	1	34	0	FSJEYH
39	1	4	6	1	34	0	GMSLFR
40	1	4	7	1	34	0	INCHMO
41	1	4	8	1	34	0	IPXMNO
42	1	4	9	1	34	0	ISMEHR
43	1	4	10	2	34	0	MJWONN
44	1	4	11	1	34	0	MJWONX
45	1	4	12	1	34	0	NPOSMN
46	1	4	13	1	34	0	NPOSNF
47	1	4	14	1	34	0	OCUNNN
48	1	4	15	1	34	0	OSWMNN
49	1	4	16	1	34	0	OXRUYJ
50	1	4	17	1	34	0	SNMTMO
51	1	4	18	1	34	0	TMZONN
52	1	4	19	1	34	0	UNRSYH
53	1	4	20	2	34	0	XBZONN
54	1	4	21	2	34	0	XBZONW
55	1	4	22	1	34	0	XJMTWM
56	1	4	23	1	34	0	ZRTMNO

span #	span	working span route (span length)	protection span route (span length)
1	(1, 2)	1- 2- (4.7)	(0.0)
2	(1, 3)	1- 4- 3- (17.4)	(0.0)
3	(1, 4)	1- 4- (9.7)	(0.0)
4	(1, 5)	1- 4- 8- 5- (28.5)	(0.0)
5	(1, 6)	1- 2- 6- (16.7)	(0.0)
6	(1, 7)	1- 4- 3- 7- (29.9)	(0.0)
7	(1, 8)	1- 4- 8- (20.4)	(0.0)

```
  8   ( 1, 9)   1- 9-   ( 15.4 )        (  0.0 )
  9   ( 1,10)   1- 10-   ( 11.9 )        (  0.0 )
 10   (11,12)   11- 12-   (  2.8 )        (  0.0 )
 11   (11,13)   11- 13-   (  2.4 )     11- 12- 14- 30- 28- 15- 13-   ( 27.8 )
 12   (11,14)   11- 12- 14-   (  7.6 )     11- 13- 15- 28- 30- 14-   ( 22.6 )
 13   (15,16)   15- 16-   (  1.4 )        (  0.0 )
 14   (15,17)   15- 24- 17-   (  5.8 )        (  0.0 )
 15   (15,18)   15- 18-   (  6.1 )        (  0.0 )
 16   (15,19)   15- 16- 19-   (  3.5 )        (  0.0 )
 17   (15,20)   15- 18- 20-   (  9.4 )        (  0.0 )
 18   (15,21)   15- 21-   (  4.4 )        (  0.0 )
 19   (15,22)   15- 21- 22-   (  8.6 )     15- 16- 19- 29- 25- 22-   ( 14.9 )
 20   (15,23)   15- 23-   (  1.7 )        (  0.0 )
 21   (15,24)   15- 24-   (  2.9 )     15- 16- 19- 24-   (  6.2 )
 22   (15,25)   15- 16- 19- 29- 25-   (  9.6 )     15- 21- 22- 25-   ( 13.9 )
 23   (15,26)   15- 16- 19- 29- 26-   (  9.6 )        (  0.0 )
 24   (15,27)   15- 24- 17- 27-   (  8.5 )     15- 16- 19- 29- 25- 94- 27-   ( 24.1 )
 25   (15,28)   15- 28-   (  4.1 )        (  0.0 )
 26   (15,29)   15- 16- 19- 29-   (  5.9 )        (  0.0 )
 27   (15,30)   15- 28- 30-   (  9.6 )     15- 13- 11- 12- 14- 30-   ( 20.6 )
 28   (15,31)   15- 28- 30- 33- 32- 31-   ( 24.8 )        (  0.0 )
 29   (15,32)   15- 28- 30- 33- 32-   ( 18.5 )        (  0.0 )
 30   (15,33)   15- 28- 30- 33-   ( 13.0 )        (  0.0 )
 31   (34,35)   34- 48- 51- 35-   ( 26.8 )        (  0.0 )
 32   (34,36)   34- 54- 36-   ( 12.8 )        (  0.0 )
 33   (34,37)   34- 54- 36- 50- 39- 37-   ( 37.7 )        (  0.0 )
 34   (34,38)   34- 54- 36- 50- 39- 45- 38-   ( 53.9 )        (  0.0 )
 35   (34,39)   34- 54- 36- 50- 39-   ( 30.9 )        (  0.0 )
 36   (34,40)   34- 48- 51- 35- 40-   ( 33.1 )        (  0.0 )
 37   (34,41)   34- 48- 51- 35- 41-   ( 36.6 )        (  0.0 )
 38   (34,42)   34- 48- 94- 100- 97- 73- 69- 42-   ( 26.8 )        (  0.0 )
 39   (34,43)   34- 43-   (  6.8 )     34- 54- 53- 43-   ( 20.3 )
 40   (34,44)   34- 44-   (  6.0 )        (  0.0 )
 41   (34,45)   34- 54- 36- 50- 39- 45-   ( 43.4 )        (  0.0 )
 42   (34,46)   34- 54- 36- 50- 39- 45- 46-   ( 50.0 )        (  0.0 )
 43   (34,47)   34- 54- 36- 50- 47-   ( 26.5 )        (  0.0 )
 44   (34,48)   34- 48-   (  6.1 )        (  0.0 )
 45   (34,49)   34- 54- 36- 50- 39- 49-   ( 44.6 )        (  0.0 )
 46   (34,50)   34- 54- 36- 50-   ( 20.9 )        (  0.0 )
 47   (34,51)   34- 48- 51-   ( 16.4 )        (  0.0 )
 48   (34,52)   34- 54- 36- 50- 39- 45- 38- 52-   ( 58.6 )        (  0.0 )
 49   (34,53)   34- 54- 53-   ( 12.0 )     34- 43- 53-   ( 15.1 )
 50   (34,54)   34- 54-   (  4.0 )     34- 43- 53- 54-   ( 23.1 )
 51   (34,55)   34- 54- 36- 55-   ( 19.9 )        (  0.0 )
 52   (34,56)   34- 54- 56-   ( 12.9 )        (  0.0 )
 53   ( 1,15)   1- 2- 56- 54- 53- 12- 11- 13- 15-   ( 43.5 )     1- 2- 56- 54- 53- 12- 11- 13-
15-   ( 43.5 )
 54   (11,15)   11- 13- 15-   (  8.0 )     11- 12- 14- 30- 28- 15-   ( 22.2 )
 55   (15,34)   15- 24- 17- 27- 94- 48- 34-   ( 27.6 )     15- 13- 11- 12- 53- 54- 34-   ( 29.0
)
 56   ( 1,11)   1- 2- 56- 54- 53- 12- 11-   ( 35.5 )     1- 2- 56- 54- 53- 12- 11-   ( 35.5 )
 57   ( 1,34)   1- 2- 56- 54- 34-   ( 22.5 )     1- 2- 56- 54- 34-   ( 22.5 )
 58   (11,34)   11- 12- 53- 54- 34-   ( 21.0 )     11- 13- 15- 24- 17- 27- 94- 48- 34-   ( 35.6
)

total number of links = 66

link #   link    link length

  1   ( 1, 2)    4.7
  2   ( 1, 4)    9.7
  3   ( 1, 9)    15.4
  4   ( 1,10)    11.9
  5   ( 2,56)    4.9
  6   ( 2, 6)    12.0
  7   ( 3, 4)    7.7
  8   ( 3, 7)    12.5
  9   ( 4, 8)    10.7
```

10	(5, 8)	8.1
11	(11,13)	2.4
12	(11,12)	2.8
13	(12,53)	6.2
14	(12,14)	4.8
15	(13,15)	5.6
16	(14,30)	5.0
17	(15,24)	2.9
18	(15,23)	1.7
19	(15,28)	4.1
20	(15,18)	6.1
21	(15,21)	4.4
22	(15,16)	1.4
23	(16,19)	2.1
24	(17,24)	2.9
25	(17,27)	2.7
26	(18,20)	3.3
27	(19,29)	2.4
28	(19,24)	2.7
29	(21,22)	4.2
30	(22,25)	5.3
31	(25,29)	3.7
32	(25,94)	7.5
33	(26,29)	3.7
34	(94,27)	7.0
35	(28,30)	5.5
36	(30,33)	3.4
37	(31,32)	6.3
38	(32,33)	5.5
39	(73,69)	4.8
40	(69,42)	0.5
41	(97,73)	0.4
42	(34,48)	6.1
43	(34,54)	4.0
44	(34,43)	6.8
45	(34,44)	6.0
46	(35,40)	6.3
47	(35,51)	10.4
48	(35,41)	9.8
49	(36,50)	8.1
50	(36,55)	7.1
51	(36,54)	8.8
52	(37,39)	6.8
53	(38,52)	4.7
54	(38,45)	10.5
55	(39,49)	13.7
56	(39,50)	10.0
57	(39,45)	12.5
58	(43,53)	8.3
59	(45,46)	6.6
60	(47,50)	5.6
61	(48,94)	6.0
62	(48,51)	10.3
63	(53,54)	8.0
64	(54,56)	8.9
65	(94,100)	5.6
66	(100,97)	3.4

pair #	demand pair	DS3 demand
1	(1, 2)	4
2	(1, 15)	6
3	(1, 34)	9
4	(1, 56)	2
5	(2, 15)	2
6	(2, 34)	2

7	(2, 56)	1
8	(11, 12)	5
9	(11, 13)	5
10	(11, 15)	9
11	(11, 23)	1
12	(11, 30)	3
13	(11, 43)	1
14	(12, 13)	1
15	(12, 14)	1
16	(12, 15)	4
17	(12, 30)	1
18	(12, 43)	1
19	(12, 53)	1
20	(13, 15)	3
21	(13, 28)	1
22	(14, 15)	1
23	(14, 30)	1
24	(14, 33)	1
25	(14, 34)	2
26	(14, 50)	1
27	(15, 16)	8
28	(15, 17)	6
29	(15, 18)	6
30	(15, 19)	16
31	(15, 20)	7
32	(15, 21)	7
33	(15, 22)	8
34	(15, 23)	13
35	(15, 24)	5
36	(15, 25)	6
37	(15, 26)	10
38	(15, 27)	7
39	(15, 28)	6
40	(15, 29)	8
41	(15, 30)	5
42	(15, 32)	4
43	(15, 33)	6
44	(15, 34)	10
45	(15, 43)	3
46	(15, 48)	1
47	(15, 50)	1
48	(15, 53)	2
49	(16, 19)	2
50	(16, 24)	1
51	(16, 26)	1
52	(17, 24)	1
53	(17, 26)	2
54	(17, 27)	2
55	(17, 29)	1
56	(18, 20)	1
57	(18, 21)	1
58	(18, 22)	1
59	(18, 26)	1
60	(19, 21)	1
61	(19, 23)	1
62	(19, 24)	1
63	(19, 25)	1
64	(19, 26)	1
65	(19, 29)	1
66	(20, 22)	1
67	(21, 22)	1
68	(21, 25)	1
69	(21, 26)	1
70	(21, 29)	1
71	(22, 25)	1
72	(24, 26)	1
73	(24, 27)	1
74	(24, 29)	1

75	(25, 26)	1
76	(25, 29)	1
77	(26, 27)	3
78	(26, 29)	1
79	(27, 29)	1
80	(28, 30)	2
81	(30, 33)	1
82	(30, 34)	2
83	(32, 33)	1
84	(34, 35)	3
85	(34, 43)	9
86	(34, 44)	4
87	(34, 45)	4
88	(34, 48)	5
89	(34, 50)	4
90	(34, 53)	6
91	(34, 54)	4
92	(34, 56)	6
93	(43, 44)	1
94	(43, 53)	1
95	(4, 34)	1
96	(6, 34)	1
97	(8, 34)	1
98	(9, 34)	1
99	(11, 34)	3
100	(12, 34)	1
101	(13, 34)	1
102	(11, 17)	1
103	(17, 34)	1
104	(11, 19)	1
105	(19, 34)	1
106	(11, 24)	1
107	(11, 26)	1
108	(26, 34)	1
109	(11, 27)	1
110	(27, 34)	1
111	(11, 28)	1
112	(28, 34)	1
113	(11, 32)	1
114	(34, 39)	3
115	(32, 34)	2
116	(33, 34)	1
117	(11, 14)	3
118	(1, 11)	1
119	(34, 36)	3
120	(34, 41)	2
121	(34, 51)	2
122	(1, 3)	2
123	(1, 9)	1
124	(34, 37)	1
125	(15, 31)	1
126	(1, 4)	1
127	(1, 5)	1
128	(1, 6)	1
129	(1, 7)	1
130	(1, 8)	1
131	(1, 10)	1
132	(34, 38)	1
133	(34, 40)	1
134	(34, 42)	1
135	(34, 46)	1
136	(34, 47)	1
137	(34, 49)	1
138	(34, 52)	1
139	(34, 55)	1

Total number of DS3s in Sector(1) = 360

The hub-to-hub DS3 distribution is as follows:

hub pair	DS3 demands
(1, 1)	13
(1,11)	1
(1,15)	8
(1,34)	18
(11,11)	15
(11,15)	32
(11,34)	11
(15,15)	169
(15,34)	27
(34,34)	66

*** Note DS3 demands for hub pair (i,i) means ***
*** total intra-cluster demands for cluster i ***

***** Network Cost Statistics for Sector (1) *****

Network Architecture Option:	SH/1:N/EP/1:1/OP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Embedded System Option:	Not Used
Multiplexing Strategy Option:	Dedicated

Note: the cost unit is $1,000.00

span#	span	DS3s	system rate(DS3)	1:N term.	working	protection	sub_total
1	(1, 2)	10	2	5	145.8	49.6	195.4
2	(1, 3)	3	3	1	61.7	54.9	116.6
3	(1, 4)	3	3	1	48.6	41.8	90.4
4	(1, 5)	2	2	1	70.1	69.3	139.3
5	(1, 6)	3	3	1	60.5	53.7	114.2
6	(1, 7)	2	2	1	72.4	71.6	144.1
7	(1, 8)	3	3	1	66.8	60.0	126.8
8	(1, 9)	3	3	1	58.3	51.5	109.8
9	(1,10)	2	2	1	41.8	41.0	82.9
10	(11,12)	16	9	2	152.6	91.2	243.8
11	(11,13)	11	12	1	96.2	139.0	235.2
12	(11,14)	10	12	1	105.1	130.1	235.2
13	(15,16)	13	3	5	147.9	52.0	199.9
14	(15,17)	15	3	5	189.5	59.5	249.0
15	(15,18)	11	12	1	102.5	102.1	204.6
16	(15,19)	27	9	3	229.3	92.4	321.7
17	(15,20)	10	12	1	108.1	107.7	215.8
18	(15,21)	14	3	5	175.5	57.1	232.6
19	(15,22)	12	12	1	106.8	117.1	223.8
20	(15,23)	16	3	6	185.5	52.5	238.0
21	(15,24)	12	12	1	97.1	102.3	199.4
22	(15,25)	11	12	1	108.5	115.3	223.8
23	(15,26)	25	9	3	260.4	102.8	363.2
24	(15,27)	16	9	2	171.9	172.4	344.3
25	(15,28)	12	12	1	99.1	98.7	197.8
26	(15,29)	16	9	2	163.1	96.5	259.6
27	(15,30)	15	9	2	166.8	160.5	327.2
28	(15,31)	2	2	1	63.8	63.0	126.7
29	(15,32)	9	9	1	106.1	93.6	199.7
30	(15,33)	11	12	1	114.3	113.8	228.1
31	(34,35)	4	9	1	111.3	98.8	210.0
32	(34,36)	4	2	2	85.9	59.1	145.0
33	(34,37)	2	2	1	96.5	95.7	192.3
34	(34,38)	2	2	1	124.1	123.3	247.3
35	(34,39)	4	9	1	137.7	125.2	262.8
36	(34,40)	2	2	1	88.7	87.9	176.6

37	(34,41)	3	3	1	108.2	101.4	209.5
38	(34,42)	2	2	1	67.2	66.4	133.5
39	(34,43)	16	9	2	166.2	159.5	325.6
40	(34,44)	6	3	2	77.9	59.8	137.7
41	(34,45)	5	9	1	158.9	146.4	305.3
42	(34,46)	2	2	1	117.4	116.6	234.1
43	(34,47)	2	2	1	66.7	65.9	132.5
44	(34,48)	7	9	1	85.0	72.5	157.5
45	(34,49)	2	2	1	108.3	107.5	215.7
46	(34,50)	7	9	1	110.2	97.7	207.8
47	(34,51)	3	3	1	60.0	53.2	113.2
48	(34,52)	2	2	1	132.1	131.3	263.3
49	(34,53)	10	12	1	112.6	117.4	230.0
50	(34,54)	4	9	1	72.5	92.5	165.0
51	(34,55)	2	2	1	55.4	54.6	110.1
52	(34,56)	10	12	1	114.1	113.7	227.7
53	(1,15)	9	9	1	168.0	155.5	323.5
54	(11,15)	33	12	3	310.7	237.3	548.0
55	(15,34)	27	9	3	352.2	242.3	594.5
56	(1,34)	18	9	2	219.5	166.9	386.5
57	(11,34)	11	12	1	127.9	179.9	307.7

The total working system cost = 7011.1 (k)
The total protection cost = 5741.0 (k)
The total route mile cost = 2066.0 (k)
The total network cost (working + protection + route) = 14818.1 (k)

*** Network Component Cost Statistics for Sector (1) ***

span #	working terms($k)	protection terms($k)	working fiber($k)	protection fiber($k)	working regs($k)	protection regs($k)	APS ($k)	optical switches($k)
1	105.81	20.81	39.95	7.99	0.00	0.00	20.81	0.00
2	32.12	25.33	29.58	29.58	0.00	0.00	0.00	0.00
3	32.12	25.33	16.49	16.49	0.00	0.00	0.00	0.00
4	21.61	20.81	48.45	48.45	0.00	0.00	0.00	0.00
5	32.12	25.33	28.39	28.39	0.00	0.00	0.00	0.00
6	21.61	20.81	50.83	50.83	0.00	0.00	0.00	0.00
7	32.12	25.33	34.68	34.68	0.00	0.00	0.00	0.00
8	32.12	25.33	26.18	26.18	0.00	0.00	0.00	0.00
9	21.61	20.81	20.23	20.23	0.00	0.00	0.00	0.00
10	143.04	62.13	9.52	4.76	0.00	0.00	24.31	0.00
11	92.16	91.72	4.08	47.26	0.00	0.00	0.00	0.00
12	92.16	91.72	12.92	38.42	0.00	0.00	0.00	0.00
13	136.01	25.33	11.90	2.38	0.00	0.00	24.31	0.00
14	140.23	25.33	49.30	9.86	0.00	0.00	24.31	0.00
15	92.16	91.72	10.37	10.37	0.00	0.00	0.00	0.00
16	211.43	62.13	17.85	5.95	0.00	0.00	24.31	0.00
17	92.16	91.72	15.98	15.98	0.00	0.00	0.00	0.00
18	138.12	25.33	37.40	7.48	0.00	0.00	24.31	0.00
19	92.16	91.72	14.62	25.33	0.00	0.00	0.00	0.00
20	168.13	25.33	17.34	2.89	0.00	0.00	24.31	0.00
21	92.16	91.72	4.93	10.54	0.00	0.00	0.00	0.00
22	92.16	91.72	16.32	23.63	0.00	0.00	0.00	0.00
23	211.43	62.13	48.96	16.32	0.00	0.00	24.31	0.00
24	143.04	62.13	28.90	81.94	0.00	0.00	24.31	4.00
25	92.16	91.72	6.97	6.97	0.00	0.00	0.00	0.00
26	143.04	62.13	20.06	10.03	0.00	0.00	24.31	0.00
27	134.11	62.13	32.64	70.04	0.00	0.00	24.31	4.00
28	21.61	20.81	42.16	42.16	0.00	0.00	0.00	0.00
29	74.65	62.13	31.45	31.45	0.00	0.00	0.00	0.00
30	92.16	91.72	22.10	22.10	0.00	0.00	0.00	0.00
31	65.72	53.20	45.56	45.56	0.00	0.00	0.00	0.00
32	42.42	20.81	43.52	21.76	0.00	0.00	16.49	0.00
33	21.61	20.81	64.09	64.09	10.83	10.83	0.00	0.00
34	21.61	20.81	91.63	91.63	10.83	10.83	0.00	0.00
35	65.72	53.20	52.53	52.53	19.42	19.42	0.00	0.00

36	21.61	20.81	56.27	56.27	10.83	10.83	0.00	0.00
37	32.12	25.33	62.22	62.22	13.83	13.83	0.00	0.00
38	21.61	20.81	45.56	45.56	0.00	0.00	0.00	0.00
39	143.04	62.13	23.12	69.02	0.00	0.00	24.31	4.00
40	57.45	25.33	20.40	10.20	0.00	0.00	24.31	0.00
41	65.72	53.20	73.78	73.78	19.42	19.42	0.00	0.00
42	21.61	20.81	85.00	85.00	10.83	10.83	0.00	0.00
43	21.61	20.81	45.05	45.05	0.00	0.00	0.00	0.00
44	74.65	62.13	10.37	10.37	0.00	0.00	0.00	0.00
45	21.61	20.81	75.82	75.82	10.83	10.83	0.00	0.00
46	74.65	62.13	35.53	35.53	0.00	0.00	0.00	0.00
47	32.12	25.33	27.88	27.88	0.00	0.00	0.00	0.00
48	21.61	20.81	99.62	99.62	10.83	10.83	0.00	0.00
49	92.16	91.72	20.40	25.67	0.00	0.00	0.00	0.00
50	65.72	53.20	6.80	39.27	0.00	0.00	0.00	0.00
51	21.61	20.81	33.83	33.83	0.00	0.00	0.00	0.00
52	92.16	91.72	21.93	21.93	0.00	0.00	0.00	0.00
53	74.65	62.13	73.95	73.95	19.42	19.42	0.00	0.00
54	269.92	91.72	40.80	113.22	0.00	0.00	24.31	8.00
55	211.43	62.13	140.76	147.90	0.00	0.00	24.31	8.00
56	143.04	62.13	76.50	76.50	0.00	0.00	24.31	4.00
57	92.16	91.72	35.70	60.52	0.00	27.64	0.00	0.00

*** DS3 ROUTING INFORMATION ***

*** NOTE: The following set of spans in the 'routing path' column is unordered, and corresponds to the set of spans described in the above Network Cost Statistics Table.

pair#	demand pair	DS3 demands	routing miles	DS3 x miles	routing path (span set)
1	(1, 2)	4	4.7	18.8	1 ,
2	(1, 15)	6	43.5	261.0	53 ,
3	(1, 34)	9	22.5	202.5	56 ,
4	(1, 56)	2	35.4	70.8	52 , 56 ,
5	(2, 15)	2	48.2	96.4	1 , 53 ,
6	(2, 34)	2	27.2	54.4	1 , 56 ,
7	(2, 56)	1	40.1	40.1	1 , 52 , 56 ,
8	(11, 12)	5	2.8	14.0	10 ,
9	(11, 13)	5	2.4	12.0	11 ,
10	(11, 15)	9	8.0	72.0	54 ,
11	(11, 23)	1	9.7	9.7	20 , 54 ,
12	(11, 30)	3	17.6	52.8	27 , 54 ,
13	(11, 43)	1	27.8	27.8	39 , 57 ,
14	(12, 13)	1	5.2	5.2	10 , 11 ,
15	(12, 14)	1	10.4	10.4	10 , 12 ,
16	(12, 15)	4	10.8	43.2	10 , 54 ,
17	(12, 30)	1	20.4	20.4	10 , 27 , 54 ,
18	(12, 43)	1	30.6	30.6	10 , 39 , 57 ,
19	(12, 53)	1	35.8	35.8	10 , 49 , 57 ,
20	(13, 15)	3	10.4	31.2	11 , 54 ,
21	(13, 28)	1	14.5	14.5	11 , 25 , 54 ,
22	(14, 15)	1	15.6	15.6	12 , 54 ,
23	(14, 30)	1	25.2	25.2	12 , 27 , 54 ,
24	(14, 33)	1	28.6	28.6	12 , 30 , 54 ,
25	(14, 34)	2	28.6	57.2	12 , 57 ,
26	(14, 50)	1	49.5	49.5	12 , 46 , 57 ,
27	(15, 16)	8	1.4	11.2	13 ,
28	(15, 17)	6	5.8	34.8	14 ,
29	(15, 18)	6	6.1	36.6	15 ,
30	(15, 19)	16	3.5	56.0	16 ,
31	(15, 20)	7	9.4	65.8	17 ,
32	(15, 21)	7	4.4	30.8	18 ,
33	(15, 22)	8	8.6	68.8	19 ,
34	(15, 23)	13	1.7	22.1	20 ,
35	(15, 24)	5	2.9	14.5	21 ,

36	(15, 25)	6	9.6	57.6	22 ,	
37	(15, 26)	10	9.6	96.0	23 ,	
38	(15, 27)	7	8.5	59.5	24 ,	
39	(15, 28)	6	4.1	24.6	25 ,	
40	(15, 29)	8	5.9	47.2	26 ,	
41	(15, 30)	5	9.6	48.0	27 ,	
42	(15, 32)	4	18.5	74.0	29 ,	
43	(15, 33)	6	13.0	78.0	30 ,	
44	(15, 34)	10	27.6	276.0	55 ,	
45	(15, 43)	3	34.4	103.2	39 ,	55 ,
46	(15, 48)	1	33.7	33.7	44 ,	55 ,
47	(15, 50)	1	48.5	48.5	46 ,	55 ,
48	(15, 53)	2	39.6	79.2	49 ,	55 ,
49	(16, 19)	2	4.9	9.8	13 ,	16 ,
50	(16, 24)	1	4.3	4.3	13 ,	21 ,
51	(16, 26)	1	11.0	11.0	13 ,	23 ,
52	(17, 24)	1	8.7	8.7	14 ,	21 ,
53	(17, 26)	2	15.4	30.8	14 ,	23 ,
54	(17, 27)	2	14.3	28.6	14 ,	24 ,
55	(17, 29)	1	11.7	11.7	14 ,	26 ,
56	(18, 20)	1	15.5	15.5	15 ,	17 ,
57	(18, 21)	1	10.5	10.5	15 ,	18 ,
58	(18, 22)	1	14.7	14.7	15 ,	19 ,
59	(18, 26)	1	15.7	15.7	15 ,	23 ,
60	(19, 21)	1	7.9	7.9	16 ,	18 ,
61	(19, 23)	1	5.2	5.2	16 ,	20 ,
62	(19, 24)	1	6.4	6.4	16 ,	21 ,
63	(19, 25)	1	13.1	13.1	16 ,	22 ,
64	(19, 26)	1	13.1	13.1	16 ,	23 ,
65	(19, 29)	1	9.4	9.4	16 ,	26 ,
66	(20, 22)	1	18.0	18.0	17 ,	19 ,
67	(21, 22)	1	13.0	13.0	18 ,	19 ,
68	(21, 25)	1	14.0	14.0	18 ,	22 ,
69	(21, 26)	1	14.0	14.0	18 ,	23 ,
70	(21, 29)	1	10.3	10.3	18 ,	26 ,
71	(22, 25)	1	18.2	18.2	19 ,	22 ,
72	(24, 26)	1	12.5	12.5	21 ,	23 ,
73	(24, 27)	1	11.4	11.4	21 ,	24 ,
74	(24, 29)	1	8.8	8.8	21 ,	26 ,
75	(25, 26)	1	19.2	19.2	22 ,	23 ,
76	(25, 29)	1	15.5	15.5	22 ,	26 ,
77	(26, 27)	3	18.1	54.3	23 ,	24 ,
78	(26, 29)	1	15.5	15.5	23 ,	26 ,
79	(27, 29)	1	14.4	14.4	24 ,	26 ,
80	(28, 30)	2	13.7	27.4	25 ,	27 ,
81	(30, 33)	1	22.6	22.6	27 ,	30 ,
82	(30, 34)	2	37.2	74.4	27 ,	55 ,
83	(32, 33)	1	31.5	31.5	29 ,	30 ,
84	(34, 35)	3	26.8	80.4	31 ,	
85	(34, 43)	9	6.8	61.2	39 ,	
86	(34, 44)	4	6.0	24.0	40 ,	
87	(34, 45)	4	43.4	173.6	41 ,	
88	(34, 48)	5	6.1	30.5	44 ,	
89	(34, 50)	4	20.9	83.6	46 ,	
90	(34, 53)	6	12.0	72.0	49 ,	
91	(34, 54)	4	4.0	16.0	50 ,	
92	(34, 56)	6	12.9	77.4	52 ,	
93	(43, 44)	1	12.8	12.8	39 ,	40 ,
94	(43, 53)	1	18.8	18.8	39 ,	49 ,
95	(4, 34)	1	32.2	32.2	3 ,	56 ,
96	(6, 34)	1	39.2	39.2	5 ,	56 ,
97	(8, 34)	1	42.9	42.9	7 ,	56 ,
98	(9, 34)	1	37.9	37.9	8 ,	56 ,
99	(11, 34)	3	21.0	63.0	57 ,	
100	(12, 34)	1	23.8	23.8	10 ,	57 ,
101	(13, 34)	1	23.4	23.4	11 ,	57 ,
102	(11, 17)	1	13.8	13.8	14 ,	54 ,
103	(17, 34)	1	33.4	33.4	14 ,	55 ,

104	(11, 19)	1	11.5	11.5	16 ,	54 ,
105	(19, 34)	1	31.1	31.1	16 ,	55 ,
106	(11, 24)	1	10.9	10.9	21 ,	54 ,
107	(11, 26)	1	17.6	17.6	23 ,	54 ,
108	(26, 34)	1	37.2	37.2	23 ,	55 ,
109	(11, 27)	1	16.5	16.5	24 ,	54 ,
110	(27, 34)	1	36.1	36.1	24 ,	55 ,
111	(11, 28)	1	12.1	12.1	25 ,	54 ,
112	(28, 34)	1	31.7	31.7	25 ,	55 ,
113	(11, 32)	1	26.5	26.5	29 ,	54 ,
114	(34, 39)	3	30.9	92.7	35 ,	
115	(32, 34)	2	46.1	92.2	29 ,	55 ,
116	(33, 34)	1	40.6	40.6	30 ,	55 ,
117	(11, 14)	3	7.6	22.8	12 ,	
118	(1, 11)	1	51.5	51.5	53 ,	54 ,
119	(34, 36)	3	12.8	38.4	32 ,	
120	(34, 41)	2	36.6	73.2	37 ,	
121	(34, 51)	2	16.4	32.8	47 ,	
122	(1, 3)	2	17.4	34.8	2 ,	
123	(1, 9)	1	15.4	15.4	8 ,	
124	(34, 37)	1	37.7	37.7	33 ,	
125	(15, 31)	1	24.8	24.8	28 ,	
126	(1, 4)	1	9.7	9.7	3 ,	
127	(1, 5)	1	28.5	28.5	4 ,	
128	(1, 6)	1	16.7	16.7	5 ,	
129	(1, 7)	1	29.9	29.9	6 ,	
130	(1, 8)	1	20.4	20.4	7 ,	
131	(1, 10)	1	11.9	11.9	9 ,	
132	(34, 38)	1	53.9	53.9	34 ,	
133	(34, 40)	1	33.1	33.1	36 ,	
134	(34, 42)	1	26.8	26.8	38 ,	
135	(34, 46)	1	50.0	50.0	42 ,	
136	(34, 47)	1	26.5	26.5	43 ,	
137	(34, 49)	1	44.6	44.6	45 ,	
138	(34, 52)	1	58.6	58.6	48 ,	
139	(34, 55)	1	19.9	19.9	51 ,	

*** Network Design Process for Sector 2 ***

The gateway = 94
hub(1) = 57
hub(2) = 84
hub(3) = 94

total number of nodes = 44

**** building = 2 : special building or hub which requires 2-connectivity ;
**** building = 1 : building which requires 1-connectivity ;
**** building = 0 : building which requires 0-connectivity ;

node#	sector#	cluster#	local node#	building	home_hub	for_hub	name
57	2	1	1	1	57	0	GMOUNN
58	2	1	2	1	57	0	BMNUYH
59	2	1	3	1	57	0	CUOHRG
60	2	1	4	1	57	0	CZSOBY
61	2	1	5	1	57	0	DCWMYH
62	2	1	6	1	57	0	DMJPNO
63	2	1	7	1	57	0	ESZDYH
64	2	1	8	1	57	0	EWTOYH
65	2	1	9	1	57	0	GMOUNF
66	2	1	10	1	57	0	GMOUNS
67	2	1	11	1	57	0	GMOUNX
68	2	1	12	1	57	0	GMTIFS
69	2	1	13	1	57	0	GOUNNN
70	2	1	14	1	57	0	HESDYK

71	2	1	15	1	57	0	HSCMNO
72	2	1	16	1	57	0	IEMZYJ
73	2	1	17	1	57	0	IMMZHY
74	2	1	18	1	57	0	JNDZYI
75	2	1	19	1	57	0	MOENYH
76	2	1	20	1	57	0	MOPNYJ
77	2	1	21	1	57	0	MRFSMQ
78	2	1	22	1	57	0	NUSTYJ
79	2	1	23	1	57	0	OCSNYH
80	2	1	24	1	57	0	OMUIYK
81	2	1	25	1	57	0	PUWMYH
82	2	1	26	1	57	0	SOLNYH
83	2	1	27	1	57	0	TXDSYH
84	2	2	1	1	84	0	NUDMMO
85	2	2	2	1	84	0	BMHONN
86	2	2	3	1	84	0	ISJTNO
87	2	2	4	1	84	0	NSDZMO
88	2	2	5	1	84	0	NUDMCM
89	2	2	6	1	84	0	NUDMOS
90	2	2	7	1	84	0	OCNSMN
91	2	2	8	1	84	0	OXINNN
92	2	2	9	1	84	0	STWMNO
93	2	2	10	1	84	0	STWMOR
94	2	3	1	2	94	0	ROUDNN
95	2	3	2	1	94	0	BCIHNO
96	2	3	3	1	94	0	BSNEMO
97	2	3	4	1	94	0	DLUONN
98	2	3	5	1	94	0	DNSCCM
99	2	3	6	1	94	0	DNSCOR
100	2	3	7	1	94	0	ESRMNO

span #	span	working span route (span length)	protection span route (span length)
1	(57,58)	57- 59- 77- 74- 58- (42.8)	(0.0)
2	(57,59)	57- 59- (4.5)	(0.0)
3	(57,60)	57- 59- 71- 73- 69- 75- 60- (42.1)	(0.0)
4	(57,61)	57- 59- 77- 61- (34.4)	(0.0)
5	(57,62)	57- 66- 62- (9.8)	(0.0)
6	(57,63)	57- 59- 77- 74- 63- (46.2)	(0.0)
7	(57,64)	57- 59- 64- (14.5)	(0.0)
8	(57,65)	57- 66- 65- (8.4)	(0.0)
9	(57,66)	57- 66- (4.2)	(0.0)
10	(57,67)	57- 67- (4.5)	(0.0)
11	(57,68)	57- 67- 68- (11.6)	(0.0)
12	(57,69)	57- 59- 71- 73- 69- (21.6)	(0.0)
13	(57,70)	57- 59- 71- 70- (18.2)	(0.0)
14	(57,71)	57- 59- 71- (9.3)	(0.0)
15	(57,72)	57- 59- 77- 72- (35.4)	(0.0)
16	(57,73)	57- 59- 71- 73- (16.8)	(0.0)
17	(57,74)	57- 59- 77- 74- (37.1)	(0.0)
18	(57,75)	57- 59- 71- 73- 69- 75- (26.1)	(0.0)
19	(57,76)	57- 67- 76- (11.2)	(0.0)
20	(57,77)	57- 59- 77- (23.8)	(0.0)
21	(57,78)	57- 67- 68- 78- (21.4)	(0.0)
22	(57,79)	57- 59- 77- 61- 79- (47.6)	(0.0)
23	(57,80)	57- 67- 68- 80- (21.3)	(0.0)
24	(57,81)	57- 59- 77- 61- 81- (39.9)	(0.0)
25	(57,82)	57- 59- 71- 82- (14.7)	(0.0)
26	(57,83)	57- 67- 83- (12.4)	(0.0)
27	(84,85)	84- 89- 90- 87- 85- (38.1)	(0.0)
28	(84,86)	84- 89- 90- 87- 85- 86- (42.9)	(0.0)
29	(84,87)	84- 89- 90- 87- (28.1)	(0.0)
30	(84,88)	84- 88- (5.5)	(0.0)
31	(84,89)	84- 89- (5.8)	(0.0)
32	(84,90)	84- 89- 90- (12.5)	(0.0)
33	(84,91)	84- 89- 91- (11.8)	(0.0)
34	(84,92)	84- 93- 92- (7.8)	(0.0)
35	(84,93)	84- 93- (3.4)	(0.0)
36	(94,95)	94- 95- (7.3)	(0.0)

37	(94,96)	94- 96-	(9.5)	(0.0)
38	(94,97)	94- 100- 97-	(9.0)	(0.0)
39	(94,98)	94- 100- 97- 99- 98-	(14.6)	(0.0)
40	(94,99)	94- 100- 97- 99-	(9.4)	(0.0)
41	(94,100)	94- 100-	(5.6)	(0.0)
42	(57,94)	57- 59- 71- 73- 97- 100- 94-	(26.2)	(0.0)
43	(84,94)	84- 89- 91- 96- 94-	(22.0)	(0.0)
44	(57,84)	57- 59- 71- 73- 97- 100- 94- 96- 91- 89- 84-	(48.2)	(0.0)

total number of links = 43

link #	link	link length
1	(57,59)	4.5
2	(57,66)	4.2
3	(57,67)	4.5
4	(58,74)	5.7
5	(59,64)	10.0
6	(59,71)	4.8
7	(59,77)	19.3
8	(60,75)	16.0
9	(61,77)	10.6
10	(61,79)	13.2
11	(61,81)	5.5
12	(62,66)	5.6
13	(63,74)	9.1
14	(65,66)	4.2
15	(67,68)	7.1
16	(67,76)	6.7
17	(67,83)	7.9
18	(68,78)	9.8
19	(68,80)	9.7
20	(69,73)	4.8
21	(69,75)	4.5
22	(70,71)	8.9
23	(71,73)	7.5
24	(71,82)	5.4
25	(72,77)	11.6
26	(73,97)	0.4
27	(74,77)	13.3
28	(84,88)	5.5
29	(84,89)	5.8
30	(84,93)	3.4
31	(85,86)	4.8
32	(85,87)	10.0
33	(87,90)	15.6
34	(89,90)	6.7
35	(89,91)	6.0
36	(91,96)	0.7
37	(92,93)	4.4
38	(94,100)	5.6
39	(94,95)	7.3
40	(94,96)	9.5
41	(97,99)	0.4
42	(97,100)	3.4
43	(98,99)	5.2

pair #	demand pair	DS3 demand
1	(57, 59)	6
2	(57, 62)	3
3	(57, 65)	3
4	(57, 66)	6
5	(57, 67)	6
6	(57, 68)	2
7	(57, 69)	3

8	(57, 71)	4
9	(57, 83)	2
10	(57, 94)	11
11	(83, 94)	1
12	(84, 88)	3
13	(84, 92)	4
14	(84, 93)	4
15	(92, 93)	2
16	(94, 95)	5
17	(94, 97)	2
18	(94, 98)	2
19	(94, 99)	2
20	(84, 94)	11
21	(57, 77)	2
22	(57, 64)	2
23	(84, 89)	2
24	(84, 90)	2
25	(57, 58)	1
26	(57, 60)	1
27	(57, 61)	1
28	(57, 63)	1
29	(57, 70)	1
30	(57, 72)	1
31	(57, 73)	1
32	(57, 74)	1
33	(57, 75)	1
34	(57, 76)	1
35	(57, 78)	1
36	(57, 79)	1
37	(57, 80)	1
38	(57, 81)	1
39	(57, 82)	1
40	(84, 85)	1
41	(84, 86)	1
42	(84, 87)	1
43	(84, 91)	1
44	(94, 96)	1

Total number of DS3s in Sector(2) = 110

The hub-to-hub DS3 distribution is as follows:

hub pair	DS3 demands
(57,57)	54
(57,84)	0
(57,94)	12
(84,84)	21
(84,94)	11
(94,94)	12

*** Note DS3 demands for hub pair (i,i) means ***
*** total intra-cluster demands for cluster i ***

***** Network Cost Statistics for Sector (2) *****

Network Architecture Option:	SH/1:N/EP/1:1/OP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Embedded System Option:	Not Used
Multiplexing Strategy Option:	Dedicated

Note: the cost unit is $1,000.00

span#	span	DS3s	system rate(DS3)	1:N term.	working	protection	sub_total

1	(57,58)	2	2	1	105.2	104.4	209.6
2	(57,59)	7	9	1	82.3	69.8	152.1
3	(57,60)	2	2	1	104.0	103.2	207.2
4	(57,61)	2	2	1	90.9	90.1	181.0
5	(57,62)	4	2	2	75.7	54.0	129.7
6	(57,63)	2	2	1	111.0	110.2	221.2
7	(57,64)	3	3	1	56.8	50.0	106.8
8	(57,65)	4	2	2	71.0	51.6	122.6
9	(57,66)	7	9	1	81.8	69.3	151.1
10	(57,67)	7	9	1	82.3	69.8	152.1
11	(57,68)	3	3	1	51.8	45.1	96.9
12	(57,69)	4	2	2	115.9	74.0	189.9
13	(57,70)	2	2	1	52.6	51.8	104.3
14	(57,71)	5	9	1	81.5	69.0	150.5
15	(57,72)	2	2	1	92.6	91.8	184.4
16	(57,73)	2	2	1	50.2	49.4	99.5
17	(57,74)	2	2	1	95.5	94.7	190.2
18	(57,75)	2	2	1	66.0	65.2	131.2
19	(57,76)	2	2	1	40.7	39.8	80.5
20	(57,77)	3	3	1	72.6	65.8	138.4
21	(57,78)	2	2	1	58.0	57.2	115.2
22	(57,79)	2	2	1	113.4	112.6	225.9
23	(57,80)	2	2	1	57.8	57.0	114.8
24	(57,81)	2	2	1	100.3	99.5	199.7
25	(57,82)	2	2	1	46.6	45.8	92.4
26	(57,83)	4	2	2	84.6	58.4	143.0
27	(84,85)	2	2	1	97.2	96.4	193.6
28	(84,86)	2	2	1	105.4	104.6	209.9
29	(84,87)	2	2	1	69.4	68.6	138.0
30	(84,88)	4	2	2	61.1	46.7	107.8
31	(84,89)	3	3	1	42.0	35.2	77.2
32	(84,90)	3	3	1	53.4	46.6	100.0
33	(84,91)	2	2	1	41.7	40.9	82.5
34	(84,92)	7	9	1	87.9	75.4	163.3
35	(84,93)	7	9	1	80.4	67.9	148.3
36	(94,95)	6	9	1	78.1	65.6	143.7
37	(94,96)	2	2	1	37.8	37.0	74.7
38	(94,97)	3	3	1	47.4	40.6	88.0
39	(94,98)	3	3	1	56.9	50.2	107.1
40	(94,99)	3	3	1	48.1	41.3	89.4
41	(94,100)	1	1	1	23.8	23.8	47.5
42	(57,94)	12	12	1	136.7	91.7	228.4
43	(84,94)	11	12	1	129.6	91.7	221.3

The total working system cost = 3237.7 (k)
The total protection cost = 2873.2 (k)
The total route mile cost = 1474.5 (k)
The total network cost (working + protection + route) = 7585.4 (k)

*** Network Component Cost Statistics for Sector (2) ***

span #	working terms($k)	protection terms($k)	working fiber($k)	protection fiber($k)	working regs($k)	protection regs($k)	APS ($k)	optical switches($k)
1	21.61	20.81	72.76	72.76	10.83	10.83	0.00	0.00
2	74.65	62.13	7.65	7.65	0.00	0.00	0.00	0.00
3	21.61	20.81	71.57	71.57	10.83	10.83	0.00	0.00
4	21.61	20.81	58.48	58.48	10.83	10.83	0.00	0.00
5	42.42	20.81	33.32	16.66	0.00	0.00	16.49	0.00
6	21.61	20.81	78.54	78.54	10.83	10.83	0.00	0.00
7	32.12	25.33	24.65	24.65	0.00	0.00	0.00	0.00
8	42.42	20.81	28.56	14.28	0.00	0.00	16.49	0.00
9	74.65	62.13	7.14	7.14	0.00	0.00	0.00	0.00
10	74.65	62.13	7.65	7.65	0.00	0.00	0.00	0.00
11	32.12	25.33	19.72	19.72	0.00	0.00	0.00	0.00
12	42.42	20.81	73.44	36.72	0.00	0.00	16.49	0.00
13	21.61	20.81	30.94	30.94	0.00	0.00	0.00	0.00

14	65.72	53.20	15.81	15.81	0.00	0.00	0.00	0.00
15	21.61	20.81	60.18	60.18	10.83	10.83	0.00	0.00
16	21.61	20.81	28.56	28.56	0.00	0.00	0.00	0.00
17	21.61	20.81	63.07	63.07	10.83	10.83	0.00	0.00
18	21.61	20.81	44.37	44.37	0.00	0.00	0.00	0.00
19	21.61	20.81	19.04	19.04	0.00	0.00	0.00	0.00
20	32.12	25.33	40.46	40.46	0.00	0.00	0.00	0.00
21	21.61	20.81	36.38	36.38	0.00	0.00	0.00	0.00
22	21.61	20.81	80.92	80.92	10.83	10.83	0.00	0.00
23	21.61	20.81	36.21	36.21	0.00	0.00	0.00	0.00
24	21.61	20.81	67.83	67.83	10.83	10.83	0.00	0.00
25	21.61	20.81	24.99	24.99	0.00	0.00	0.00	0.00
26	42.42	20.81	42.16	21.08	0.00	0.00	16.49	0.00
27	21.61	20.81	64.77	64.77	10.83	10.83	0.00	0.00
28	21.61	20.81	72.93	72.93	10.83	10.83	0.00	0.00
29	21.61	20.81	47.77	47.77	0.00	0.00	0.00	0.00
30	42.42	20.81	18.70	9.35	0.00	0.00	16.49	0.00
31	32.12	25.33	9.86	9.86	0.00	0.00	0.00	0.00
32	32.12	25.33	21.25	21.25	0.00	0.00	0.00	0.00
33	21.61	20.81	20.06	20.06	0.00	0.00	0.00	0.00
34	74.65	62.13	13.26	13.26	0.00	0.00	0.00	0.00
35	74.65	62.13	5.78	5.78	0.00	0.00	0.00	0.00
36	65.72	53.20	12.41	12.41	0.00	0.00	0.00	0.00
37	21.61	20.81	16.15	16.15	0.00	0.00	0.00	0.00
38	32.12	25.33	15.30	15.30	0.00	0.00	0.00	0.00
39	32.12	25.33	24.82	24.82	0.00	0.00	0.00	0.00
40	32.12	25.33	15.98	15.98	0.00	0.00	0.00	0.00
41	14.23	14.23	9.52	9.52	0.00	0.00	0.00	0.00
42	92.16	91.72	44.54	0.00	0.00	0.00	0.00	0.00
43	92.16	91.72	37.40	0.00	0.00	0.00	0.00	0.00

*** DS3 ROUTING INFORMATION ***

*** NOTE: The following set of spans in the 'routing path' column is unordered, and corresponds to the set of spans described in the above Network Cost Statistics Table.

pair#	demand pair	DS3 demands	routing miles	DS3 x miles	routing path (span set)
1	(57, 59)	6	4.5	27.0	2 ,
2	(57, 62)	3	9.8	29.4	5 ,
3	(57, 65)	3	8.4	25.2	8 ,
4	(57, 66)	6	4.2	25.2	9 ,
5	(57, 67)	6	4.5	27.0	10 ,
6	(57, 68)	2	11.6	23.2	11 ,
7	(57, 69)	3	21.6	64.8	12 ,
8	(57, 71)	4	9.3	37.2	14 ,
9	(57, 83)	2	12.4	24.8	26 ,
10	(57, 94)	11	26.2	288.2	42 ,
11	(83, 94)	1	38.6	38.6	26 , 42 ,
12	(84, 88)	3	5.5	16.5	30 ,
13	(84, 92)	4	7.8	31.2	34 ,
14	(84, 93)	4	3.4	13.6	35 ,
15	(92, 93)	2	11.2	22.4	34 , 35 ,
16	(94, 95)	5	7.3	36.5	36 ,
17	(94, 97)	2	9.0	18.0	38 ,
18	(94, 98)	2	14.6	29.2	39 ,
19	(94, 99)	2	9.4	18.8	40 ,
20	(84, 94)	11	22.0	242.0	43 ,
21	(57, 77)	2	23.8	47.6	20 ,
22	(57, 64)	2	14.5	29.0	7 ,
23	(84, 89)	2	5.8	11.6	31 ,
24	(84, 90)	2	12.5	25.0	32 ,
25	(57, 58)	1	42.8	42.8	1 ,
26	(57, 60)	1	42.1	42.1	3 ,
27	(57, 61)	1	34.4	34.4	4 ,

28	(57, 63)	1	46.2	46.2	6 ,
29	(57, 70)	1	18.2	18.2	13 ,
30	(57, 72)	1	35.4	35.4	15 ,
31	(57, 73)	1	16.8	16.8	16 ,
32	(57, 74)	1	37.1	37.1	17 ,
33	(57, 75)	1	26.1	26.1	18 ,
34	(57, 76)	1	11.2	11.2	19 ,
35	(57, 78)	1	21.4	21.4	21 ,
36	(57, 79)	1	47.6	47.6	22 ,
37	(57, 80)	1	21.3	21.3	23 ,
38	(57, 81)	1	39.9	39.9	24 ,
39	(57, 82)	1	14.7	14.7	25 ,
40	(84, 85)	1	38.1	38.1	27 ,
41	(84, 86)	1	42.9	42.9	28 ,
42	(84, 87)	1	28.1	28.1	29 ,
43	(84, 91)	1	11.8	11.8	33 ,
44	(94, 96)	1	9.5	9.5	37 ,

*** Network Design Process for Inter-Gateway Subnetwork ***

total number of links = 9

link #	link	link length
1	(15,24)	2.9
2	(24,17)	2.9
3	(17,27)	2.7
4	(27,94)	7.0
5	(15,16)	1.4
6	(16,19)	2.1
7	(19,29)	2.4
8	(29,25)	3.7
9	(25,94)	7.5

span #	span	working span route (span length)		protection span route (span length)	
1	(15,94)	15- 24- 17- 27- 94-	(15.5)	15- 16- 19- 29- 25- 94-	(17.1)

pair #	demand pair	DS3 demand
1	(15, 94)	37

Total number of DS3s in the inter-gate subnetwork = 37

***** Network Cost Statistics for Inter-Gate Subnet *****

Network Architecture Option:	SH/1:N/EP/1:1/OP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Embedded System Option:	Not Used
Multiplexing Strategy Option:	Dedicated

Note: the cost unit is $1,000.00

span#	span	DS3s	system rate(DS3)	1:N term.	working	protection	sub_total
1	(15,94)	37	12	4	449.8	244.3	694.1

The total working system cost = 449.8 (k)
The total protection cost = 244.3 (k)
The total route mile cost = 0.0 (k)

The total network cost (working + protection + route) = 694.1 (k)

*** Network Component Cost Statistics for Inter-Gate Subnet ***

span #	working terms($k)	protection terms($k)	working fiber($k)	protection fiber($k)	working regs($k)	protection regs($k)	APS ($k)	optical switches($k)
1	344.40	91.72	105.40	116.28	0.00	0.00	24.31	12.00

*** DS3 ROUTING INFORMATION ***

*** NOTE: The following set of spans in the 'routing path' column is unordered, and corresponds to the set of spans described in the above Network Cost Statistics Table.

pair#	demand pair	DS3 demands	routing miles	DS3 x miles	routing path (span set)
1	(15, 94)	37	15.5	573.5	1 ,

Network Cost Statistics (Summary)

Network Architecture Option:	SH/1:N/EP/1:1/OP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Embedded System Option:	Not Used
Multiplexing Strategy Option:	Dedicated

COST FACTOR	COST
Working Facilities and Equipment	10698.6(k)
Protection Facilities and Equipment	8858.5(k)
Fiber Placement	3540.5(k)
Total Network Cost	23097.6(k)

**** Network Component Cost Summary *****

Component	Cost ($k)	Ratio
Working Fibers	3789.47	0.1641
Protection Fibers	3774.51	0.1634
Working Terminals	6663.76	0.2885
Protection Terminals	4258.29	0.1844
Working Regenerators	245.37	0.0106
Protection Regenerators	273.01	0.0118
Optical Switches	44.00	0.0019
APS	508.71	0.0220
Fiber Placement	3540.50	0.1533
Total Network	23097.62	

APPENDIX E

******* COST VS STATISTICS REPORT *******

Total number of circuits = 185520

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******** NODE AND LINK SURVIVABILITY SUMMARY FOR SECTOR(1) *********

Total number of circuits for section (1) = 149875

link#	link	link name	link survivability
1	(1, 2)	(AZNBCD,YOMANE)	0.9790
2	(1, 4)	(AZNBCD,EYUSDX)	0.9969
3	(1, 9)	(AZNBCD,TBMOYH)	0.9964
4	(1,10)	(AZNBCD,XSMLNO)	0.9984
5	(2,56)	(YOMANE,ZRTMNO)	0.9964
6	(2, 6)	(YOMANE,NGASSA)	1.0000
7	(3, 4)	(EDNCUN,EYUSDX)	1.0000
8	(3, 7)	(EDNCUN,CHUMFO)	1.0000
9	(4, 8)	(EYUSDX,RODNNN)	1.0000
10	(5, 8)	(HSGRYJ,RODNNN)	1.0000
11	(11,13)	(ESCRGB,ESCRPR)	1.0000
12	(11,12)	(ESCRGB,ESCRDB)	0.9647
13	(12,14)	(ESCRDB,UBZMXL)	1.0000
14	(12,53)	(ESCRDB,XBZONN)	0.9971
15	(13,15)	(ESCRPR,EUSTCM)	1.0000
16	(14,30)	(UBZMXL,MORLBU)	1.0000
17	(15,28)	(EUSTCM,EUSTWX)	0.9805
18	(15,24)	(EUSTCM,EUSTTF)	1.0000
19	(15,16)	(EUSTCM,EUSTDM)	0.9696
20	(15,23)	(EUSTCM,EUSTRW)	0.9590
21	(15,18)	(EUSTCM,EUSTMY)	0.9723
22	(15,21)	(EUSTCM,EUSTRF)	0.9638
23	(16,19)	(EUSTDM,EUSTND)	0.9928
24	(17,27)	(EUSTIH,EUSTWT)	1.0000
25	(17,24)	(EUSTIH,EUSTTF)	0.9968
26	(18,20)	(EUSTMY,EUSTOJ)	0.9969
27	(19,29)	(EUSTND,IHRLUT)	0.9970
28	(21,22)	(EUSTRF,EUSTRH)	1.0000
29	(22,25)	(EUSTRH,EUSTTX)	1.0000
30	(94,25)	(ROUDNN,EUSTTX)	1.0000
31	(26,29)	(EUSTVW,IHRLUT)	0.9964
32	(27,94)	(EUSTWT,ROUDNN)	1.0000
33	(28,30)	(EUSTWX,MORLBU)	1.0000
34	(30,33)	(MORLBU,XZOENN)	0.9964
35	(31,32)	(SLXERW,USFONN)	1.0000
36	(32,33)	(USFONN,XZOENN)	0.9964
37	(73,69)	(IMMZHY,GOUNNN)	1.0000
38	(69,42)	(GOUNNN,ISMEHR)	1.0000
39	(97,73)	(DLUONN,IMMZHY)	1.0000
40	(34,48)	(RMNPMO,OSWMNN)	0.9877
41	(34,43)	(RMNPMO,MJWONN)	1.0000
42	(34,54)	(RMNPMO,XBZONW)	1.0000
43	(34,44)	(RMNPMO,MJWONX)	0.9859
44	(35,40)	(CJUOFT,INCHMO)	1.0000
45	(35,41)	(CJUOFT,IPXMNO)	1.0000
46	(35,51)	(CJUOFT,TMZONN)	1.0000
47	(36,50)	(CMWMBV,SNMTMO)	1.0000
48	(36,54)	(CMWMBV,XBZONW)	1.0000
49	(36,55)	(CMWMBV,XJMTWM)	1.0000
50	(37,39)	(DBUOCT,GMSLFR)	1.0000
51	(38,45)	(FSJEYH,NPOSMN)	1.0000

52	(38,52)	(FSJEYH,UNRSYH)	1.0000
53	(39,49)	(GMSLFR,OXRUYJ)	1.0000
54	(39,45)	(GMSLFR,NPOSMN)	1.0000
55	(39,50)	(GMSLFR,SNMTMO)	1.0000
56	(43,53)	(MJWONN,XBZONN)	1.0000
57	(45,46)	(NPOSMN,NPOSNF)	1.0000
58	(47,50)	(OCUNNN,SNMTMO)	1.0000
59	(48,94)	(OSWMNN,ROUDNN)	1.0000
60	(48,51)	(OSWMNN,TMZONN)	1.0000
61	(53,54)	(XBZONN,XBZONW)	1.0000
62	(54,56)	(XBZONW,ZRTMNO)	1.0000
63	(94,100)	(ROUDNN,ESRMNO)	1.0000
64	(100,97)	(ESRMNO,DLUONN)	1.0000

The average link survivability = 0.9956
The worst link survivability = 0.9590

node	node name	node survivability
1	AZNBCD	0.9715
2	YOMANE	0.9753
3	EDNCUN	1.0000
4	EYUSDX	0.9969
5	HSGRYJ	1.0000
6	NGASSA	1.0000
7	CHUMFO	1.0000
8	RODNNN	1.0000
9	TBMOYH	0.9964
10	XSMLNO	0.9984
11	ESCRGB	0.9173
12	ESCRDB	0.9332
13	ESCRPR	0.9662
14	UBZMXL	0.9726
15	EUSTCM	0.7903
16	EUSTDM	0.9623
17	EUSTIH	0.9944
18	EUSTMY	0.9692
19	EUSTND	0.9897
20	EUSTOJ	0.9969
21	EUSTRF	0.9368
22	EUSTRH	0.9671
23	EUSTRW	0.9590
24	EUSTTF	0.9724
25	EUSTTX	0.9977
26	EUSTVW	0.9964
27	EUSTWT	0.9946
28	EUSTWX	0.9537
29	IHRLUT	0.9933
30	MORLBU	0.9695
31	SLXERW	1.0000
32	USFONN	0.9964
33	XZOENN	0.9928
34	RMNPMO	0.9363
35	CJUOFT	1.0000
36	CMWMBV	1.0000
37	DBUOCT	1.0000
38	FSJEYH	1.0000
39	GMSLFR	1.0000
40	INCHMO	1.0000
41	IPXMNO	1.0000
42	ISMEHR	1.0000
43	MJWONN	0.9658
44	MJWONX	0.9859
45	NPOSMN	1.0000
46	NPOSNF	1.0000
47	OCUNNN	1.0000
48	OSWMNN	0.9846

49	OXRUYJ	1.0000
50	SNMTMO	1.0000
51	TMZONN	1.0000
52	UNRSYH	1.0000
53	XBZONN	0.9971
54	XBZONW	0.9906
55	XJMTWM	1.0000
56	ZRTMNO	0.9964

The average node survivability = 0.9824
The worst node survivability = 0.7903

hub#	hub	hub name	hub survivability
1	1	AZNBCD	0.9715
2	11	ESCRGB	0.9173
3	15	EUSTCM	0.7903
4	34	RMNPMO	0.9363

The average hub survivability = 0.9039
The worst hub survivability = 0.7903

COST VS SURVIVABILITY STATISTICS FOR SECTOR(1)

Network Section : 1
Architecture Option: SH/1:N/EP/1:1/OP
Spare Ds3s Option : Used
Cost Model Option : Default (Present)
Multiplexing Option: Mixed

	Network Cost	Link Survivability	Hub Survivability	Worst Link	Worst Hub
Worst-Case	20618.68(k)	0.9590	0.7903	(EUSTCM,EUSTRW)	EUSTCM
Average-Case	20618.68(k)	0.9956	0.9039		
CSR (worst)	**	115.89	140.63		
CSR (average)	**	111.63	122.96		

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******** NODE AND LINK SURVIVABILITY SUMMARY FOR SECTOR(2) *********

Total number of circuits for section (2) = 38913

link#	link	link name	link survivability
1	(57,59)	(GMOUNN,CUOHRG)	0.9806
2	(57,66)	(GMOUNN,GMOUNS)	0.9823
3	(57,67)	(GMOUNN,GMOUNX)	0.9818
4	(58,74)	(BMNUYH,JNDZYI)	1.0000
5	(59,71)	(CUOHRG,HSCMNO)	1.0000
6	(59,64)	(CUOHRG,EWTOYH)	1.0000
7	(59,77)	(CUOHRG,MRFSMQ)	1.0000
8	(60,75)	(CZSOBY,MOENYH)	1.0000
9	(61,77)	(DCWMYH,MRFSMQ)	1.0000
10	(61,79)	(DCWMYH,OCSNYH)	1.0000
11	(61,81)	(DCWMYH,PUWMYH)	1.0000
12	(62,66)	(DMJPNO,GMOUNS)	1.0000
13	(63,74)	(ESZDYH,JNDZYI)	1.0000
14	(65,66)	(GMOUNF,GMOUNS)	1.0000
15	(67,68)	(GMOUNX,GMTIFS)	1.0000
16	(67,76)	(GMOUNX,MOPNYJ)	1.0000
17	(67,83)	(GMOUNX,TXDSYH)	1.0000

18	(68,78)	(GMTIFS,NUSTYJ)	1.0000
19	(68,80)	(GMTIFS,OMUIYK)	1.0000
20	(69,73)	(GOUNNN,IMMZHY)	1.0000
21	(69,75)	(GOUNNN,MOENYH)	1.0000
22	(70,71)	(HESDYK,HSCMNO)	1.0000
23	(71,73)	(HSCMNO,IMMZHY)	1.0000
24	(71,82)	(HSCMNO,SOLNYH)	1.0000
25	(72,77)	(IEMZYJ,MRFSMQ)	1.0000
26	(73,97)	(IMMZHY,DLUONN)	1.0000
27	(74,77)	(JNDZYI,MRFSMQ)	1.0000
28	(84,88)	(NUDMMO,NUDMCM)	0.9930
29	(84,89)	(NUDMMO,NUDMOS)	0.9964
30	(84,93)	(NUDMMO,STWMOR)	0.9891
31	(85,86)	(BMHONN,ISJTNO)	1.0000
32	(85,87)	(BMHONN,NSDZMO)	1.0000
33	(87,90)	(NSDZMO,OCNSMN)	1.0000
34	(89,90)	(NUDMOS,OCNSMN)	1.0000
35	(89,91)	(NUDMOS,OXINNN)	1.0000
36	(91,96)	(OXINNN,BSNEMO)	1.0000
37	(92,93)	(STWMNO,STWMOR)	0.9928
38	(94,96)	(ROUDNN,BSNEMO)	0.9993
39	(94,95)	(ROUDNN,BCIHNO)	0.9894
40	(94,100)	(ROUDNN,ESRMNO)	1.0000
41	(97,99)	(DLUONN,DNSCOR)	1.0000
42	(97,100)	(DLUONN,ESRMNO)	1.0000
43	(98,99)	(DNSCCM,DNSCOR)	1.0000

The average link survivability = 0.9978
The worst link survivability = 0.9806

node	node name	node survivability
57	GMOUNN	0.9489
58	BMNUYH	1.0000
59	CUOHRG	0.9806
60	CZSOBY	1.0000
61	DCWMYH	1.0000
62	DMJPNO	1.0000
63	ESZDYH	1.0000
64	EWTOYH	1.0000
65	GMOUNF	1.0000
66	GMOUNS	0.9823
67	GMOUNX	0.9818
68	GMTIFS	1.0000
69	GOUNNN	1.0000
70	HESDYK	1.0000
71	HSCMNO	1.0000
72	IEMZYJ	1.0000
73	IMMZHY	1.0000
74	JNDZYI	1.0000
75	MOENYH	1.0000
76	MOPNYJ	1.0000
77	MRFSMQ	1.0000
78	NUSTYJ	1.0000
79	OCSNYH	1.0000
80	OMUIYK	1.0000
81	PUWMYH	1.0000
82	SOLNYH	1.0000
83	TXDSYH	1.0000
84	NUDMMO	0.9805
85	BMHONN	1.0000
86	ISJTNO	1.0000
87	NSDZMO	1.0000
88	NUDMCM	0.9930
89	NUDMOS	0.9964
90	OCNSMN	1.0000
91	OXINNN	1.0000

92	STWMNO	0.9928
93	STWMOR	0.9819
94	ROUDNN	0.9888
95	BCIHNO	0.9894
96	BSNEMO	0.9993
97	DLUONN	1.0000
98	DNSCCM	1.0000
99	DNSCOR	1.0000
100	ESRMNO	1.0000

The average node survivability = 0.9958
The worst node survivability = 0.9489

hub#	hub	hub name	hub survivability
1	57	GMOUNN	0.9489
2	84	NUDMMO	0.9805
3	94	ROUDNN	0.9888

The average hub survivability = 0.9727
The worst hub survivability = 0.9489

COST VS SURVIVABILITY STATISTICS FOR SECTOR(2)

Network Section : 2
Architecture Option: SH/1:N/EP/1:1/OP
Spare Ds3s Option : Used
Cost Model Option : Default (Present)
Multiplexing Option: Mixed

	Network Cost	Link Survivability	Hub Survivability	Worst Link	Worst Hub
Worst-Case	8804.95(k)	0.9806	0.9489	(GMOUNN,CUOHRG)	GMOUNN
Average-Case	8804.95(k)	0.9978	0.9727		
CSR (worst)	**	48.40	50.01		
CSR (average)	**	47.57	48.79		

==

******** NODE AND LINK SURVIVABILITY SUMMARY FOR INTER-GATE SUBNET *********

Total number of circuits for the inter-gateway subnetwork = 15735

link#	link	link name	link survivability
1	(15,24)	(EUSTCM,EUSTTF)	1.0000
2	(24,17)	(EUSTTF,EUSTIH)	1.0000
3	(17,27)	(EUSTIH,EUSTWT)	1.0000
4	(27,94)	(EUSTWT,ROUDNN)	1.0000
5	(15,21)	(EUSTCM,EUSTRF)	1.0000
6	(21,22)	(EUSTRF,EUSTRH)	1.0000
7	(22,25)	(EUSTRH,EUSTTX)	1.0000
8	(25,94)	(EUSTTX,ROUDNN)	1.0000

The average link survivability = 1.0000
The worst link survivability = 1.0000

node	node name	node survivability
15	EUSTCM	0.7903
24	EUSTTF	1.0000

17	EUSTIH	1.0000
27	EUSTWT	1.0000
94	ROUDNN	0.9888
21	EUSTRF	1.0000
22	EUSTRH	1.0000
25	EUSTTX	1.0000

The average node survivability = 0.9724
The worst node survivability = 0.7903

hub#	hub	hub name	hub survivability
1	15	EUSTCM	0.7903
2	94	ROUDNN	0.9888

The average hub survivability = 0.8895
The worst hub survivability = 0.7903

COST VS SURVIVABILITY STATISTICS FOR INTER-GATE SUBNET

Network Section : 3
Architecture Option: SH/1:N/EP/1:1/OP
Spare Ds3s Option : Used
Cost Model Option : Default (Present)
Multiplexing Option: Mixed

	Network Cost	Link Survivability	Hub Survivability	Worst Link	Worst Hub
Worst-Case	2394.21(k)	1.0000	0.7903	(******,******)	EUSTCM
Average-Case	2394.21(k)	1.0000	0.8895		
CSR (worst)	**	12.91	16.33		
CSR (average)	**	12.91	14.51		

==

*** COST VS SURVIVABILITY (NETWORK SUMMARY) ***

Architecture Option: SH/1:N/EP/1:1/OP
Spare Ds3s Option : Used
Cost Model Option : Default (Present)
Multiplexing Option: Mixed

	Network Cost	Link Survivability	Hub Survivability	Worst Link	Worst Hub
Worst-Case	21550.17(k)	0.9590	0.7903	(EUSTCM, EUSTRW)	EUSTCM
Average-Case	21550.17(k)	0.9978	0.9383		
CSR (worst)	**	121.13	146.99		
CSR (average)	**	116.42	123.80		

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APPENDIX F

***** Cost Function ****

Fiber material cost = $ 1700.00 per mile per fiber pair
Fiber placement cost = $ 5000.00 per route mile
1 x 2 mechanical optical switch cost = $ 1000.00 (for each)
Distance threshold required for a regenerator = 30.00 miles

Total number of transmission systems = 6

system#	DS3 rate	max_N (for 1:N)	regenerator cost ($k)
1	1	1	6.88
2	2	11	10.83
3	3	15	13.83
4	9	15	19.42
5	12	15	27.64
6	24	15	49.10

------ Terminal Cost -----

** NOTE : THE COST UNIT IS $1,000

system#	DS3= 1	DS3= 2	DS3= 3	DS3= 4	DS3= 5	DS3= 6
1	7.11	*	*	*	*	*
2	9.30	10.40	*	*	*	*
3	10.56	11.61	12.66	*	*	*
4	22.14	22.14	22.14	26.60	26.60	26.60
5	34.18	34.18	34.18	37.24	37.24	37.24
6	70.44	70.44	70.44	73.50	73.50	73.50

system#	DS3= 7	DS3= 8	DS3= 9	DS3= 10	DS3= 11	DS3= 12
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	31.07	31.07	31.07	*	*	*
5	42.80	42.80	42.80	45.86	45.86	45.86
6	79.06	79.06	79.06	82.12	82.12	82.12

system#	DS3= 13	DS3= 14	DS3= 15	DS3= 16	DS3= 17	DS3= 18
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	*	*	*	*	*	*
5	*	*	*	*	*	*
6	87.68	87.68	87.68	90.74	90.74	90.74

system#	DS3= 19	DS3= 20	DS3= 21	DS3= 22	DS3= 23	DS3= 24
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	*	*	*	*	*	*
5	*	*	*	*	*	*
6	96.30	96.30	96.30	99.36	99.36	99.36

----- Bay Cost -----

system#	N= 1	N= 2	N= 3	N= 4	N= 5	N= 6	N= 7	N= 8
1	0.00	*	*	*	*	*	*	*
2	0.40	0.40	0.40	0.40	0.88	0.88	0.88	0.88
3	3.39	3.39	6.79	6.79	6.79	10.19	10.19	10.19
4	6.26	9.39	12.52	15.65	18.78	21.91	25.04	28.17
5	0.22	0.22	0.44	0.44	0.66	0.66	0.88	0.88
6	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60

system#	N= 9	N=10	N=11	N=12	N=13	N=14	N=15
1	*	*	*	*	*	*	*
2	0.88	0.88	0.88	*	*	*	*
3	13.58	13.58	13.58	16.98	16.98	16.98	20.37
4	31.30	34.43	37.56	40.69	43.82	46.95	50.08
5	1.01	1.01	1.32	1.32	1.54	1.54	1.76
6	1.80	2.00	2.20	2.40	2.60	2.80	3.00

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**** Network Span Layout Using Mixed Multiplexing ***

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*** Network Span Layout for Sector(1) Using Mixed Multiplexing ***

*** Initial Dedicated Network Multiplex Span Layout for Sector(1) ***

span #	span	DS3 flow	working span route (span length)	protection span route (span length)
1	(1, 2)	10	1-2- (4.7)	(0.0)
2	(1, 3)	3	1-4-3- (17.4)	(0.0)
3	(1, 4)	3	1-4- (9.7)	(0.0)
4	(1, 5)	2	1-4-8-5- (28.5)	(0.0)
5	(1, 6)	3	1-2-6- (16.7)	(0.0)
6	(1, 7)	2	1-4-3-7- (29.9)	(0.0)
7	(1, 8)	3	1-4-8- (20.4)	(0.0)
8	(1, 9)	3	1-9- (15.4)	(0.0)
9	(1,10)	2	1-10- (11.9)	(0.0)
10	(11,12)	16	11-12- (2.8)	(0.0)
11	(11,13)	11	11-13- (2.4)	11- 12- 14- 30- 28- 15- 13- (27.8)
12	(11,14)	10	11-12-14- (7.6)	11- 13- 15- 28- 30- 14- (22.6)
13	(15,16)	13	15-16- (1.4)	(0.0)
14	(15,17)	15	15-24-17- (5.8)	(0.0)
15	(15,18)	11	15-18- (6.1)	(0.0)
16	(15,19)	27	15-16-19- (3.5)	(0.0)
17	(15,20)	10	15-18-20- (9.4)	(0.0)
18	(15,21)	14	15-21- (4.4)	(0.0)
19	(15,22)	12	15-21-22- (8.6)	15- 16- 19- 29- 25- 22- (14.9)
20	(15,23)	16	15-23- (1.7)	(0.0)
21	(15,24)	12	15-24- (2.9)	15- 16- 19- 24- (6.2)
22	(15,25)	11	15-16-19-29-25- (9.6)	15- 21- 22- 25- (13.9)
23	(15,26)	25	15-16-19-29-26- (9.6)	(0.0)
24	(15,27)	16	15-24-17-27- (8.5)	15- 16- 19- 29- 25- 94- 27- (24.1)
25	(15,28)	12	15-28- (4.1)	(0.0)
26	(15,29)	16	15-16-19-29- (5.9)	(0.0)
27	(15,30)	15	15-28-30- (9.6)	15- 13- 11- 12- 14- 30- (20.6)
28	(15,31)	2	15-28-30-33-32-31- (24.8)	(0.0)
29	(15,32)	9	15-28-30-33-32- (18.5)	(0.0)
30	(15,33)	11	15-28-30-33- (13.0)	(0.0)
31	(34,35)	4	34-48-51-35- (26.8)	(0.0)
32	(34,36)	4	34-54-36- (12.8)	(0.0)
33	(34,37)	2	34-54-36-50-39-37- (37.7)	(0.0)
34	(34,38)	2	34-54-36-50-39-45-38- (53.9)	(0.0)
35	(34,39)	4	34-54-36-50-39- (30.9)	(0.0)
36	(34,40)	2	34-48-51-35-40- (33.1)	(0.0)
37	(34,41)	3	34-48-51-35-41- (36.6)	(0.0)
38	(34,42)	2	34-48-94-100-97-73-69-42- (26.8)	(0.0)
39	(34,43)	16	34-43- (6.8)	34- 54- 53- 43- (20.3)
40	(34,44)	6	34-44- (6.0)	(0.0)
41	(34,45)	5	34-54-36-50-39-45- (43.4)	(0.0)
42	(34,46)	2	34-54-36-50-39-45-46- (50.0)	(0.0)
43	(34,47)	2	34-54-36-50-47- (26.5)	(0.0)
44	(34,48)	7	34-48- (6.1)	(0.0)
45	(34,49)	2	34-54-36-50-39-49- (44.6)	(0.0)
46	(34,50)	7	34-54-36-50- (20.9)	(0.0)
47	(34,51)	3	34-48-51- (16.4)	(0.0)
48	(34,52)	2	34-54-36-50-39-45-38-52- (58.6)	(0.0)
49	(34,53)	10	34-54-53- (12.0)	34- 43- 53- (15.1)
50	(34,54)	4	34-54- (4.0)	34- 43- 53- 54- (23.1)
51	(34,55)	2	34-54-36-55- (19.9)	(0.0)
52	(34,56)	10	34-54-56- (12.9)	(0.0)

53	(1,15)	9	1-2-56-54-53-12-11-13-15- (43.5) 1- 2- 56- 54- 53- 12- 11- 13- 15- (43.5)
54	(11,15)	33	11-13-15- (8.0) 11- 12- 14- 30- 28- 15- (22.2)
55	(15,34)	27	15-24-17-27-94-48-34- (27.6) 15- 13- 11- 12- 53- 54- 34- (29.0)
56	(1,34)	18	1-2-56-54-34- (22.5) 1- 2- 56- 54- 34- (22.5)
57	(11,34)	11	11-12-53-54-34- (21.0) 11- 13- 15- 24- 17- 27- 94- (35.6)

The initial network cost (dedicated span layout) = 14818.08 (k)

#	demand pair	node-path									
1	(1, 2)	1	2								
2	(1, 15)	1	2	56	54	53	12	11	13	15	
3	(1, 34)	1	2	56	54	34					
4	(1, 56)	1	2	56	54	34	54	56			
5	(2, 15)	2	1	2	56	54	53	12	11	13	15
6	(2, 34)	2	1	2	56	54	34				
7	(2, 56)	2	1	2	56	54	34	54	56		
8	(11, 12)	11	12								
9	(11, 13)	11	13								
10	(11, 15)	11	13	15							
11	(11, 23)	11	13	15	23						
12	(11, 30)	11	13	15	28	30					
13	(11, 43)	11	12	53	54	34	43				
14	(12, 13)	12	11	13							
15	(12, 14)	12	11	12	14						
16	(12, 15)	12	11	13	15						
17	(12, 30)	12	11	13	15	28	30				
18	(12, 43)	12	11	12	53	54	34	43			
19	(12, 53)	12	11	12	53	54	34	54	53		
20	(13, 15)	13	11	13	15						
21	(13, 28)	13	11	13	15	28					
22	(14, 15)	14	12	11	13	15					
23	(14, 30)	14	12	11	13	15	28	30			
24	(14, 33)	14	12	11	13	15	28	30	33		
25	(14, 34)	14	12	11	12	53	54	34			
26	(14, 50)	14	12	11	12	53	54	34	54	36	50
27	(15, 16)	15	16								
28	(15, 17)	15	24	17							
29	(15, 18)	15	18								
30	(15, 19)	15	16	19							
31	(15, 20)	15	18	20							
32	(15, 21)	15	21								
33	(15, 22)	15	21	22							
34	(15, 23)	15	23								
35	(15, 24)	15	24								
36	(15, 25)	15	16	19	29	25					
37	(15, 26)	15	16	19	29	26					
38	(15, 27)	15	24	17	27						
39	(15, 28)	15	28								
40	(15, 29)	15	16	19	29						
41	(15, 30)	15	28	30							
42	(15, 32)	15	28	30	33	32					
43	(15, 33)	15	28	30	33						
44	(15, 34)	15	24	17	27	94	48	34			
45	(15, 43)	15	24	17	27	94	48	34	43		
46	(15, 48)	15	24	17	27	94	48	34	48		
47	(15, 50)	15	24	17	27	94	48	34	54	36	50
48	(15, 53)	15	24	17	27	94	48	34	54	53	
49	(16, 19)	16	15	16	19						
50	(16, 24)	16	15	24							
51	(16, 26)	16	15	16	19	29	26				
52	(17, 24)	17	24	15	24						
53	(17, 26)	17	24	15	16	19	29	26			
54	(17, 27)	17	24	15	24	17	27				
55	(17, 29)	17	24	15	16	19	29				
56	(18, 20)	18	15	18	20						
57	(18, 21)	18	15	21							

58	(18, 22)	18	15	21	22							
59	(18, 26)	18	15	16	19	29	26					
60	(19, 21)	19	16	15	21							
61	(19, 23)	19	16	15	23							
62	(19, 24)	19	16	15	24							
63	(19, 25)	19	16	15	16	19	29	25				
64	(19, 26)	19	16	15	16	19	29	26				
65	(19, 29)	19	16	15	16	19	29					
66	(20, 22)	20	18	15	21	22						
67	(21, 22)	21	15	21	22							
68	(21, 25)	21	15	16	19	29	25					
69	(21, 26)	21	15	16	19	29	26					
70	(21, 29)	21	15	16	19	29						
71	(22, 25)	22	21	15	16	19	29	25				
72	(24, 26)	24	15	16	19	29	26					
73	(24, 27)	24	15	24	17	27						
74	(24, 29)	24	15	16	19	29						
75	(25, 26)	25	29	19	16	15	16	19	29	26		
76	(25, 29)	25	29	19	16	15	16	19	29			
77	(26, 27)	26	29	19	16	15	24	17	27			
78	(26, 29)	26	29	19	16	15	16	19	29			
79	(27, 29)	27	17	24	15	16	19	29				
80	(28, 30)	28	15	28	30							
81	(30, 33)	30	28	15	28	30	33					
82	(30, 34)	30	28	15	24	17	27	94	48	34		
83	(32, 33)	32	33	30	28	15	28	30	33			
84	(34, 35)	34	48	51	35							
85	(34, 43)	34	43									
86	(34, 44)	34	44									
87	(34, 45)	34	54	36	50	39	45					
88	(34, 48)	34	48									
89	(34, 50)	34	54	36	50							
90	(34, 53)	34	54	53								
91	(34, 54)	34	54									
92	(34, 56)	34	54	56								
93	(43, 44)	43	34	44								
94	(43, 53)	43	34	54	53							
95	(4, 34)	4	1	2	56	54	34					
96	(6, 34)	6	2	1	2	56	54	34				
97	(8, 34)	8	4	1	2	56	54	34				
98	(9, 34)	9	1	2	56	54	34					
99	(11, 34)	11	12	53	54	34						
100	(12, 34)	12	11	12	53	54	34					
101	(13, 34)	13	11	12	53	54	34					
102	(11, 17)	11	13	15	24	17						
103	(17, 34)	17	24	15	24	17	27	94	48	34		
104	(11, 19)	11	13	15	16	19						
105	(19, 34)	19	16	15	24	17	27	94	48	34		
106	(11, 24)	11	13	15	24							
107	(11, 26)	11	13	15	16	19	29	26				
108	(26, 34)	26	29	19	16	15	24	17	27	94	48	34
109	(11, 27)	11	13	15	24	17	27					
110	(27, 34)	27	17	24	15	24	17	27	94	48	34	
111	(11, 28)	11	13	15	28							
112	(28, 34)	28	15	24	17	27	94	48	34			
113	(11, 32)	11	13	15	28	30	33	32				
114	(34, 39)	34	54	36	50	39						
115	(32, 34)	32	33	30	28	15	24	17	27	94	48	34
116	(33, 34)	33	30	28	15	24	17	27	94	48	34	
117	(11, 14)	11	12	14								
118	(1, 11)	1	2	56	54	53	12	11	13	15	13	11
119	(34, 36)	34	54	36								
120	(34, 41)	34	48	51	35	41						
121	(34, 51)	34	48	51								
122	(1, 3)	1	4	3								
123	(1, 9)	1	9									
124	(34, 37)	34	54	36	50	39	37					
125	(15, 31)	15	28	30	33	32	31					

126	(1, 4)	1	4						
127	(1, 5)	1	4	8	5				
128	(1, 6)	1	2	6					
129	(1, 7)	1	4	3	7				
130	(1, 8)	1	4	8					
131	(1, 10)	1	10						
132	(34, 38)	34	54	36	50	39	45	38	
133	(34, 40)	34	48	51	35	40			
134	(34, 42)	34	48	94	100	97	73	69	42
135	(34, 46)	34	54	36	50	39	45	46	
136	(34, 47)	34	54	36	50	47			
137	(34, 49)	34	54	36	50	39	49		
138	(34, 52)	34	54	36	50	39	45	38	52
139	(34, 55)	34	54	36	55				

******* Final Mixed Span Layout for Sector(1) ********

The final mixed span layout is obtained from re-multiplexing DS3 demands at the following nodes::

span #	span	DS3_flow	working span route (span length)	protection span route (span length)
1	(1, 2)	40	1- 2- (4.7)	(0.0)
2	(1, 4)	13	1- 4- (9.7)	(0.0)
3	(1, 9)	3	1- 9- (15.4)	(0.0)
4	(1,10)	2	1- 10- (11.9)	(0.0)
5	(11,12)	16	11- 12- (2.8)	(0.0)
6	(11,13)	44	11- 13- (2.4)	11- 12- 14- 30- 28- 15- 13- (27.8)
7	(11,14)	10	11- 12- 14- (7.6)	11- 13- 15- 28- 30- 14- (22.6)
8	(15,16)	81	15- 16- (1.4)	(0.0)
9	(15,18)	21	15- 18- (6.1)	(0.0)
10	(15,21)	14	15- 21- (4.4)	(0.0)
11	(15,22)	12	15- 21- 22- (8.6)	15- 16- 19- 29- 25- 22- (14.9)
12	(15,23)	16	15- 23- (1.7)	(0.0)
13	(15,24)	70	15- 24- (2.9)	15- 16- 19- 24- (6.2)
14	(15,25)	11	15- 16- 19- 29- 25- (9.6)	15- 21- 22- 25- (13.9)
15	(15,28)	34	15- 28- (4.1)	(0.0)
16	(15,30)	15	15- 28- 30- (9.6)	15- 13- 11- 12- 14- 30- (20.6)
17	(34,43)	16	34- 43- (6.8)	34- 54- 53- 43- (20.3)
18	(34,44)	6	34- 44- (6.0)	(0.0)
19	(34,48)	21	34- 48- (6.1)	(0.0)
20	(34,54)	87	34- 54- (4.0)	34- 43- 53- 54- (23.1)
21	(39,37)	2	39- 37- (6.8)	(0.0)
22	(39,45)	11	39- 45- (12.5)	(0.0)
23	(39,49)	2	39- 49- (13.7)	(0.0)
24	(35,40)	2	35- 40- (6.3)	(0.0)
25	(35,41)	3	35- 41- (9.8)	(0.0)
26	(45,38)	4	45- 38- (10.5)	(0.0)
27	(45,46)	2	45- 46- (6.6)	(0.0)
28	(32,31)	2	32- 31- (6.3)	(0.0)
29	(8, 5)	2	8- 5- (8.1)	(0.0)
30	(3, 7)	2	3- 7- (12.5)	(0.0)
31	(38,52)	2	38- 52- (4.7)	(0.0)
32	(50,39)	19	50- 39- (10.0)	(0.0)
33	(50,47)	2	50- 47- (5.6)	(0.0)
34	(51,35)	9	51- 35- (10.4)	(0.0)
35	(18,20)	10	18- 20- (3.3)	(0.0)
36	(33,32)	11	33- 32- (5.5)	(0.0)
37	(4, 3)	5	4- 3- (7.7)	(0.0)
38	(4, 8)	5	4- 8- (10.7)	(0.0)
39	(48,42)	2	48- 94- 100- 97- 73- 69- 42- (20.7)	(0.0)
40	(48,51)	12	48- 51- (10.3)	(0.0)
41	(29,26)	25	29- 26- (3.7)	(0.0)
42	(36,50)	28	36- 50- (8.1)	(0.0)

```
43    (36,55)    2   36- 55- (  7.1)  (  0.0)
44    ( 2, 6)    3    2-  6- ( 12.0)  (  0.0)
45    ( 2,56)   27    2- 56- (  4.9)  (  0.0)
46    (28,30)   22   28- 30- (  5.5)  (  0.0)
47    (30,33)   22   30- 33- (  3.4)  (  0.0)
48    (11,53)   11   11- 12- 53- (  9.0)  11- 13- 15- 24- 17- 27- 94- 34- 54- 53- ( 40.2)
49    (53,12)    9   53- 12- (  6.2)  (  0.0)
50    (19,29)   41   19- 29- (  2.4)  (  0.0)
51    (27,34)   27   27- 94- 48- 34- ( 19.1)  27- 17- 24- 15- 13- 11- 12- 53- 54- 34- ( 37.5)
52    (16,19)   68   16- 19- (  2.1)  (  0.0)
53    (24,17)   15   24- 17- (  2.9)  (  0.0)
54    (24,27)   43   24- 17- 27- (  5.6)  24- 15- 16- 19- 29- 25- 94- 27- ( 27.0)
55    (13,15)   42   13- 15- (  5.6)  13- 11- 12- 14- 30- 28- 15- ( 24.6)
56    (12,13)    9   12- 11- 13- (  5.2)  12- 53- 54- 56-  2-  1-  2- 56- 54- 53- 12- 11- 13- 15- 15- 13-
86.5)
57    (54,36)   34   54- 36- (  8.8)  (  0.0)
58    (54,53)   39   54- 53- (  8.0)  54- 34- 43- 53- ( 19.1)
59    (54,56)   37   54- 56- (  8.9)  (  0.0)
```

***** Final Network Cost Statistics for Sector(1) *****

Network Architecture Option:	SH/1:N/EP/1:1/DP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Embedded System Option:	Not Used
Multiplexing Strategy Option:	Mixed
Cost Improvement Option:	Combinatorial

Note: the cost unit is $1,000.00

span#	span	DS3s	system rate(DS3)	1:N term.	working	protection	sub_total
1	(1, 2)	40	9	5	379.2	94.4	473.7
2	(1, 4)	13	9	2	167.1	102.9	270.0
3	(1, 9)	3	3	1	58.3	51.5	109.8
4	(1,10)	2	2	1	41.8	41.0	82.9
5	(11,12)	16	9	2	152.6	91.2	243.8
6	(11,13)	44	12	4	378.0	317.1	695.0
7	(11,14)	10	12	1	105.1	130.1	235.2
8	(15,16)	81	9	9	643.2	88.8	732.0
9	(15,18)	21	9	3	224.7	96.8	321.5
10	(15,21)	14	3	5	175.5	57.1	232.6
11	(15,22)	12	12	1	106.8	117.1	223.8
12	(15,23)	16	3	6	185.5	52.5	238.0
13	(15,24)	70	12	6	581.2	199.3	780.5
14	(15,25)	11	12	1	108.5	115.4	223.8
15	(15,28)	34	9	4	307.7	93.4	401.1
16	(15,30)	15	9	2	166.8	160.5	327.2
17	(34,43)	16	9	2	166.2	159.5	325.6
18	(34,44)	6	3	2	77.9	59.8	137.7
19	(34,48)	21	9	3	224.7	96.8	321.5
20	(34,54)	87	24	4	800.3	392.1	1192.4
21	(39,37)	2	2	1	33.2	32.4	65.5
22	(39,45)	11	12	1	113.4	113.0	226.4
23	(39,49)	2	2	1	44.9	44.1	89.0
24	(35,40)	2	2	1	32.3	31.5	63.8
25	(35,41)	3	3	1	48.8	42.0	90.8
26	(45,38)	4	2	2	78.1	55.2	133.3
27	(45,46)	2	2	1	32.8	32.0	64.9
28	(32,31)	2	2	1	32.3	31.5	63.8
29	(8, 5)	2	2	1	35.4	34.6	70.0
30	(3, 7)	2	2	1	42.9	42.1	84.9
31	(38,52)	2	2	1	29.6	28.8	58.4

32	(50,39)	19	12	2	211.8	133.0	344.8
33	(50,47)	2	2	1	31.1	30.3	61.5
34	(51,35)	9	9	1	92.3	79.8	172.1
35	(18,20)	10	2	5	133.9	47.2	181.1
36	(33,32)	11	12	1	101.5	101.1	202.6
37	(4, 3)	5	3	2	81.5	62.7	144.3
38	(4, 8)	5	9	1	83.9	71.4	155.3
39	(48,42)	2	2	1	56.8	56.0	112.8
40	(48,51)	12	12	1	109.7	109.2	218.9
41	(29,26)	25	9	3	230.3	92.7	323.0
42	(36,50)	28	9	4	317.0	100.2	417.3
43	(36,55)	2	2	1	33.7	32.9	66.6
44	(2, 6)	3	3	1	52.5	45.7	98.3
45	(2,56)	27	9	3	236.4	94.8	331.2
46	(28,30)	22	12	2	202.6	120.0	322.6
47	(30,33)	22	9	3	219.8	92.2	312.1
48	(11,53)	11	12	1	107.5	187.7	295.2
49	(53,12)	9	9	1	85.2	72.7	157.9
50	(19,29)	41	9	5	359.7	90.5	450.2
51	(27,34)	27	9	3	308.8	344.0	652.8
52	(16,19)	68	9	8	573.0	90.0	663.0
53	(24,17)	15	3	5	164.9	54.6	219.5
54	(24,27)	43	12	4	399.7	311.6	711.4
55	(13,15)	42	12	4	388.6	295.3	683.9
56	(12,13)	9	9	1	83.5	248.0	331.5
57	(54,36)	34	9	4	339.7	101.4	441.1
58	(54,53)	39	12	4	398.8	257.9	656.7
59	(54,56)	37	9	5	406.0	101.6	507.6

The total working system cost = 11384.7 (k)
The total protection cost = 6429.1 (k)
The total route mile cost = 2066.0 (k)
The total network cost (working + protection + route) = 19879.9 (k)

*** Network Component Cost Statistics for Sector(1)***

span #	working terms($k)	protection terms($k)	working fiber($k)	protection fiber($k)	working regs($k)	protection regs($k)	APS ($k)	optical switches($k)
1	339.28	62.13	39.95	7.99	0.00	0.00	24.31	0.00
2	134.11	62.13	32.98	16.49	0.00	0.00	24.31	0.00
3	32.12	25.33	26.18	26.18	0.00	0.00	0.00	0.00
4	21.61	20.81	20.23	20.23	0.00	0.00	0.00	0.00
5	143.04	62.13	9.52	4.76	0.00	0.00	24.31	0.00
6	361.64	91.72	16.32	189.04	0.00	0.00	24.31	12.00
7	92.16	91.72	12.92	38.42	0.00	0.00	0.00	0.00
8	621.77	62.13	21.42	2.38	0.00	0.00	24.31	0.00
9	193.57	62.13	31.11	10.37	0.00	0.00	24.31	0.00
10	138.12	25.33	37.40	7.48	0.00	0.00	24.31	0.00
11	92.16	91.72	14.62	25.33	0.00	0.00	0.00	0.00
12	168.13	25.33	17.34	2.89	0.00	0.00	24.31	0.00
13	551.64	91.72	29.58	63.24	0.00	0.00	24.31	20.00
14	92.16	91.72	16.32	23.63	0.00	0.00	0.00	0.00
15	279.82	62.13	27.88	6.97	0.00	0.00	24.31	0.00
16	134.11	62.13	32.64	70.04	0.00	0.00	24.31	4.00
17	143.04	62.13	23.12	69.02	0.00	0.00	24.31	4.00
18	57.45	25.33	20.40	10.20	0.00	0.00	24.31	0.00
19	193.57	62.13	31.11	10.37	0.00	0.00	24.31	0.00
20	773.12	198.72	27.20	157.08	0.00	0.00	24.31	12.00
21	21.61	20.81	11.56	11.56	0.00	0.00	0.00	0.00
22	92.16	91.72	21.25	21.25	0.00	0.00	0.00	0.00
23	21.61	20.81	23.29	23.29	0.00	0.00	0.00	0.00
24	21.61	20.81	10.71	10.71	0.00	0.00	0.00	0.00
25	32.12	25.33	16.66	16.66	0.00	0.00	0.00	0.00
26	42.42	20.81	35.70	17.85	0.00	0.00	16.49	0.00
27	21.61	20.81	11.22	11.22	0.00	0.00	0.00	0.00
28	21.61	20.81	10.71	10.71	0.00	0.00	0.00	0.00

29	21.61	20.81	13.77	13.77	0.00	0.00	0.00	0.00
30	21.61	20.81	21.25	21.25	0.00	0.00	0.00	0.00
31	21.61	20.81	7.99	7.99	0.00	0.00	0.00	0.00
32	177.76	91.72	34.00	17.00	0.00	0.00	24.31	0.00
33	21.61	20.81	9.52	9.52	0.00	0.00	0.00	0.00
34	74.65	62.13	17.68	17.68	0.00	0.00	0.00	0.00
35	105.81	20.81	28.05	5.61	0.00	0.00	20.81	0.00
36	92.16	91.72	9.35	9.35	0.00	0.00	0.00	0.00
37	55.34	25.33	26.18	13.09	0.00	0.00	24.31	0.00
38	65.72	53.20	18.19	18.19	0.00	0.00	0.00	0.00
39	21.61	20.81	35.19	35.19	0.00	0.00	0.00	0.00
40	92.16	91.72	17.51	17.51	0.00	0.00	0.00	0.00
41	211.43	62.13	18.87	6.29	0.00	0.00	24.31	0.00
42	261.96	62.13	55.08	13.77	0.00	0.00	24.31	0.00
43	21.61	20.81	12.07	12.07	0.00	0.00	0.00	0.00
44	32.12	25.33	20.40	20.40	0.00	0.00	0.00	0.00
45	211.43	62.13	24.99	8.33	0.00	0.00	24.31	0.00
46	183.88	91.72	18.70	0.00	0.00	0.00	24.31	4.00
47	202.50	62.13	17.34	5.78	0.00	0.00	24.31	0.00
48	92.16	91.72	15.30	68.34	0.00	27.64	0.00	0.00
49	74.65	62.13	10.54	10.54	0.00	0.00	0.00	0.00
50	339.28	62.13	20.40	4.08	0.00	0.00	24.31	0.00
51	211.43	62.13	97.41	191.25	0.00	58.26	24.31	8.00
52	544.45	62.13	28.56	3.57	0.00	0.00	24.31	0.00
53	140.23	25.33	24.65	4.93	0.00	0.00	24.31	0.00
54	361.64	91.72	38.08	183.60	0.00	0.00	24.31	12.00
55	350.52	91.72	38.08	167.28	0.00	0.00	24.31	12.00
56	74.65	62.13	8.84	147.05	0.00	38.84	0.00	0.00
57	279.82	62.13	59.84	14.96	0.00	0.00	24.31	0.00
58	344.40	91.72	54.40	129.88	0.00	0.00	24.31	12.00
59	330.35	62.13	75.65	15.13	0.00	0.00	24.31	0.00

******* DS3 ROUTING INFORMATION ******

*** NOTE: The following set of spans in the 'routing path' column is unordered, and corresponds to the set of spans described in the above Network Cost Statistics Table.

pair#	demand pair	DS3 demands	routing miles	DS3 x miles	routing path (span set)
1	(1, 2)	4	4.7	18.8	1 ,
2	(1, 15)	6	0.0	0.0	
3	(1, 34)	9	0.0	0.0	
4	(1, 56)	2	0.0	0.0	
5	(2, 15)	2	4.7	9.4	1 ,
6	(2, 34)	2	4.7	9.4	1 ,
7	(2, 56)	1	4.9	4.9	45 ,
8	(11, 12)	5	2.8	14.0	5 ,
9	(11, 13)	5	2.4	12.0	6 ,
10	(11, 15)	9	0.0	0.0	
11	(11, 23)	1	0.0	0.0	
12	(11, 30)	3	0.0	0.0	
13	(11, 43)	1	0.0	0.0	
14	(12, 13)	1	5.2	5.2	56 ,
15	(12, 14)	1	10.4	10.4	5 , 7 ,
16	(12, 15)	4	2.8	11.2	5 ,
17	(12, 30)	1	2.8	2.8	5 ,
18	(12, 43)	1	2.8	2.8	5 ,
19	(12, 53)	1	6.2	6.2	49 ,
20	(13, 15)	3	5.6	16.8	55 ,
21	(13, 28)	1	2.4	2.4	6 ,
22	(14, 15)	1	7.6	7.6	7 ,
23	(14, 30)	1	7.6	7.6	7 ,
24	(14, 33)	1	7.6	7.6	7 ,
25	(14, 34)	2	7.6	15.2	7 ,
26	(14, 50)	1	7.6	7.6	7 ,
27	(15, 16)	8	1.4	11.2	8 ,

28	(15, 17)	6	0.0	0.0		
29	(15, 18)	6	6.1	36.6	9 ,	
30	(15, 19)	16	0.0	0.0		
31	(15, 20)	7	0.0	0.0		
32	(15, 21)	7	4.4	30.8	10 ,	
33	(15, 22)	8	8.6	68.8	11 ,	
34	(15, 23)	13	1.7	22.1	12 ,	
35	(15, 24)	5	2.9	14.5	13 ,	
36	(15, 25)	6	9.6	57.6	14 ,	
37	(15, 26)	10	0.0	0.0		
38	(15, 27)	7	0.0	0.0		
39	(15, 28)	6	4.1	24.6	15 ,	
40	(15, 29)	8	0.0	0.0		
41	(15, 30)	5	9.6	48.0	16 ,	
42	(15, 32)	4	0.0	0.0		
43	(15, 33)	6	0.0	0.0		
44	(15, 34)	10	0.0	0.0		
45	(15, 43)	3	0.0	0.0		
46	(15, 48)	1	0.0	0.0		
47	(15, 50)	1	0.0	0.0		
48	(15, 53)	2	0.0	0.0		
49	(16, 19)	2	2.1	4.2	52 ,	
50	(16, 24)	1	4.3	4.3	8 ,	13 ,
51	(16, 26)	1	1.4	1.4	8 ,	
52	(17, 24)	1	2.9	2.9	53 ,	
53	(17, 26)	2	0.0	0.0		
54	(17, 27)	2	0.0	0.0		
55	(17, 29)	1	0.0	0.0		
56	(18, 20)	1	3.3	3.3	35 ,	
57	(18, 21)	1	10.5	10.5	9 ,	10 ,
58	(18, 22)	1	14.7	14.7	9 ,	11 ,
59	(18, 26)	1	6.1	6.1	9 ,	
60	(19, 21)	1	0.0	0.0		
61	(19, 23)	1	0.0	0.0		
62	(19, 24)	1	0.0	0.0		
63	(19, 25)	1	0.0	0.0		
64	(19, 26)	1	0.0	0.0		
65	(19, 29)	1	2.4	2.4	50 ,	
66	(20, 22)	1	0.0	0.0		
67	(21, 22)	1	13.0	13.0	10 ,	11 ,
68	(21, 25)	1	14.0	14.0	10 ,	14 ,
69	(21, 26)	1	4.4	4.4	10 ,	
70	(21, 29)	1	4.4	4.4	10 ,	
71	(22, 25)	1	18.2	18.2	11 ,	14 ,
72	(24, 26)	1	2.9	2.9	13 ,	
73	(24, 27)	1	5.6	5.6	54 ,	
74	(24, 29)	1	2.9	2.9	13 ,	
75	(25, 26)	1	9.6	9.6	14 ,	
76	(25, 29)	1	9.6	9.6	14 ,	
77	(26, 27)	3	0.0	0.0		
78	(26, 29)	1	3.7	3.7	41 ,	
79	(27, 29)	1	0.0	0.0		
80	(28, 30)	2	5.5	11.0	46 ,	
81	(30, 33)	1	3.4	3.4	47 ,	
82	(30, 34)	2	9.6	19.2	16 ,	
83	(32, 33)	1	5.5	5.5	36 ,	
84	(34, 35)	3	0.0	0.0		
85	(34, 43)	9	6.8	61.2	17 ,	
86	(34, 44)	4	6.0	24.0	18 ,	
87	(34, 45)	4	0.0	0.0		
88	(34, 48)	5	6.1	30.5	19 ,	
89	(34, 50)	4	0.0	0.0		
90	(34, 53)	6	0.0	0.0		
91	(34, 54)	4	4.0	16.0	20 ,	
92	(34, 56)	6	0.0	0.0		
93	(43, 44)	1	12.8	12.8	17 ,	18 ,
94	(43, 53)	1	6.8	6.8	17 ,	
95	(4, 34)	1	9.7	9.7	2 ,	

96	(6, 34)	1	0.0	0.0	
97	(8, 34)	1	0.0	0.0	
98	(9, 34)	1	15.4	15.4	3 ,
99	(11, 34)	3	0.0	0.0	
100	(12, 34)	1	2.8	2.8	5 ,
101	(13, 34)	1	2.4	2.4	6 ,
102	(11, 17)	1	0.0	0.0	
103	(17, 34)	1	0.0	0.0	
104	(11, 19)	1	0.0	0.0	
105	(19, 34)	1	0.0	0.0	
106	(11, 24)	1	0.0	0.0	
107	(11, 26)	1	0.0	0.0	
108	(26, 34)	1	0.0	0.0	
109	(11, 27)	1	0.0	0.0	
110	(27, 34)	1	19.1	19.1	51 ,
111	(11, 28)	1	0.0	0.0	
112	(28, 34)	1	4.1	4.1	15 ,
113	(11, 32)	1	0.0	0.0	
114	(34, 39)	3	0.0	0.0	
115	(32, 34)	2	0.0	0.0	
116	(33, 34)	1	0.0	0.0	
117	(11, 14)	3	7.6	22.8	7 ,
118	(1, 11)	1	0.0	0.0	
119	(34, 36)	3	0.0	0.0	
120	(34, 41)	2	0.0	0.0	
121	(34, 51)	2	0.0	0.0	
122	(1, 3)	2	0.0	0.0	
123	(1, 9)	1	15.4	15.4	3 ,
124	(34, 37)	1	0.0	0.0	
125	(15, 31)	1	0.0	0.0	
126	(1, 4)	1	9.7	9.7	2 ,
127	(1, 5)	1	0.0	0.0	
128	(1, 6)	1	0.0	0.0	
129	(1, 7)	1	0.0	0.0	
130	(1, 8)	1	0.0	0.0	
131	(1, 10)	1	11.9	11.9	4 ,
132	(34, 38)	1	0.0	0.0	
133	(34, 40)	1	0.0	0.0	
134	(34, 42)	1	0.0	0.0	
135	(34, 46)	1	0.0	0.0	
136	(34, 47)	1	0.0	0.0	
137	(34, 49)	1	0.0	0.0	
138	(34, 52)	1	0.0	0.0	
139	(34, 55)	1	0.0	0.0	

==

*** Network Span Layout for Sector(2) Using Mixed Multiplexing ***

*** Initial Dedicated Network Multiplex Span Layout for Sector(2) ***

span #	span	DS3 flow	working span route (span length)	protection span route (span length)
1	(57,58)	2	57-59-77-74-58- (42.8)	(0.0)
2	(57,59)	7	57-59- (4.5)	(0.0)
3	(57,60)	2	57-59-71-73-69-75-60- (42.1)	(0.0)
4	(57,61)	2	57-59-77-61- (34.4)	(0.0)
5	(57,62)	4	57-66-62- (9.8)	(0.0)
6	(57,63)	2	57-59-77-74-63- (46.2)	(0.0)
7	(57,64)	3	57-59-64- (14.5)	(0.0)
8	(57,65)	4	57-66-65- (8.4)	(0.0)
9	(57,66)	7	57-66- (4.2)	(0.0)
10	(57,67)	7	57-67- (4.5)	(0.0)
11	(57,68)	3	57-67-68- (11.6)	(0.0)
12	(57,69)	4	57-59-71-73-69- (21.6)	(0.0)
13	(57,70)	2	57-59-71-70- (18.2)	(0.0)
14	(57,71)	5	57-59-71- (9.3)	(0.0)
15	(57,72)	2	57-59-77-72- (35.4)	(0.0)

16	(57,73)	2	57-59-71-73- (16.8) (0.0)
17	(57,74)	2	57-59-77-74- (37.1) (0.0)
18	(57,75)	2	57-59-71-73-69-75- (26.1) (0.0)
19	(57,76)	2	57-67-76- (11.2) (0.0)
20	(57,77)	3	57-59-77- (23.8) (0.0)
21	(57,78)	2	57-67-68-78- (21.4) (0.0)
22	(57,79)	2	57-59-77-61-79- (47.6) (0.0)
23	(57,80)	2	57-67-68-80- (21.3) (0.0)
24	(57,81)	2	57-59-77-61-81- (39.9) (0.0)
25	(57,82)	2	57-59-71-82- (14.7) (0.0)
26	(57,83)	4	57-67-83- (12.4) (0.0)
27	(84,85)	2	84-89-90-87-85- (38.1) (0.0)
28	(84,86)	2	84-89-90-87-85-86- (42.9) (0.0)
29	(84,87)	2	84-89-90-87- (28.1) (0.0)
30	(84,88)	4	84-88- (5.5) (0.0)
31	(84,89)	3	84-89- (5.8) (0.0)
32	(84,90)	3	84-89-90- (12.5) (0.0)
33	(84,91)	2	84-89-91- (11.8) (0.0)
34	(84,92)	7	84-93-92- (7.8) (0.0)
35	(84,93)	7	84-93- (3.4) (0.0)
36	(94,95)	6	94-95- (7.3) (0.0)
37	(94,96)	2	94-96- (9.5) (0.0)
38	(94,97)	3	94-100-97- (9.0) (0.0)
39	(94,98)	3	94-100-97-99-98- (14.6) (0.0)
40	(94,99)	3	94-100-97-99- (9.4) (0.0)
41	(94,100)	1	94-100- (5.6) (0.0)
42	(57,94)	12	57-59-71-73-97-100-94- (26.2) (0.0)
43	(84,94)	11	84-89-91-96-94- (22.0) (0.0)

The initial network cost (dedicated span layout) = 7585.43 (k)

#	demand pair	node-path
1	(57, 59)	57 59
2	(57, 62)	57 66 62
3	(57, 65)	57 66 65
4	(57, 66)	57 66
5	(57, 67)	57 67
6	(57, 68)	57 67 68
7	(57, 69)	57 59 71 73 69
8	(57, 71)	57 59 71
9	(57, 83)	57 67 83
10	(57, 94)	57 59 71 73 97 100 94
11	(83, 94)	83 67 57 59 71 73 97 100 94
12	(84, 88)	84 88
13	(84, 92)	84 93 92
14	(84, 93)	84 93
15	(92, 93)	92 93 84 93
16	(94, 95)	94 95
17	(94, 97)	94 100 97
18	(94, 98)	94 100 97 99 98
19	(94, 99)	94 100 97 99
20	(84, 94)	84 89 91 96 94
21	(57, 77)	57 59 77
22	(57, 64)	57 59 64
23	(84, 89)	84 89
24	(84, 90)	84 89 90
25	(57, 58)	57 59 77 74 58
26	(57, 60)	57 59 71 73 69 75 60
27	(57, 61)	57 59 77 61
28	(57, 63)	57 59 77 74 63
29	(57, 70)	57 59 71 70
30	(57, 72)	57 59 77 72
31	(57, 73)	57 59 71 73
32	(57, 74)	57 59 77 74
33	(57, 75)	57 59 71 73 69 75
34	(57, 76)	57 67 76

35	(57, 78)	57 67 68 78
36	(57, 79)	57 59 77 61 79
37	(57, 80)	57 67 68 80
38	(57, 81)	57 59 77 61 81
39	(57, 82)	57 59 71 82
40	(84, 85)	84 89 90 87 85
41	(84, 86)	84 89 90 87 85 86
42	(84, 87)	84 89 90 87
43	(84, 91)	84 89 91
44	(94, 96)	94 96

******* Final Mixed Span Layout for Sector(2) ********

The final mixed span layout is obtained from re-multiplexing DS3 demands at the following nodes::

span #	span	DS3_flow	working span route (span length)	protection span route (span length)
1	(57,59)	58	57- 59- (4.5)	(0.0)
2	(57,66)	15	57- 66- (4.2)	(0.0)
3	(57,67)	20	57- 67- (4.5)	(0.0)
4	(84,88)	4	84- 88- (5.5)	(0.0)
5	(84,89)	25	84- 89- (5.8)	(0.0)
6	(84,93)	14	84- 93- (3.4)	(0.0)
7	(94,95)	6	94- 95- (7.3)	(0.0)
8	(94,96)	13	94- 96- (9.5)	(0.0)
9	(94,100)	22	94- 100- (5.6)	(0.0)
10	(77,61)	6	77- 61- (10.6)	(0.0)
11	(77,72)	2	77- 72- (11.6)	(0.0)
12	(77,74)	6	77- 74- (13.3)	(0.0)
13	(87,85)	4	87- 85- (10.0)	(0.0)
14	(69,75)	4	69- 75- (4.5)	(0.0)
15	(74,58)	2	74- 58- (5.7)	(0.0)
16	(74,63)	2	74- 63- (9.1)	(0.0)
17	(68,78)	2	68- 78- (9.8)	(0.0)
18	(68,80)	2	68- 80- (9.7)	(0.0)
19	(61,79)	2	61- 79- (13.2)	(0.0)
20	(61,81)	2	61- 81- (5.5)	(0.0)
21	(85,86)	2	85- 86- (4.8)	(0.0)
22	(99,98)	3	99- 98- (5.2)	(0.0)
23	(75,60)	2	75- 60- (16.0)	(0.0)
24	(90,87)	6	90- 87- (15.6)	(0.0)
25	(66,62)	4	66- 62- (5.6)	(0.0)
26	(66,65)	4	66- 65- (4.2)	(0.0)
27	(93,92)	7	93- 92- (4.4)	(0.0)
28	(67,68)	7	67- 68- (7.1)	(0.0)
29	(67,76)	2	67- 76- (6.7)	(0.0)
30	(67,83)	4	67- 83- (7.9)	(0.0)
31	(71,70)	2	71- 70- (8.9)	(0.0)
32	(71,73)	22	71- 73- (7.5)	(0.0)
33	(71,82)	2	71- 82- (5.4)	(0.0)
34	(97,99)	6	97- 99- (0.4)	(0.0)
35	(91,96)	11	91- 96- (0.7)	91- 89- 84- 94- 96- (25.8)
36	(73,69)	8	73- 69- (4.8)	(0.0)
37	(73,97)	12	73- 97- (0.4)	(0.0)
38	(89,90)	9	89- 90- (6.7)	(0.0)
39	(89,91)	13	89- 91- (6.0)	(0.0)
40	(100,97)	21	100- 97- (3.4)	(0.0)
41	(59,64)	3	59- 64- (10.0)	(0.0)
42	(59,71)	31	59- 71- (4.8)	(0.0)
43	(59,77)	17	59- 77- (19.3)	(0.0)

***** Final Network Cost Statistics for Sector(2) *****

Network Architecture Option:	SH/1:N/EP/1:1/DP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Embedded System Option:	Not Used
Multiplexing Strategy Option:	Mixed
Cost Improvement Option:	Combinatorial

Note: the cost unit is $1,000.00

span#	span	DS3s	system rate(DS3)	1:N term.	working	protection	sub_total
1	(57,59)	58	12	5	498.2	123.7	621.9
2	(57,66)	15	3	5	175.9	56.8	232.7
3	(57,67)	20	3	7	249.1	57.3	306.4
4	(84,88)	4	2	2	61.1	46.7	107.8
5	(84,89)	25	9	3	241.0	96.3	337.3
6	(84,93)	14	3	5	167.0	55.4	222.4
7	(94,95)	6	9	1	78.1	65.6	143.7
8	(94,96)	13	9	2	166.4	102.6	269.0
9	(94,100)	22	9	3	231.1	96.0	327.0
10	(77,61)	6	9	1	83.7	71.2	155.0
11	(77,72)	2	2	1	41.3	40.5	81.9
12	(77,74)	6	9	1	88.3	75.8	164.1
13	(87,85)	4	2	2	76.4	54.3	130.7
14	(69,75)	4	2	2	57.7	45.0	102.7
15	(74,58)	2	2	1	31.3	30.5	61.8
16	(74,63)	2	2	1	37.1	36.3	73.4
17	(68,78)	2	2	1	38.3	37.5	75.7
18	(68,80)	2	2	1	38.1	37.3	75.4
19	(61,79)	2	2	1	44.0	43.3	87.3
20	(61,81)	2	2	1	31.0	30.2	61.1
21	(85,86)	2	2	1	29.8	29.0	58.7
22	(99,98)	3	3	1	41.0	34.2	75.1
23	(75,60)	2	2	1	48.8	48.0	96.8
24	(90,87)	6	9	1	92.2	79.7	172.0
25	(66,62)	4	2	2	61.5	46.8	108.3
26	(66,65)	4	2	2	56.7	44.4	101.1
27	(93,92)	7	9	1	82.1	69.6	151.7
28	(67,68)	7	9	1	86.7	74.2	160.9
29	(67,76)	2	2	1	33.0	32.2	65.2
30	(67,83)	4	2	2	69.3	50.7	120.0
31	(71,70)	2	2	1	36.7	35.9	72.7
32	(71,73)	22	12	2	209.4	128.8	338.2
33	(71,82)	2	2	1	30.8	30.0	60.8
34	(97,99)	6	2	3	65.3	39.4	104.7
35	(91,96)	11	3	4	117.6	50.8	168.4
36	(73,69)	8	9	1	82.8	70.3	153.1
37	(73,97)	12	3	4	117.6	50.3	167.9
38	(89,90)	9	9	1	86.0	73.5	159.6
39	(89,91)	13	3	5	187.0	59.8	246.8
40	(100,97)	21	3	7	238.1	55.4	293.6
41	(59,64)	3	3	1	49.1	42.3	91.5
42	(59,71)	31	9	4	303.5	94.6	398.1
43	(59,77)	17	9	2	208.7	119.3	327.9

The total working system cost = 4769.0 (k)
The total protection cost = 2561.4 (k)
The total route mile cost = 1474.5 (k)
The total network cost (working + protection + route) = 8805.0 (k)

*** Network Component Cost Statistics for Sector(2)***

span #	working terms($k)	protection terms($k)	working fiber($k)	protection fiber($k)	working regs($k)	protection regs($k)	APS ($k)	optical switches($k)
1	459.92	91.72	38.25	7.65	0.00	0.00	24.31	0.00
2	140.23	25.33	35.70	7.14	0.00	0.00	24.31	0.00
3	195.57	25.33	53.55	7.65	0.00	0.00	24.31	0.00
4	42.42	20.81	18.70	9.35	0.00	0.00	16.49	0.00
5	211.43	62.13	29.58	9.86	0.00	0.00	24.31	0.00
6	138.12	25.33	28.90	5.78	0.00	0.00	24.31	0.00
7	65.72	53.20	12.41	12.41	0.00	0.00	0.00	0.00
8	134.11	62.13	32.30	16.15	0.00	0.00	24.31	0.00
9	202.50	62.13	28.56	9.52	0.00	0.00	24.31	0.00
10	65.72	53.20	18.02	18.02	0.00	0.00	0.00	0.00
11	21.61	20.81	19.72	19.72	0.00	0.00	0.00	0.00
12	65.72	53.20	22.61	22.61	0.00	0.00	0.00	0.00
13	42.42	20.81	34.00	17.00	0.00	0.00	16.49	0.00
14	42.42	20.81	15.30	7.65	0.00	0.00	16.49	0.00
15	21.61	20.81	9.69	9.69	0.00	0.00	0.00	0.00
16	21.61	20.81	15.47	15.47	0.00	0.00	0.00	0.00
17	21.61	20.81	16.66	16.66	0.00	0.00	0.00	0.00
18	21.61	20.81	16.49	16.49	0.00	0.00	0.00	0.00
19	21.61	20.81	22.44	22.44	0.00	0.00	0.00	0.00
20	21.61	20.81	9.35	9.35	0.00	0.00	0.00	0.00
21	21.61	20.81	8.16	8.16	0.00	0.00	0.00	0.00
22	32.12	25.33	8.84	8.84	0.00	0.00	0.00	0.00
23	21.61	20.81	27.20	27.20	0.00	0.00	0.00	0.00
24	65.72	53.20	26.52	26.52	0.00	0.00	0.00	0.00
25	42.42	20.81	19.04	9.52	0.00	0.00	16.49	0.00
26	42.42	20.81	14.28	7.14	0.00	0.00	16.49	0.00
27	74.65	62.13	7.48	7.48	0.00	0.00	0.00	0.00
28	74.65	62.13	12.07	12.07	0.00	0.00	0.00	0.00
29	21.61	20.81	11.39	11.39	0.00	0.00	0.00	0.00
30	42.42	20.81	26.86	13.43	0.00	0.00	16.49	0.00
31	21.61	20.81	15.13	15.13	0.00	0.00	0.00	0.00
32	183.88	91.72	25.50	12.75	0.00	0.00	24.31	0.00
33	21.61	20.81	9.18	9.18	0.00	0.00	0.00	0.00
34	63.23	20.81	2.04	0.68	0.00	0.00	17.93	0.00
35	112.79	25.33	4.76	1.19	0.00	0.00	24.31	0.00
36	74.65	62.13	8.16	8.16	0.00	0.00	0.00	0.00
37	114.90	25.33	2.72	0.68	0.00	0.00	24.31	0.00
38	74.65	62.13	11.39	11.39	0.00	0.00	0.00	0.00
39	136.01	25.33	51.00	10.20	0.00	0.00	24.31	0.00
40	197.68	25.33	40.46	5.78	0.00	0.00	24.31	0.00
41	32.12	25.33	17.00	17.00	0.00	0.00	0.00	0.00
42	270.89	62.13	32.64	8.16	0.00	0.00	24.31	0.00
43	143.04	62.13	65.62	32.81	0.00	0.00	24.31	0.00

******* DS3 ROUTING INFORMATION ******

*** NOTE: The following set of spans in the 'routing path' column is unordered, and corresponds to the set of spans described in the above Network Cost Statistics Table.

pair#	demand pair	DS3 demands	routing miles	DS3 x miles	routing path (span set)
1	(57, 59)	6	4.5	27.0	1 ,
2	(57, 62)	3	0.0	0.0	
3	(57, 65)	3	0.0	0.0	
4	(57, 66)	6	4.2	25.2	2 ,
5	(57, 67)	6	4.5	27.0	3 ,
6	(57, 68)	2	0.0	0.0	
7	(57, 69)	3	0.0	0.0	
8	(57, 71)	4	0.0	0.0	
9	(57, 83)	2	0.0	0.0	
10	(57, 94)	11	0.0	0.0	
11	(83, 94)	1	0.0	0.0	
12	(84, 88)	3	5.5	16.5	4 ,
13	(84, 92)	4	0.0	0.0	

14	(84, 93)	4	3.4	13.6	6 ,
15	(92, 93)	2	4.4	8.8	27 ,
16	(94, 95)	5	7.3	36.5	7 ,
17	(94, 97)	2	0.0	0.0	
18	(94, 98)	2	0.0	0.0	
19	(94, 99)	2	0.0	0.0	
20	(84, 94)	11	0.0	0.0	
21	(57, 77)	2	0.0	0.0	
22	(57, 64)	2	0.0	0.0	
23	(84, 89)	2	5.8	11.6	5 ,
24	(84, 90)	2	0.0	0.0	
25	(57, 58)	1	0.0	0.0	
26	(57, 60)	1	0.0	0.0	
27	(57, 61)	1	0.0	0.0	
28	(57, 63)	1	0.0	0.0	
29	(57, 70)	1	0.0	0.0	
30	(57, 72)	1	0.0	0.0	
31	(57, 73)	1	0.0	0.0	
32	(57, 74)	1	0.0	0.0	
33	(57, 75)	1	0.0	0.0	
34	(57, 76)	1	0.0	0.0	
35	(57, 78)	1	0.0	0.0	
36	(57, 79)	1	0.0	0.0	
37	(57, 80)	1	0.0	0.0	
38	(57, 81)	1	0.0	0.0	
39	(57, 82)	1	0.0	0.0	
40	(84, 85)	1	0.0	0.0	
41	(84, 86)	1	0.0	0.0	
42	(84, 87)	1	0.0	0.0	
43	(84, 91)	1	0.0	0.0	
44	(94, 96)	1	9.5	9.5	8 ,

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*** Network Span Layout for Inter-Gate Subnet Using Mixed Multiplexing

*** Initial Dedicated Network Multiplex Span Layout for Inter-Gateway Section ***

span #	span	DS3 flow	working span route (span length)	protection span route (span length)
1	(15,94)	37	15-24-17-27-94- (15.5)	15- 16- 19- 29- 25- 94- (17.1)

The initial network cost (dedicated span layout) = 694.11 (k)

The initial network cost (dedicated span layout) = 23097.62 (k)

#	demand pair	node-path
1	(15, 94)	15 24 17 27 94

******* New Span Layout ********

span #	span	DS3_flow	working span route (span length)	protection span route (span length)
1	(15,94)	37	15- 24- 17- 27- 94- (15.5)	15- 16- 19- 29- 25- 94- (17.1)

******* New Span Layout ********

span #	span	DS3_flow	working span route (span length)	protection span route (span length)
1	(15,94)	37	15- 24- 17- 27- 94- (15.5)	15- 16- 19- 29- 25- 94- (17.1)

******* Final Mixed Span Layout for Inter-Gate Subnet ********

The final mixed span layout is obtained from re-multiplexing DS3 demands at the following nodes::

span #	span	DS3_flow	working span route (span length)	protection span route (span length)
1	(27,94)	37	27- 94- (7.0)	27- 17- 24- 15- 16- 19- 29- 25- 94- (25.6)
2	(15,24)	37	15- 24- (2.9)	15- 16- 19- 29- 25- 94- 94- 27- 27- 17- 24- (35.5)
3	(24,27)	37	24- 17- 27- (5.6)	24- 15- 16- 19- 29- 25- 94- 94- 27- (29.9)

***** Final Network Cost Statistics for Inter-Gate Subnet *****

Network Architecture Option:	SH/1:N/EP/1:1/DP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Embedded System Option:	Not Used
Multiplexing Strategy Option:	Mixed
Cost Improvement Option:	Combinatorial

Note: the cost unit is $1,000.00

span#	span	DS3s	system rate(DS3)	1:N term.	working	protection	sub_total
1	(27,94)	37	12	4	392.0	302.1	694.1
2	(15,24)	37	24	2	384.7	445.9	830.7
3	(24,27)	37	12	4	382.5	331.4	713.8

The total working system cost = 1159.2 (k)
The total protection cost = 1079.4 (k)
The total route mile cost = 0.0 (k)
The total network cost (working + protection + route) = 2238.6 (k)

*** Network Component Cost Statistics for Inter-Gate Subnet ***

span #	working terms($k)	protection terms($k)	working fiber($k)	protection fiber($k)	working regs($k)	protection regs($k)	APS ($k)	optical switches($k)
1	344.40	91.72	47.60	174.08	0.00	0.00	24.31	12.00
2	374.88	198.72	9.86	120.70	0.00	98.20	24.31	4.00
3	344.40	91.72	38.08	203.32	0.00	0.00	24.31	12.00

******* DS3 ROUTING INFORMATION ******

*** NOTE: The following set of spans in the 'routing path' column is unordered, and corresponds to the set of spans described in the above Network Cost Statistics Table.

pair#	demand pair	DS3 demands	routing miles	DS3 x miles	routing path (span set)
1	(15, 94)	37	0.0	0.0	

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Network Cost Statistics (Summary)

Network Architecture Option:	SH/1:N/EP/1:1/DP
Spare DS3 Capacity Option:	Used
Cost Model Option:	Default (Present)
Multiplexing Strategy Option:	Mixed

Cost Improvement Option: Combinatorial

Initial Network Cost	Final Network Cost	Improvement (%)
23097.6(k)	21417.8(k)	7.27

**** Network Component Cost Summary *****

Component	Cost ($k)	Ratio
Working Fibers	2527.90	0.1180
Protection Fibers	3102.33	0.1448
Working Terminals	14785.08	0.6903
Protection Terminals	5295.64	0.2473
Working Regenerators	0.00	0.0000
Protection Regenerators	222.94	0.0104
Optical Switches	128.00	0.0060
APS	1321.05	0.0617
Fiber Placement	3540.50	0.1653
Total Network	21417.85	

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