RESTORATION NETWORK DESIGN

and

NEURAL NETWORK

by

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ABSTRACT

This thesis focuses on the representation and generation of the constrained parameters of telecommunication network by means of a neural network (ANN[1]) architecture. The objective is to develop an optimization tool for application of restoration network design. The approach of BACKPROPOGATION ALGORITHM is adopted in which all the traffic, working or spared equipments and the physical constrains are transformed into the neurons or weights of the neural model, and then optimization in cost is applied on a predefined telecommunication network configuration to find out a satisfactory result. An experiment with four traffic nodes bearing DS3 high speed digital signal in Digital Cross-Connect (DACS) equipment on a meshed configuration is demonstrated. The performance compared with to the result of some current design practice is investigated and recommendations are provided.

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[1]In this thesis, the word "network" describes telecommunication network, while "ANN" will be used for neural networks.

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CONTENTS

SECTION 1: INTRODUCTION

As long as the computerized planning tools become popular and reliable in telecommunication network design, the philosophies underlying network planning are changing. There are basically two different philosophies adopted by most Telcos and other network operators. The first is centred on mathematical modelling and achieves single solution, optimal, in theory, if all input data is complete and reliable and if the model actually reflects the network behaviour. The second philosophy is based on the heuristic and practical approach, requiring the active participation of the planner to prescribe as many network behaviour and the topology[1], and selects the most suitable one after the computer evaluation. In second case, the input data need not be stringent as that as in mathematical model since the computer software will generate and build up the traffic matrix according to the desired algorithm.

This thesis will describe one of application of the second philosophy and focus on the demonstration of DS3 (45 Mbps) restoration network design. Among various practical approaches neural network (ANN) - BACKPROPAGATION ALGORITHM - is adopted in which optimization in cost aspect will be

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[1] Magazine, ed. Eitel Rizzoni and Mario Pietrogrande, "The Best Laid Plans", Washington D.C., USA. *Communications International*/June 1991, p.67

applied on a predefined network configuration. Turbo C language is used in the software development and the demonstration runs on the 386 personal computer.

SECTION 2: FORMULATION OF PROBLEM

2.1 PROBLEM IDENTIFICATION

In a high speed transmission network, DS3 (45 Mbps) is nearly the fundamental unit in digital signal transmission. As a result, for a static DS3 backbone transmission network it is important to determine the spare capacity requirements so that adequate spare capacity is available for network restoration in the event of link failures. The spare network design for restoration is achieved by deploying the Digital Cross-Connect Systems(DACS) and the optical fibre products.

It is noted that there is no single topology that meets most requirements for all cases of network for restoration. Therefore, it should evaluate different promising network architectures to select the best meeting the needs of particular network. Two most commonly used criteria in evaluating the merits of different topology are cost and restoration speed. The simulation in this thesis will only address the cost aspect to encourage the economical spare network design based upon the specified topology option.

The topology in MESHed type is selected in simulation of this thesis. This type of topology promotes more sharing of the spare capacity among various alternate paths which may result in a more economical network for the desired levels of promotion than other topology such as RING, STAR etc..

2.2 NETWORK PLANNING PARAMETERS AND ASSUMPTIONS

To realize a practical network analysis for the network configuration prescribed, following parameters are selected for investigation:

1. Point-to-point inter-trunk traffic (DS3) matrices
2. Point-to-point local traffic (DS3) matrices
3. Point-to-point inter-trunk spare traffic (DS3) matrices
4 Basic equipment at individual node
5. Spare equipment (DS3) at individual node
6. Cost of network, existing and additional investment for ultimate demand

7 Physical path (optical fibre) constraints in terms of the link cost

The graphical representation of a four(4) DACS nodes network is drawn in the figure 1. To work out the optimized spare network capacity, following assumptions and criteria must be followed:

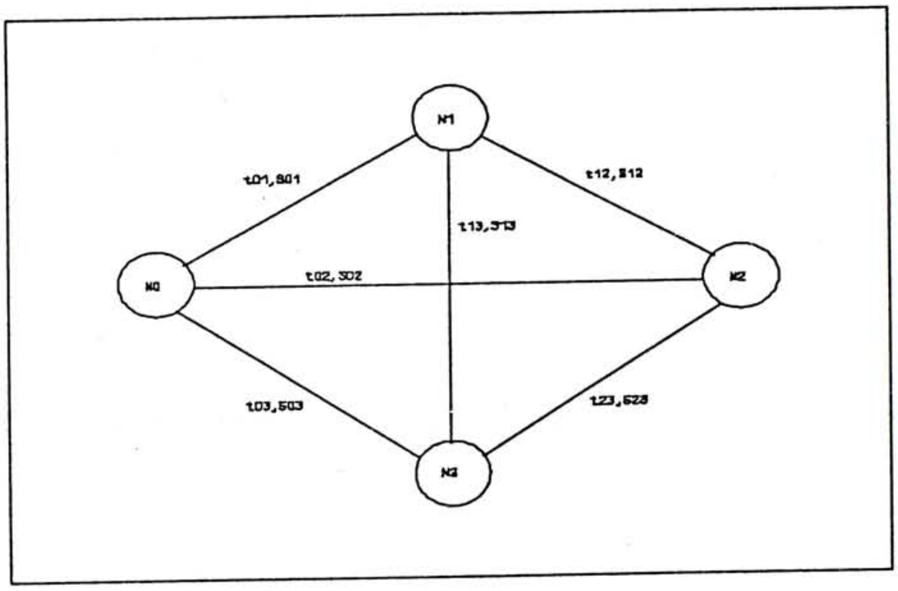

Figure 1. Four Nodes (DS3) Configuration

1. The normal traffic between node i and j will be carried along the direct route.

   i.e t_{ij} travels along N_iN_j.

2. The network topology is MESH connected.
3. Not more than one (1) physical path fails at any

one time.

4. If one of the physical path fails, the affected traffic (t_{ij}) will be split to all its adjacent paths to form an indirect route.
5. All the indirect routes are allowed to pass through only one more node besides the source and destination node.
6. The affected traffic (t_{ij}) in indirect route will be carried in spare link (s_{ik}, s_{kj}) along the indirect route.

2.3 NEURAL NETWORK MODEL TRANSFORMATION

For simplicity, the backpropagation ANN model for four DACS traffic node network is represented graphically in the figure 2a and figure 2b. The notations in the figure 2a and 2b are illustrated respectively in following sub-sections 2.3.1 and 2.3.2 while the derivation of the model is driven from the simple mathematical cost equations and the restored traffic constraints that are illustrated in sub-section 2.3.3.

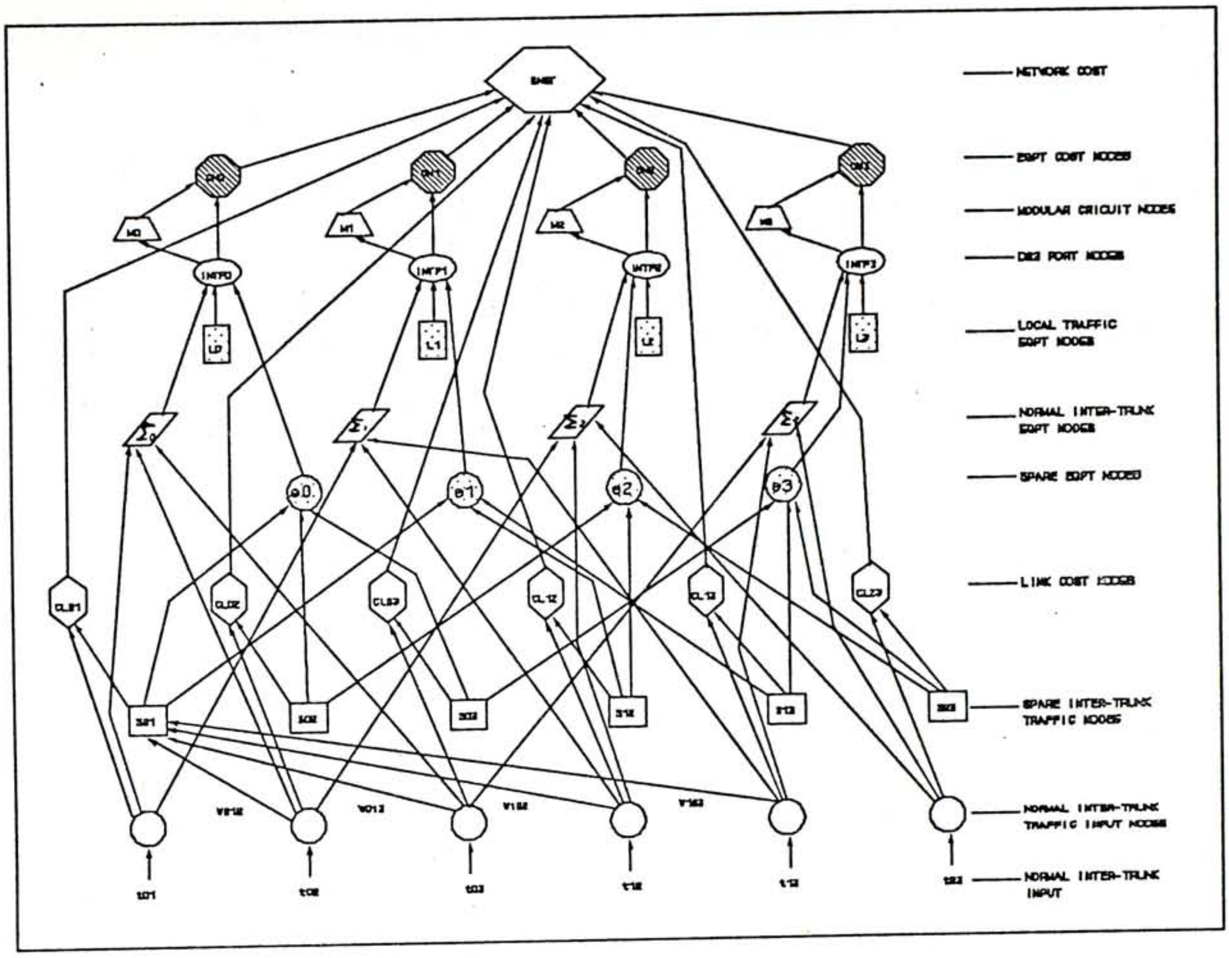

Figure 2a. ANN Model of Restoration Network (Costing Forward Aspect)

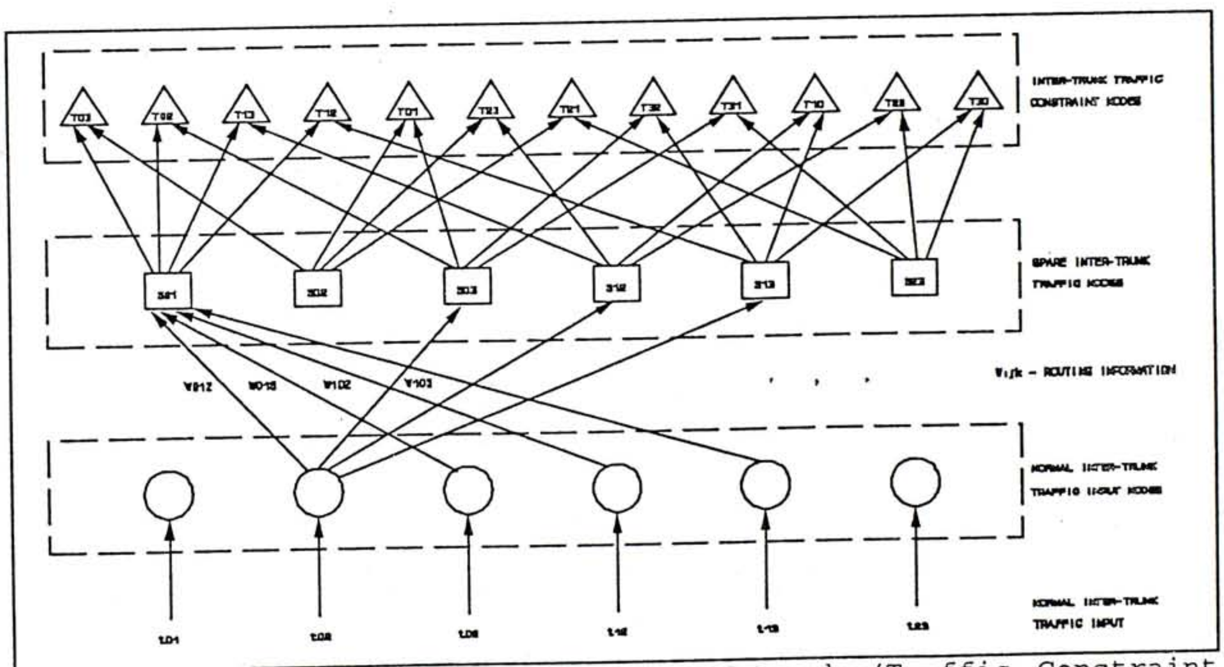

Figure 2b. ANN Model of Restoration Network (Traffic Constraint Forward Aspect)

2.3.1 *Input Requirements and Notations*

1) N_i - Node i, accommodate local DS3 (L_i) traffic as well as inter-trunk DS3 (t_{ij}, s_{ij}) traffic.

2) t_{ij} - Normal inter-trunk traffic from DACS node i to j (or from Node j to i) i.e. $t_{ij} = t_{ji}$, $i \neq j$

$$\begin{matrix} 0 & t_{01} & t_{02} & t_{03} \\ t_{10} & 0 & t_{12} & t_{13} \\ t_{20} & t_{21} & 0 & t_{23} \\ t_{30} & t_{31} & t_{32} & 0 \end{matrix}$$

Practically, the inter-trunk traffic between DACS node i and j varies quarterly in many Telcos. That requires at least five (5) increasing input patterns with the last one indicating the last demand.

3) s_{ij} - Spare inter-trunk traffic link capacity between node i and j required for adjacent link restoration. s_{ij} = s_{ji} for identical quantity of duplex communication.

$$\begin{matrix} 0 & s_{01} & s_{02} & s_{03} \\ s_{10} & 0 & s_{12} & s_{13} \\ s_{20} & s_{21} & 0 & s_{23} \\ s_{30} & s_{31} & s_{32} & 0 \end{matrix}$$

4) L_i - Local DS3 traffic at DACS node i (L_0, L_1, L_2, L_3)

5) e_i - Spare equipment (DS3) at DACS node i which must satisfy any one of its restoration route. i.e. $e_i = \max(s_{ij})$ for $j \neq i$

e.g. $e_2 = \max(s_{02}, s_{12}, s_{23})$

6) E_i - Basic equipment cost at DACS node i, which includes the common control and switching network equipment cost.

Normally, E_i is the same for same type of DS3 Cross-Connect equipment housing in different DACS node i. i.e. $E_i = E_j$ (say E).

Also, E only supports a fixed number of DS3 interfaces/ports, say m.

If number of ports is larger than value of m, another E must be added for this growing capacity, etc..

7) C_p - One(1) DS3 interface/port cost, including the required line terminal equipment (LTE) cost.

8) C_{Lij} - One(1) DS3 link cost (from DACS node i to j). Normally, it depends on

i) whether fibre duct has been constructed

ii) length of the fibre

i.e.

$$
\begin{matrix}
0 & C_{L01} & C_{L02} & C_{L03} \\
C_{L10} & 0 & C_{L12} & C_{L13} \\
C_{L20} & C_{L21} & 0 & C_{L23} \\
C_{L30} & C_{L31} & C_{L32} & 0
\end{matrix}
$$

where $C_{Lij} = C_{Lji}$

2.3.2 Output Specification

The backpropagation ANN model will provide the following results after the computer evaluation:

1) Spare inter-trunk link capacity s_{ij}
2) Individual DACS node equipments

3) Total network cost

4) Individual node cost

5) Routing information, when restoration occurs, in terms of weights of ANN model ω_{ikj}, where

i = starting node
j = destination node
k = intermediate node

The value of ω_{ikj} lies between the range of 0 to 1 in order to indicate the percentage of the restored traffic along the path connecting node i, k and j.

2.3.3 Mathematical Equations and Constraints

Following equations and constraint inequalities are employed in the forward feeding of the neural model:

- Spare equipment requirements

$$e_0 = \max(s_{01}, s_{02}, s_{03})$$
$$e_1 = \max(s_{10}, s_{12}, s_{13})$$
$$e_2 = \max(s_{02}, s_{12}, s_{23})$$
$$e_3 = \max(s_{30}, s_{31}, s_{32})$$

- Spare traffic requirements

$$
\begin{aligned}
s_{02} + s_{03} &\geq t_{01} \\
s_{12} + s_{13} &\geq t_{01} \\
s_{01} + s_{03} &\geq t_{02} \\
s_{12} + s_{23} &\geq t_{02} \\
s_{01} + s_{02} &\geq t_{03} \\
s_{13} + s_{23} &\geq t_{03} \\
s_{01} + s_{13} &\geq t_{12} \\
s_{02} + s_{23} &\geq t_{12} \\
s_{01} + s_{12} &\geq t_{13} \\
s_{03} + s_{23} &\geq t_{13} \\
s_{02} + s_{12} &\geq t_{23} \\
s_{03} + s_{13} &\geq t_{23}
\end{aligned}
$$

- Equipment cost at DACS node is summation of following:

Local traffic DS3 port cost	: $L_i\ C_p$
Inter_trunk DS3 port cost	: $(\sum_{j \neq i} t_{ij})\ C_p$
Spare DS3 port cost	: $e_i\ C_p$
Common equipment cost	: $n_i\ E$ where n_i is Roundup integer of $\left(\frac{L_i + \sum_{j \neq i} t_{ij} + e_i}{m}\right)$

- Total node cost : $\sum_{i=1}^{4} n_i E + C_p \sum_{i=1}^{4} (L_i + \sum_{j \neq i} t_{ij} + e_i)$

- Link ij cost : $(t_{ij} + s_{ij})\ C_{Lij}$

- Total link cost : $\sum_{i=1}^{4} \sum_{\substack{j \neq i \\ j=1}}^{4} (t_{ij} + s_{ij}) C_{Lij}$

- Network cost : Total node cost + Total link cost

2.4 ALGORITHM AND IMPLEMENTATION

According to the backpropagation algorithm, the simulation will perform two modes of operation. The first is the forward feed in which those related to the traffic constraints are processed in advance. If the traffic requirements are satisfactory, forward feed will branch to the cost evaluating step to calculate the network cost. The second is the backward feed to re-train the weights of the ANN model if the traffic constraints or the optimized network cost are not met.

The details of error propagation are graphically represented in the Figure 3a and 3b:

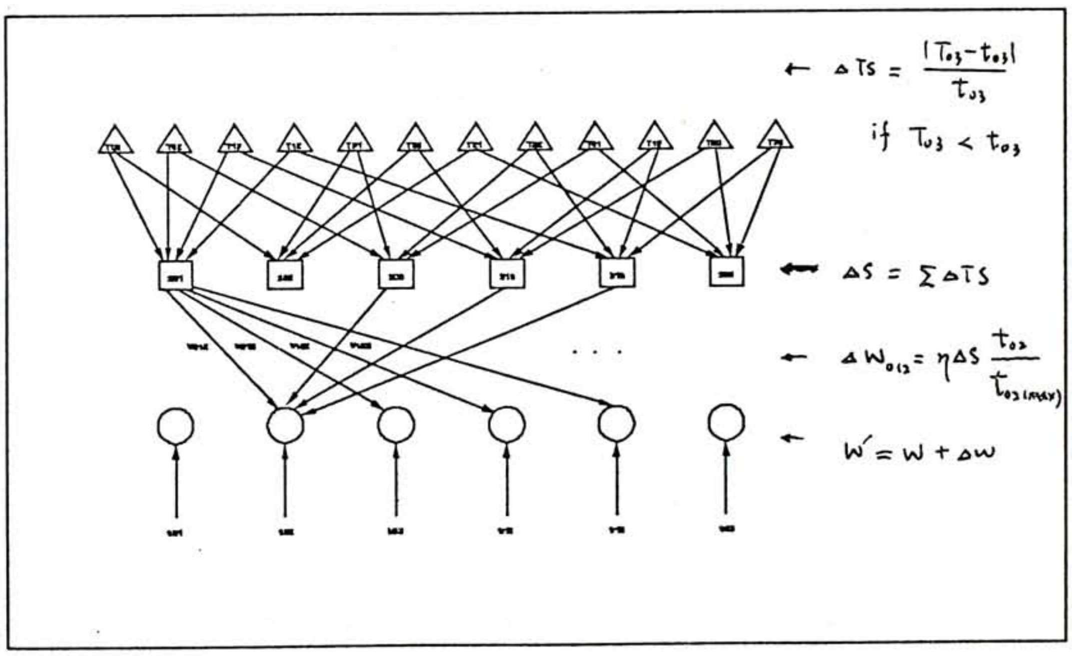

Figure 3a. ANN Model of Restoration Network (Traffic Constraint Backward Aspect)

2.4.1 Traffic Error Propagation

As in the figure 3a, the result T_{ij} at the output of the traffic constraint node is compared with normal inter-trunk traffic t_{ij}. If $T_{ij} < t_{ij}$, the traffic requirement fails at that particular traffic constraint node and the error results as the following:

$$\varepsilon_T = |T_{ij} - t_{ij}| / t_{ij}$$

Backpropagate ε_T to the layer of s_{ij} by

$$\varepsilon_s = \sum \varepsilon_T$$

The change of weight ω is:

$$\Delta\omega = \eta \, \varepsilon_s \, (t_{ij}/t_{ij(max)}),$$ where η = gain term

The adjustment of weight is:

$$\omega' = \omega + \Delta\omega$$

2.4.2 Optimization Error Backpropagation

As in the figure 3b, the network cost at the output of ANN total cost node is compared with the previous optimized value. If there is no improvement, backpropagate the following error:

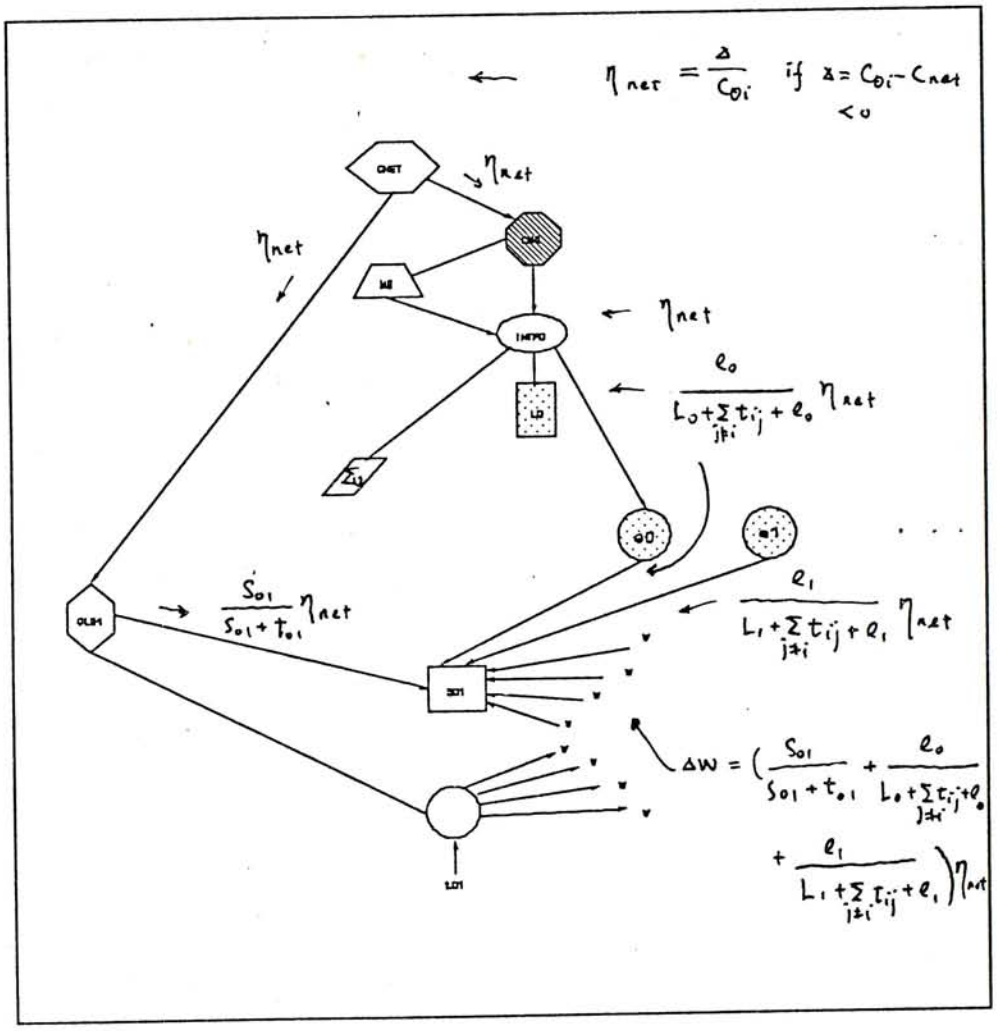

Figure 3b. ANN Model of Restoration Network (Costing Backward Aspect)

ε_{net} = error / $C_{\theta i}$ where $C_{\theta i}$ is previous optimized value.

Hence the error accumulated in the node of layer s_{ij} is:

$$\varepsilon_s = \left(\frac{s_{ij}}{s_{ij}+t_{ij}} + \frac{e_i}{L_i+\sum_{j\neq i} t_{ij}+e_i} + \frac{e_j}{L_j+\sum_{j\neq i} t_{ij}+e_j} \right) \varepsilon_{net}$$

The adjustment of weight will then be processed as that in traffic constraints section.

SECTION 3: SIMULATION RESULTS

In different planning environment (e.g. fluctuation in cost of different fibre routing), the results are tabled[1] in the Appendix A. At the same time, the result from current design practice in calculating the spare capacity is also demonstrated for comparison. This method has been once undertaken in Group Special Mobile (GSM) DACS (Digital Cross-connect) network planning in one of telecommunication network operator companies in Hong Kong, which distributes the restored traffic evenly to the indirect routes.

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[1]The results in the first two pages highlight the comparison while the remaining is the details.

All the input values (e.g fibre cost, equipment cost and traffic demand patterns) are for reference, but not taken from any authorized network operator. The simulation is operated on the different set of input parameters such as the following items:

- Different inter-trunk traffic patterns including the graduated increasing traffic and the fluctuated pattern.

- Different fibre cost in individual routing. To simulate the situations in Hong Kong, all the fibre route costs are nearly the same. However, the situations in North American require the fibre routing cost fluctuates a lot. Those cost patterns are taken into consideration.

- The option to offer flexible arrangement of physically separated paths for each inter-trunk is provided (# of phy'l/trunk), range from one(1) to four(4) separated paths.

The results can be analyzed into three categories: the first concerns about the same(or nearly the same) cost for all fibre paths to emulated the Hong Kong environment while the second addresses the large cost difference in some of the fibre paths to simulate the North American situation, the last one emphasises on the traffic demand fluctuation in the last two traffic seasons in one year.

3.1 All Link Costs Are Same or Nearly the Same

Both the backpropagation method and the conventional design give the closed results. From the cost aspect it seems that the backpropagation ANN model contributes a superior output than that of the conventional design. The network cost from the backpropagation model is little bit less than that in conventional design. It is also noted that the spare inter-trunk assignments s_{ij} in ANN model make sense since it avoids putting more spare fibres in the expensive paths for the case of nearly same link cost.

The speed in deriving the optimized result is acceptable (less than the order of 10^3 in iterations) in the backpropagation ANN model even it is much slower than that in conventional design (less than 1 second, approximate the order of 10^1 in iterations). If the network planner using this simulation just wants to get a result superior than that in conventional design, the performance of this ANN model is much encouraging since it needs to look for a virtual global minimum value.

3.2 Fluctuated Cost in One or Two Fibre Paths

This is the situation like the transmission networks in North American in which there are some of the inter-trunk paths containing no fibres, large difference in fibre length for different paths, or maybe there are some practical difficulties in laying the fibre in some towns. Those factors contribute a sharp difference in fire costing in some paths. In this category, the simulation results show the most superior performance in ANN model. The optimized network cost value is much less (US$100-200K less) than that from the conventional design while the computer run time is within the order of 10^3.

Another interesting point is the spare link s_{ij} assignment problem. According to the conventional design all the failure links to restored are evenly distributed on the adjacent indirect paths without considering the detailed economic aspect. On the contrast, ANN model starts from the economic view point which can reasonably resolve this problem by continuous backward training to obtain the optimized value.

3.3 Sudden Traffic Demand Change in Last Season

During the simulation in this category, two kinds of the traffic input patterns are fed into ANN model and the results are compared. The first traffic pattern has the characteristics of the smooth growing traffic demand in five (5) traffic seasons(TS) for one year as described in the following:

Case 1:

	TS_1	TS_2	TS_3	TS_4	TS_5
t_{01}	11	12	13	15	16
t_{02}	6	6	7	9	10
t_{03}	9	10	11	15	16
t_{12}	21	23	23	24	25
t_{13}	8	8	9	9	10
t_{23}	23	23	24	24	24

However, the second traffic patterns have a greater demand in the last traffic season as shown as below:

Case 2:

	TS_1	TS_2	TS_3	TS_4	TS_5
t_{01}	11	12	13	15	36
t_{02}	6	6	7	9	25
t_{03}	9	10	11	15	30
t_{12}	21	23	23	24	46
t_{13}	8	8	9	9	28
t_{23}	23	23	24	24	40

The results indicates that the run time (number of iterations) in case 2 is longer than that in case 1 while the network cost accuracy is nearly the same when comparing with that in conventional design.

SECTION 4: DISCUSSION

4.1 ADVANTAGES

The demonstration of the four DACS nodes optimization in spare DS3 capacity indicated that much advantages have been achieved by backpropagation ANN model over the conventional design, especially for applications of network design in regions with large difference in fibre cost, length and underground cable ducts. This is actually the unstructured optimization technique that heavily depends on the run time computation. It does not require an accurate and perfect mathematical model. The input data can contribute to the optimization database ω. Meanwhile, the order of 10^3 run time in this algorithm operation is encouraged.

The traffic routing information hidden in ω_{ikj} allows planner to understand the restored traffic distribution when the link failures occur.

4.2 LIMITATIONS

Due to the demonstration purpose, only four DACS nodes are accounted for simulation. This limitation can be relaxed by expanding the software code but need a moderate effort even the program structure needs little change. The feasibility of ANN model make it possible to enhance this demonstration into a complete application program if a large dimension (DACS node numbers) is achieved and integrated text and graphical interfaces are added in.

Secondly, the MESHed type topology is prescribed which seems to lack of flexibility in topology selection. Actually, this can be improved by inserting an activation flag matrix A into the inter-trunk traffic t_{ij} matrix which then indicates whether the existing fibre paths can be ready for service or closure.

Activation Matrix A:

$$\begin{matrix} 0 & a_{01} & a_{02} & a_{03} \\ a_{10} & 0 & a_{12} & a_{13} \\ a_{20} & a_{21} & 0 & a_{23} \\ a_{30} & a_{31} & a_{32} & 0 \end{matrix}$$

where a_{ij} = 0 : fibre path in closure;

1 : fibre path in service.

In case of fibre path closure ($a_{ij} = 0$), the traffic t_{ij} re-distributes evenly to all its adjacient non-closure indirect routes, which is defined as the path allowed to pass through only one more node beside the source and destination nodes. i.e.

t_{ij} divides into:

$[1/(n-2)]*t_{ij}*a_{ik}$ & $[1/(n-2)]*t_{ij}*a_{kj}$, for a_{ik} & $a_{kj} \neq 0$

:

:

$[1/(n-2)]*t_{ij}*a_{im}$ & $[1/(n-2)]*t_{ij}*a_{mj}$, for a_{im} & $a_{mj} \neq 0$

where n is the number of the non-closure paths,
k & m denote the DACS nodes other than i & j.

Then the modified resultant inter-trunk traffic:

$t'_{ik} = t_{ik} + [1/(n-2)]*t_{ij}$

$t'_{kj} = t_{kj} + [1/(n-2)]*t_{ij}$

:

$t'_{im} = t_{im} + [1/(n-2)]*t_{ij}$

$t'_{mj} = t_{mj} + [1/(n-2)]*t_{ij}$

This is the generalization of the topology problem, from which all types of the architecture, e.g. ring, star and mesh, can be fully described.

Thirdly, the restoration techniques in this project research are not strongly stressed. However, they are another parameters to be considered in the restoration network design. Generally, the techniques such as Automatic Protection Switch (APS), Self-healing Ring and Self-healing Network could be adopted in the restoration design. Besides, the full picture of restoration includes the parameters such as restoration time, type of control (Centralized and Distributed control). These items should be taken into consideration.

Finally, the failure pattern herein stresses the single fibre link only. Actually, the multiple link failure, single node and multiple node failure should be investigated.

4.3 UNCERTAINTIES

Although there are a lot of advantages in this ANN model, the problem still exits. It is uncertain whether the optimized value obtained in the model is the global minimum, though it is much less than that calculated from the conventional design. At the same time, the model adopted in this thesis is the modified Backpropagation. The traditional backpropagation requires the activation function in each neuron node be differentiable and the output of the neuron node be in range of -1 to +1. However, the algorithm in this thesis keeps the backpropagation principle but deviates a lot in the above two aspect. First, the activation function in the modified algorithm is linear to reflect the real economic aspect. That turns to the second point - infinite value is allowed in each ANN node for real economic projection. Consequently, this modified backward training normalizes the error by its previous reference value and backpropogates the fraction or weighted error to the input nodes.

To ensure the optimized value be global minimum as possible, the modified algorithm provides a ten(10) sets of randomized weights ω in escalating levels, twenty(20) to sixty(60) times of training is required for each set of randomized value to check out the optimized value be virtually global minimum. At the same time, the software development equips with the backup facilities in which the program data and results obtained in current time can be reused continuously in the next program operation without restarting the whole process from beginning every time. This facility allows the multiple numbers of ten(10) sets of randomized weights to operate, which in turn increases the chance in obtaining the global minimum.

4.4 ANOTHER APPROACH

To solve the above uncertainty, another neural network model - Hoffied model - is recommended. But it is noted that this model formulation and implementation are more complex. In addition, the problem that requires an amount of neurons to represent one large value should be studied.

4.5 APPLICATIONS

When the practical application is concerned, this network optimization design requires further modification. The ideal design tool should, based on the raw point-to-point DACS node traffic, generate a network routing topology other than a planner prescribed meshed or ring type network. Then in the second phase of operation, this ANN optimization technique is taken into account to generate a spare capacity for network restoration. This is the whole picture of the real network design tools.

SECTION 5: CONCLUSION

The simulation of backpropogation ANN model in application of restoration network design shows that it is feasible to put it into implementation of large network design. This unstructured computation is superior in network cost evaluation when the problems in fibre cost, lengths and cable ducts of different paths are apparent. With the implicit meaning of the weight ω_{ikj}, traffic routing information can be easily obtained. At the same time, the order of 10^3 run time is encouraged. As a result, for a static network, such as DS3 transmission network, ANN model - backpropagation - is feasible for the network design tool implementation.

- END -

GLOSSARY OF TERMS

ANN: Artificial Neural Network is a model used to formulate the user defined problems, which is different from the telecommunication network.

DACS: Digital Access Cross-Connect equipment used to switch the digital signals statically.

DS3: The digital transmission facility over which a 44.735 Mbit/s bipolar digital signal in aggregate of twenty-eight (28) T1 lines will be transported bidirectionally.

DS3 port nodes ($intf_i$): Neural nodes to sum up all the local, normal and spare inter-trunk quantity of DS3 interface equipment at DACS node i.

Eqpt cost node (cn_i): Neural nodes to calculate the cost for both DACS common control equipment and DS3 interface port cost at DACS node i.

Inter-trunk traffic constraint nodes (T_{ij}): Neural node to calculate the restoration traffic ($\sum s_{ik}$ for $k \neq j$) and check the restoration constraint by inequality ($T_{ij} \geq t_{ij}$).

Modular circuit nodes (m_i): Roundup circuit to determine the minimum quantity of DACS common control equipment at DACS node i.

Link cost nodes (C_{Lij}): Neural nodes to calculate the total link cost between DACS nodes i and j by multiplying both the normal and spare inter-trunk traffic to the link cost C_{Lij}.

Local traffic eqpt nodes (L_i): Neural nodes for local DS3 traffic input to DACS node i.

Network: The telecommunication network carrying the traffic patterns.

Network cost (cnet): The highest neural node in costing aspect to sum up all the DS3 equipment cost at node i (i = 1..4) and the DS3 link cost C_{Lij}.

Normal inter-trunk eqpt nodes (Σ_i): Neural nodes to calculate the total quantity of equipment for inter-trunk traffic from DACS node i to j ($j \neq i$).

Normal inter-trunk input (t_{ij}): DS3 traffic input from DACS node i to j.

Normal inter-trunk traffic input nodes: Neural nodes to accept the traffic input t_{ij}.

Restoration network: The telecommunication network housing the spare equipments, together with the network management facility, prepares for the link and/or node failures.

Spare eqpt nodes (e_i): Neural nodes to select the maximum quantity of spare DS3 equipments s_{ij} ($j \neq i$) for DACS node i.

Spare inter-trunk traffic nodes (s_{ij}): Spare DS3 capacity between DACS nodes i and j for link restoration which are the items to be determined in the model.

T1 line: The digital transmission facility over which a 1544 kbit/s bipolar digital signal will be transported bidirectionally.

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APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Ultimate Network Cost (US$'000)		Run Time in (N) (Iteration)	Spare Link (DS3) Capacity S_{ij}	
			ANN	Current Design		ANN	Current Design
1. Graduate growth in 5 traffic seasons (TS) per year. Ultimate traffic demand is: t_{01} 16 t_{02} 10 t_{03} 16 t_{12} 25 t_{13} 10 t_{23} 24	a. All link costs are nearly the same: C_{Lij} C_{L01} 14K C_{L12} 16K C_{L02} 12K C_{L13} 12K C_{L03} 12K C_{L23} 20K	2	1522.0	1548.4	449	S_{ij} S_{01} = 6, S_{12} = 6 S_{02} = 6, S_{13} = 7 S_{03} = 6, S_{23} = 7	S_{ij} S_{01} = 7, S_{12} = 6 S_{02} = 7, S_{13} = 7 S_{03} = 6, S_{23} = 7
		3	1101.2	1109.6	2579	S_{ij} S_{01} = 6, S_{12} = 3 S_{02} = 6, S_{13} = 3 S_{03} = 5, S_{23} = 3	S_{ij} S_{01} = 5, S_{12} = 4 S_{02} = 5, S_{13} = 4 S_{03} = 4, S_{23} = 4
	b. Cost fluctuate in one or two fiber paths: C_{Lij} C_{L01} 12K C_{L12} 12K C_{L02} 12K C_{L13} 12K C_{L03} 12K C_{L23} 90K	2	2610.4	2772.4	1079	S_{ij} S_{01} =10, S_{12} =11 S_{02} =10, S_{13} =11 S_{03} = 7, S_{23} =3	S_{ij} S_{01} = 7, S_{12} = 6 S_{02} = 7, S_{13} = 7 S_{03} = 6, S_{23} = 7
		3	1875.6	1978.0	1459	S_{ij} S_{01} = 5, S_{12} = 4 S_{02} = 5, S_{13} = 4 S_{03} = 4, S_{23} = 4	S_{ij} S_{01} = 5, S_{12} = 4 S_{02} = 5, S_{13} = 5 S_{03} = 4, S_{23} = 5

APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Ultimate Network Cost (US$'000)		Run Time in (N) (Iteration)	Spare Link Capacity S_{ij}(DS3)	
			ANN	Current Design		ANN	Current Design
2.Fluctuate in last traffic season (TS) per year. Ultimate traffic demand is: t_{01} 36 t_{02} 25 t_{03} 30 t_{12} 41 t_{13} 28 t_{23} 40	a. All link costs are same: C_{Lij} 12K	2	2335.6	2335.6	1784	s_{ij} s_{01} =12, s_{12} = 9 s_{02} =12, s_{13} =11 s_{03} =11, s_{23} =11	s_{ij} s_{01} =12, s_{12} =10 s_{02} =12, s_{13} =11 s_{03} =10, s_{23} =11
		3	1635.0	1635.0	439	s_{ij} s_{01} = 8, s_{12} = 8 s_{02} = 8, s_{13} = 8 s_{03} = 6, s_{23} = 8	s_{ij} s_{01} = 8, s_{12} = 7 s_{02} = 8, s_{13} = 8 s_{03} = 7, s_{23} = 8
	b. Cost fluctuate in one or two fiber paths: C_{Lij} C_{L01} 70K C_{L12} 16K C_{L02} 12K C_{L13} 100K C_{L03} 12K C_{L23} 12K	2	6246.8	6462.4	154	s_{ij} s_{01} =13, s_{12} = 9 s_{02} =13, s_{13} =10 s_{03} =11, s_{23} =10	s_{ij} s_{01} =12, s_{12} =11 s_{02} =14, s_{13} =12 s_{03} =11, s_{23} =14
		3	3227.0	3330.8	3339	s_{ij} s_{01} = 7, s_{12} = 4 s_{02} = 7, s_{13} = 5 s_{03} = 6, s_{23} = 5	s_{ij} s_{01} = 6, s_{12} = 6 s_{02} = 8, s_{13} = 6 s_{03} = 6, s_{23} = 8

APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity Link S_{ij} (DS3)		Routing Information	
			by ANN	Existing design D	By ANN	Exist-ing D	By ANN	Exist-ing D	By ANN	By D
1. Graduate increase in 5 traffic seasons (TS) per year. Last season traffic' demand is: t_{01} 16 t_{02} 10 t_{03} 16 t_{12} 25 t_{13} 10 t_{23} 24	a. All link costs are same: C_{Lij} 12K	2	TS 1_{st} 2_{nd} 3_{rd} 1174.0 4_{th} 1226.0 5_{th} 1266.0	TS 5_{th} 1266.0	37 38 39	1	s_{ij} s_{01} 7 s_{02} 7 s_{03} 6 s_{12} 6 s_{13} 6 s_{23} 6	s_{ij} s_{01} 7 s_{02} 7 s_{03} 6 s_{12} 6 s_{13} 6 s_{23} 6	See Appen -dix B	See Appen -dix B
		3	TS 1_{st} 724.2 2_{nd} 763.4 3_{rd} 804.8 4_{th} 833.4 5_{th} 939.6	5_{th} 939.6	355 356 352 353 439	1	s_{ij} s_{01} 4 s_{02} 4 s_{03} 4 s_{12} 4 s_{13} 5 s_{23} 5	s_{ij} s_{01} 5 s_{02} 5 s_{03} 4 s_{12} 4 s_{13} 4 s_{23} 4	Ditto	Ditto

APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} Link (DS3)		Routing Information	
			By ANN	Existing design D	By ANN	Exist-ing D	By ANN	Exist-ing D	By ANN	By D
1. Graduate increase in 5 traffic seasons (TS) per year. Last season traffic' demand is: t_{01} 16 t_{02} 10 t_{03} 16 t_{12} 25 t_{13} 10 t_{23} 24	a. All link costs are same: C_{Lij} 12K	4	TS 1_{st} 598.6 2_{nd} 600.2 3_{rd} 626.6 4_{th} 668.0 5_{th} 708.0	TS 5_{th} 708.0	120 116 117 1173 1174	1	S_{ij} S_{01} 4 S_{02} 4 S_{03} 3 S_{12} 3 S_{13} 3 S_{23} 3	S_{ij} S_{01} 4 S_{02} 4 S_{03} 3 S_{12} 3 S_{13} 3 S_{23} 3	See Appen-dix B	See Appen-dix B
	C_{Lij} C_{L01} 14K C_{L02} 12K C_{L03} 12K C_{L12} 16K C_{L13} 12K C_{L23} 20K	2	TS 1_{st} 2_{nd} 3_{rd} 1416.0 4_{th} 1470.0 5_{th} 1522.0	5_{th} 1548.4	343 348 449	1	S_{ij} S_{01} 6 S_{02} 6 S_{03} 6 S_{12} 6 S_{13} 7 S_{23} 7	S_{ij} S_{01} 7 S_{02} 7 S_{03} 6 S_{12} 6 S_{13} 7 S_{23} 7	Ditto	Ditto

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} (DS3)		Link	Routing Information	
			By ANN	Existing design D	By ANN	Existing D	By ANN		Existing D	By ANN	By D
1. Graduate increase in 5 traffic seasons (TS) per year. Last season traffic' demand is: t_{01} 16 t_{02} 10 t_{03} 16 t_{12} 25 t_{13} 10 t_{23} 24	b. C_{Lij} C_{L01} 14K C_{L02} 12K C_{L03} 12K C_{L12} 16K C_{L13} 12K C_{L23} 20K	3	TS 1_{st} 863.8 2_{nd} 923.6 3_{rd} 966.8 4_{th} 986.0 5_{th} 1101.2	TS 5_{th} 1109.6	1065 377 452 1068 2579	1	s_{ij} s_{01} 6 s_{02} 6 s_{03} 5 s_{12} 3 s_{13} 3 s_{23} 3		s_{ij} s_{01} 5 s_{02} 5 s_{03} 4 s_{12} 4 s_{13} 4 s_{23} 4	See Appen -dix B	See Appen -dix B
		4	TS 1_{st} 710.2 2_{nd} 711.8 3_{rd} 740.0 4_{th} 781.0 5_{th} 827.6	5_{th} 836.0	1100 1101 1102 1103 1089	1	s_{ij} s_{01} 5 s_{02} 5 s_{03} 4 s_{12} 2 s_{13} 2 s_{23} 2		s_{ij} s_{01} 4 s_{02} 4 s_{03} 3 s_{12} 3 s_{13} 3 s_{23} 3	Ditto	Ditto

APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} (DS3)		Link		Routing Information	
			by ANN	Existing design D	By ANN	Exist-ing D	By ANN		Exist-ing D		By ANN	By D
1. Graduate increase in 5 traffic seasons (TS) per year. Last season traffic' demand is:	a. C_{Lij}	2	TS	TS			s_{ij}		s_{ij}			
t_{01} 16	C_{L01} 12K		1_{st} 2404.4		1075		s_{01}	10	s_{01}	7	See Appen -dix B	See Appen -dix B
t_{02} 10	C_{L02} 12K		2_{nd} 2443.2		1076		s_{02}	10	s_{02}	7		
t_{03} 16	C_{L03} 12K		3_{rd} 2507.2		1077		s_{03}	7	s_{03}	6		
t_{12} 25	C_{L12} 12K		4_{th} 2571.2		1078		s_{12}	11	s_{12}	6		
t_{13} 10	C_{L13} 12K		5_{th} 2610.4	5_{th} 2772.4	1079	1	s_{13}	11	s_{13}	7		
t_{23} 24	C_{L23} 90K						s_{23}	3	s_{23}	7		
		3	TS				s_{ij}		s_{ij}		Ditto	Ditto
			1_{st} 1580.2		1185		s_{01}	5	s_{01}	5		
			2_{nd} 1634.6		1455		s_{02}	5	s_{02}	5		
			3_{rd} 1676.0		1457		s_{03}	4	s_{03}	4		
			4_{th} 1704.6		1458		s_{12}	4	s_{12}	4		
			5_{th} 1875.6	5_{th} 1978.0	1459	1	s_{13}	4	s_{13}	5		
							s_{23}	4	s_{23}	5		

APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} Link (DS3)		Routing Information	
			by ANN	Existing design D	By ANN	Exist-ing D	By ANN	Exist-ing D	By ANN	By D
1. Graduate increase in 5 traffic seasons (TS) per year. Last season traffic' demand is: t_{01} 16 t_{02} 10 t_{03} 16 t_{12} 25 t_{13} 10 t_{23} 24	b. C_{Lij} C_{L01} 12K C_{L02} 12K C_{L03} 12K C_{L12} 12K C_{L13} 12K C_{L23} 90K	4	TS 1_{st} 1208.6 2_{nd} 1210.2 3_{rd} 1251.6 4_{th} 1368.0 5_{th} 1408.0	TS 5_{th} 1512.4	1055 1056 1057 1058 1059	1	S_{ij} S_{01} 7 S_{02} 7 S_{03} 2 S_{12} 4 S_{13} 4 S_{23} 2	S_{ij} S_{01} 4 S_{02} 4 S_{03} 3 S_{12} 3 S_{13} 4 S_{23} 4	See Appen-dix B	See Appen-dix B
	c. C_{L01} 70K C_{L02} 12K C_{L03} 12K C_{L12} 12K C_{L13} 100K C_{L23} 12K	2	TS 1_{st} 2556.4 2_{nd} 2641.2 3_{rd} 2867.6 4_{th} 2977.6 5_{th} 3075.6	5_{th} 3241.6	265 266 272 418 414	1	S_{ij} S_{01} 8 S_{02} 8 S_{03} 7 S_{12} 5 S_{13} 5 S_{23} 5	S_{ij} S_{01} 7 S_{02} 8 S_{03} 6 S_{12} 6 S_{13} 7 S_{23} 8	Ditto	Ditto

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} (DS3)	Link	Routing Information	
			By ANN	Existing design D	By ANN	Existing D	By ANN	Existing D	By ANN	By D
1. Graduate increase in 5 traffic seasons (TS) per year. Last season traffic' demand is: t_{01} 16 t_{02} 10 t_{03} 16 t_{12} 25 t_{13} 10 t_{23} 24	c. C_{Lij} C_{L01} 70K C_{L02} 12K C_{L03} 12K C_{L12} 12K C_{L13} 100K C_{L23} 12K	3	TS 1_{st} 1801.8 2_{nd} 1889.2 3_{rd} 2001.0 4_{th} 2014.6 5_{th} 2324.0	TS 5_{th} 2419.2	1120 1686 1682 1683 1679	1	S_{ij} S_{01} 4 S_{02} 5 S_{03} 3 S_{12} 5 S_{13} 5 S_{23} 5	S_{ij} S_{01} 5 S_{02} 6 S_{03} 4 S_{12} 4 S_{13} 5 S_{23} 6	Ditto	Ditto
		4	TS 1_{st} 1358.2 2_{nd} 1359.8 3_{rd} 1532.2 4_{th} 1573.6 5_{th} 1671.6	5_{th} 1812.4	1 1 3 603 609	1	S_{ij} S_{01} 5 S_{02} 5 S_{03} 4 S_{12} 2 S_{13} 2 S_{23} 2	S_{ij} S_{01} 4 S_{02} 4 S_{03} 3 S_{12} 3 S_{13} 4 S_{23} 4	Ditto	Ditto

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} Link (DS3)		Routing Information	
			By ANN	Existing design D	By ANN	Exist-ing D	By ANN	Exist-ing D	By ANN	By D
2. Fluctuate in last traffic season (TS) per year. Last season traffic' demand is: t_{01} 36 t_{02} 25 t_{03} 30 t_{12} 46 t_{13} 28 t_{23} 40	a. All link costs are same: C_{Lij} 12K	2	TS 1_{st} 2_{nd} 3_{rd} 1174.0 4_{th} 1213.2 5_{th} 2335.6	TS 5_{th} 2355.6	92 198 1784	1	S_{ij} S_{01} 12 S_{02} 12 S_{03} 11 S_{12} 9 S_{13} 11 S_{23} 11	S_{ij} S_{01} 12 S_{02} 12 S_{03} 10 S_{12} 10 S_{13} 11 S_{23} 11	See Appen-dix B	See Appen-dix B
		3	TS 1_{st} 724.2 2_{nd} 763.4 3_{rd} 804.8 4_{th} 833.4 5_{th} 1635.0	5_{th} 1635.0	435 436 437 438 439	1	S_{ij} S_{01} 8 S_{02} 8 S_{03} 6 S_{12} 8 S_{13} 8 S_{23} 8	S_{ij} S_{01} 8 S_{02} 8 S_{03} 7 S_{12} 7 S_{13} 8 S_{23} 8	Ditto	Ditto

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} Link (DS3)		Routing Information	
			By ANN	Existing design D	By ANN	Exist-ing D	By ANN	Exist-ing D	By ANN	By D
2. Fluctuate in last traffic season (TS) per year. Last season traffic' demand is: t_{01} 36 t_{02} 25 t_{03} 30 t_{12} 41 t_{13} 28 t_{23} 40	a. All link costs are same: C_{Lij} 12K	4	TS 1_{st} 2_{nd} 3_{rd} 4_{th} 5_{th} 1242.4	TS 5_{th} 1242.4	4214	1	s_{ij} s_{01} 6 s_{02} 6 s_{03} 6 s_{12} 4 s_{13} 6 s_{23} 6	s_{ij} s_{01} 6 s_{02} 6 s_{03} 5 s_{12} 5 s_{13} 6 s_{23} 6	See Appen -dix B	See Appen -dix B
	C_{Lij} C_{L01} 14K C_{L02} 12K C_{L03} 12K C_{L12} 16K C_{L13} 12K C_{L23} 20K	2	TS 1_{st} 1312.0 2_{nd} 1353.6 3_{rd} 1407.0 4_{th} 1461.0 5_{th} 2674.0	5_{th} 2714.8	4005 4561 4562 4563 5024	1	s_{ij} s_{01} 11 s_{02} 11 s_{03} 10 s_{12} 10 s_{13} 11 s_{23} 10	s_{ij} s_{01} 11 s_{02} 11 s_{03} 10 s_{12} 10 s_{13} 11 s_{23} 11	Ditto	Ditto

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} Link (DS3)		Routing Information	
			By ANN	Existing design D	By ANN	Existing D	By ANN	Existing D	By ANN	By D
1. Fluctuate in last traffic season (TS) per year. Last season traffic' demand is: t_{01} 36 t_{02} 25 t_{03} 30 t_{12} 41 t_{13} 28 t_{23} 40	b. C_{Lij} C_{L01} 14K C_{L02} 12K C_{L03} 12K C_{L12} 16K C_{L13} 12K C_{L23} 20K	3	TS 1_{st} 863.8 2_{nd} 923.6 3_{rd} 966.8 4_{th} 995.4 5_{th} 1834.8	TS 5_{th} 1834.8	6469	1	s_{ij} s_{01} 7 s_{02} 7 s_{03} 7 s_{12} 7 s_{13} 7 s_{23} 7	s_{ij} s_{01} 7 s_{02} 7 s_{03} 7 s_{12} 7 s_{13} 7 s_{23} 7	See Appen -dix B	See Appen -dix B
		4	TS 1_{st} 718.6 2_{nd} 720.2 3_{rd} 748.6 4_{th} 790.0 5_{th} 1431.6	5_{th} 1451.6	480 481 482 483 1744	1	s_{ij} s_{01} 6 s_{02} 6 s_{03} 6 s_{12} 5 s_{13} 5 s_{23} 5	s_{ij} s_{01} 6 s_{02} 6 s_{03} 5 s_{12} 5 s_{13} 6 s_{23} 6	Ditto	Ditto

APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} Link (DS3)		Routing Information	
			By ANN	Existing design D	By ANN	Existing D	By ANN	Existing D	By ANN	By D
2. Fluctuate in last traffic season (TS) per year. Last season traffic' demand is: t_{01} 36 t_{02} 25 t_{03} 30 t_{12} 46 t_{13} 28 t_{23} 40	a. C_{Lij} C_{L01} 12K C_{L02} 12K C_{L03} 12K C_{L12} 12K C_{L13} 12K C_{L23} 90K	2	TS 1_{st} 2304.0 2_{nd} 2344.0 3_{rd} 2396.0 4_{th} 2538.0 5_{th} 4482.4	TS 5_{th} 4702.8	105 106 107 108 599	1	S_{ij} S_{01} 17 S_{02} 17 S_{03} 12 S_{12} 10 S_{13} 8 S_{23} 7	S_{ij} S_{01} 11 S_{02} 11 S_{03} 10 S_{12} 10 S_{13} 11 S_{23} 11	See Appen-dix B	See Appen-dix B
		3	TS 1_{st} 1519.0 2_{nd} 1634.0 3_{rd} 1676.0 4_{th} 1704.0 5_{th} 3142.2	5_{th} 3182.8	280 106 107 108 614	1	S_{ij} S_{01} 9 S_{02} 9 S_{03} 7 S_{12} 10 S_{13} 10 S_{23} 5	S_{ij} S_{01} 7 S_{02} 7 S_{03} 7 S_{12} 7 S_{13} 7 S_{23} 7	Ditto	Ditto

APPENDIX A SIMULATION RESULTS

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} (DS3)		Link	Routing Information	
			By ANN	Existing design D	By ANN	Existing D	By ANN	Existing D	By ANN	By D
2. Fluctuate in last traffic season (TS) per year. Last season traffic' demand is: t_{01} 36 t_{02} 25 t_{03} 30 t_{12} 46 t_{13} 28 t_{23} 40	b. C_{Lij} C_{L01} 12K C_{L02} 12K C_{L03} 12K C_{L12} 12K C_{L13} 12K C_{L23} 90K	4	TS 1_{st} 1171.0 2_{nd} 1172.6 3_{rd} 1214.0 4_{th} 1265.6 5_{th} 2255.6	TS 5_{th} 2477.6	165 166 167 688 1244	1	s_{ij} s_{01} 11 s_{02} 11 s_{03} 5 s_{12} 6 s_{13} 6 s_{23} 2	s_{ij} s_{01} 6 s_{02} 6 s_{03} 5 s_{12} 5 s_{13} 6 s_{23} 6	See Appen -dix B	See Appen -dix B
	c. C_{L01} 70K C_{L02} 12K C_{L03} 12K C_{L12} 16K C_{L13} 100K C_{L23} 12K	2	TS 1_{st} 2642.0 2_{nd} 2656.4 3_{rd} 2866.4 4_{th} 3012.4 5_{th} 6246.8	5_{th} 6462.4	1 2 3 4 154	1	s_{ij} s_{01} 13 s_{02} 13 s_{03} 11 s_{12} 9 s_{13} 10 s_{23} 10	s_{ij} s_{01} 12 s_{02} 14 s_{03} 11 s_{12} 11 s_{13} 12 s_{23} 14	Ditto	Ditto

Traffic I/P Pattern (DS3)	Link Cost (US$'000)	# of phy'l /trunk	Network Cost (US$'000)		Run Time (Iteration)		Spare Capacity S_{ij} Link (DS3)		Routing Information	
			By ANN	Existing design D	By ANN	Exist-ing D	By ANN	Exist-ing D	By ANN	By D
2. Fluctuate in last traffic season (TS) per year. Last season traffic' demand is: t_{01} 36 t_{02} 25 t_{03} 30 t_{12} 46 t_{13} 28 t_{23} 40	c. C_{Lij} C_{L01} 70K C_{L02} 12K C_{L03} 12K C_{L12} 12K C_{L13} 100K C_{L23} 12K	3	TS 1_{st} 1713.0 2_{nd} 1829.9 3_{rd} 1929.4 4_{th} 1943.0 5_{th} 4375.8	TS 5_{th} 4416.2	3024	1	S_{ij} S_{01} 9 S_{02} 10 S_{03} 10 S_{12} 5 S_{13} 7 S_{23} 7	S_{ij} S_{01} 8 S_{02} 9 S_{03} 7 S_{12} 8 S_{13} 8 S_{23} 9	Ditto	Ditto
		4	TS 1_{st} 1358.2 2_{nd} 1359.8 3_{rd} 1352.2 4_{th} 1573.6 5_{th} 3227.0	5_{th} 3330.8	3310 3301 3302 3298 3339	1	S_{ij} S_{01} 7 S_{02} 7 S_{03} 6 S_{12} 4 S_{13} 5 S_{23} 5	S_{ij} S_{01} 6 S_{02} 8 S_{03} 6 S_{12} 6 S_{13} 6 S_{23} 8	Ditto	Ditto

APPENDIX B ANN TRAFFIC ROUTING EXAMPLE

CONDITIONS:

- All Link Costs are nearly the same C_{Lij}:
  $C_{L01} = 14K$, $C_{L02} = 12K$, $C_{L03} = 12K$, $C_{L12} = 16K$, $C_{L13} = 12K$, $C_{L23} = 20K$
- Number of Physical Paths in Each Trunk = 2
- Traffic Input Pattern Graduated Increased t_{ij} :
  $t_{01} = 16$, $t_{02} = 10$, $t_{03} = 16$, $t_{12} = 25$, $t_{13} = 10$, $t_{23} = 24$

ANN OUTPUT RESULTS:

- Spare Link Capacity Assignment:
  $s_{01} = 6$, $s_{02} = 6$, $s_{03} = 6$, $s_{12} = 6$, $s_{13} = 7$, $s_{23} = 7$

- Routing Information

w_{021} 0.685063,	w_{012} 0.302694,	w_{013} 0.746570,	w_{102} 0.452504,	w_{103} 0.640993,	w_{203} 0.537386,
w_{120} 0.685063,	w_{210} 0.302694,	w_{310} 0.746570,	w_{201} 0.452504,	w_{301} 0.640993,	w_{302} 0.537386,
w_{031} 0.314937,	w_{032} 0.697306,	w_{023} 0.253430,	w_{132} 0.547496,	w_{123} 0.359007,	w_{213} 0.462614,
w_{130} 0.314937,	w_{230} 0.697306,	w_{320} 0.253430,	w_{231} 0.547496,	w_{321} 0.359007,	w_{312} 0.462614,

DEMONSTRATION:

eg. Normal inter-trunk traffic between DACS nodes N_1 and N_2 is t_{12} (= 25). If one of the physical paths is broken, half of the traffic (= 13) at most has to diversify to its two adjacent paths ($N_1N_3N_2$ and $N_1N_0N_2$). The traffic routing is shown as followings:

Traffic along path $N_1N_3N_2$ (paths N_1N_3 & N_3N_2) = ROUNDDOWN(w_{132} * 13)
= 7

Traffic along path $N_1N_0N_2$ (paths N_1N_0 & N_0N_2) = ROUNDUP(w_{102} * 13)
= 6

which match the above spare link assignments.