RESOURCES OPTIMIZATION OF INTEGRATION OF SEPARATE OPTICAL NETWORKS

Raymond Hai Ming Leung and Lian Kuan Chen
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, New Terriories. Hong Kong
raymondhmleung@hotmail.com

Abstract: Multiple networks create redundancy in fibre resources. Merging of networks becomes a necessity. Simulation was made to evaluate options of interconnection. Through interconnections, fibre links can be eliminated. Required network resources are greatly reduced.

OCIS codes: (060.4250) Networks; (220.4830) Optical Systems Design

1. Introduction

Telecom networks had been designed to carry voice traffic for decades. With the growth of data traffic in recent years, carriers have constructed substantial amount of fibre optic networks. Open competition enhanced pressure on carriers to compete upon quality of service, capacity and operating margin. To cater for these needs, carriers have built networks with large capacity. Furthermore, multiple carriers have constructed networks with similar geographical coverage but demand seems not adequate to sustain the co-existence of these multiple networks [1]. Resources have not been used optimally and revenue has plunged to its lowest since inception. Many carriers are considering co-location, merging and acquisition in order to reduce cost. Much pressure is on carriers to reduce operating cost in order to survive in the present situation. Merging of networks will become necessity in the near future before another surge of bandwidth requirement. Optimal strategy for merging two overlapping optical networks is therefore indispensable to assist network planners for their network design or to facilitate business decision of merge and acquisition.

In this paper, we investigate this optimization problem and present analysis results on network merging. It is noted that only two or less interconnected nodes are needed under moderate traffic load. In addition, after merging networks and with the interconnection, fibre links can be saved from a merged network. Operating cost can therefore be reduced from the reduction on the use of fibre links, thus reducing overall cost for the carrier.

2. Background

Engineers for much of the past two decades have been promulgating of deregulation. It started with air travel in the United States in the late 1970 and onto banking, trucking, rail roads, telecommunication and electricity. The results for this deregulation were mixed. Many industries including the telecommunication industry were struggling financially. In the carrier sector, both deregulating and customer's expectation of better quality of service, larger capacity and faster restoration caused carriers to build fibre links with capacities that were well over demand. Many carrier operators operate in similar geographical coverage. There was no consideration for redundancy of resources. Government encouraged open competition on pricing but ignored resources optimization. Substantial capital investment has been put into various resources i.e. equipment, fibre links, connectivity. In recent years, pricing of providing services has dropped substantially and capital investments in infrastructure by carriers have reduced significantly. Operators sought to maximize returns from existing assets. Network planning, design, management and resources optimization became more critical for a successful operator. System flexibility was also the credo of network optimization, which was a constant balancing act between coverage, capacity, and the increasingly important quality of service (QOS). Operators tried to optimize their own network performance. Multiple operators must try to co-locate or merge with networks in the same geographical location in order to achieve network optimization [2]. This resulted in lowering overall cost for the operator and therefore more competitive in his pricing to end users or better return on investment.

Most networks are over-designed and over provisioned. Carriers generally run their network to "five-nine" or 99.999% availability, which equates to about 5 min 15 sec down-time a year. This normally does not include any "planned down time" for scheduled maintenance and system upgrades. Most internet providers are running networks at twenty-five percent utilization [3]. In a merged network situation, operator can make good use of these un-utilized capacities. Operator can find out which fibre links are redundant and can be eliminated to save cost.

When there are more operators than sustainable, it is important to consider merging or co-locating. The complexity of integrating networks determines cost effectiveness. It is therefore important to address this issue from the perspective of an operator and how we make the best use of existing networks. This paper will create a model for such purpose. With the use of Integer Programming Solver, CPLEX programme, we can identify potential saving areas and arrive at an optimal solution for a set of predetermined assumptions.

3. Optimization Model

A model is established with the intention of designing a survivable existing network with optimal cost and finding the correct interconnection node or nodes. It is assumed that no losses in nodes and fibre links will occur when commodities flow within the networks. All incoming and through traffic will go through nodes with no losses.

Mathematical programming methods have been used to formulate the spare capacity planning problem for link and path. Integer Programming approach is often used. Linear Programming (LP) model which is polynomial–time bounded and rounds the solution to integer values, seems to be the best approach and logical model to be used. A well supported and developed programme CPLEX was selected for our purpose.

One way of merging two existing networks is to build additional fibre interconnections linking network nodes locating in the same city. However, as the number of node increases, the total cost of building these interconnecting fibre links also increases dramatically. Thus the objective of this paper is to find the optimal strategy to identify the pairs of network nodes between which a new fibre link needs to be constructed. To solve this problem, CPLEX approach was employed. Costing and routing become two basic mechanisms for managing network resources. The standard multi-commodity formulation for the Minimum Cost Capacity Installation (MCCI) problem has been commonly used in the design of telecommunication and distribution networks [4]. The multi-commodity formulation can be written as follows.

Minimize

$$C = \sum_{1\le k\le K} \sum_{(i,j)\in A} c_{ij}^k x_{ij}^k + \sum_{(i,j)\in A} f_{ij} y_{ij} + \sum_{i\in V} e_i z_i \qquad (1)$$

subject to

$$\sum_{j:(i,j)\in A} x_{ij}^k - \sum_{j:(i,j)\in A} x_{ji}^k = \begin{cases} v^k & if \;\; i = s^k \\ -v^k & if \;\; i = d^k \\ 0 & otherwise \end{cases} \qquad \text{for all } i \in V, k \in K \qquad (2)$$

$$\sum_{1\le k\le K} x_{ij}^k \le u_{ij} y_{ij} \qquad \text{for all } (i,j)\in A \qquad (3)$$

$$\sum_{j:(i,j)\in A} (x_{ij}^k + x_{ji}^k) \le q_i z_i \qquad \text{for all } i\in V, k\in K \qquad (4)$$

$$x_{ij}^k \ge 0 \qquad \text{for all } (i,j)\in A, k\in B \qquad (5)$$

$$y_{ij}^k \le a_{ij} \qquad \text{for all } (i,j)\in A \qquad (6)$$

$$y_{ij} = \{0,1\} \qquad \text{for all } (i,j)\in A \qquad (7)$$

$$z_i = \{0,1\} \qquad \text{for all } i\in V \qquad (8)$$

In this formulation, $G = (V, A)$ is the directed network. V is a set of N vertices. A is a set of N x N arcs. B is set of K commodities. $|A|$ is the capacity variable and $|A|$ $|K|$ is the flow variable. The objective is to minimize the total cost C and install the required capacity on the arcs. x_{ij}^k is the flow of commodity k on arc (i, j). c_{ij}^k is the cost per unit flow of commodity k on arc (i, j). Fibre build-cost f_{ij} in arc (i, j) is the building cost of fibre link from node i to node j where $1 \le i \le N$ and $1 \le j \le N$. Since node distance for separate networks in similar geographical location vary depending on the geographical location, the interconnecting cost of fibre varies from location to location. It is assumed that the interconnection between the two networks can only occur at the same location. Interconnection between two different locations is not allowed. y_{ij} is the binary variable indicating whether arc (i, j) is included in the network. e_i is the fixed cost and operating cost of the equipment in node i. This varies depending on the equipment used at each node. z_i is the binary variable indicating whether node i is included in the network.

The objective of the model is to find the optimal cost when merging two existing networks. The intention is to maximize the use of existing network without adding additional fibre links except for the purpose of interconnection.

Constraint (2) is the flow constraint for commodity k. v^k is the volume of commodity k. s^k is the source of commodity k, where $1 \leq k \leq K$. d^k is the destination of commodity k. Commodity is the flow from an origin to a destination. The flow goes in is the same as the flow goes out and can not be larger than the volume of commodity k [4-7]. Constraint (3) ensures that the total flow on each arc cannot exceed the capacity of fibre on the arc. u_{ij} is the capacity of fibre in arc (i,j) [4]. Constraint (4) is the total flow that cannot exceed the capacity of the equipment on the node i. q_i is the capacity of equipment in node i [6]. Constraint (5) is the flow that must be greater than or equal to zero [8]. Constraint (6) indicates which fibre is allowed to be used. a_{ij} is binary parameter indicating whether arc (i, j) is allowed to be included in the network. No newly created fibre is allowed unless in allowable interconnecting nodes. Constraint (7) and (8) define y and z to be binary variables.

4. Case Studies Approach

First we consider two four-location hypothetical identical networks as shown in Fig 1.

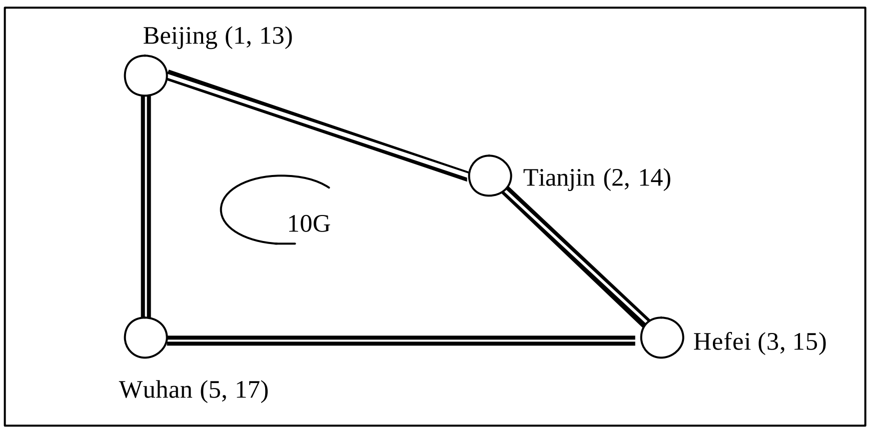

Fig 1. Two four-location Hypothetical Fibre Optic Network
(i, j) = node *i* in network A and node *i* in network B.

Traffic demand is generated randomly with traffic initiated from all source nodes to a randomly generated designated node. It has been shown that the 95th percentile of TCP data streams is around 10-20kB in size and the average for document is only around 30kB, with Web objects up to 50kB becoming common. Real audio stream may run at 180kb/s [5]. Along with concurrent users, an aggregated traffic flow size of 0.6Gb/s is assumed. Flow cost is selected to be small since flow cost was minimal for optical communication purpose. c_{ij} is set to be 1. Fibre build-cost f_{ij} varies from node to node depending upon distance between nodes. Equipment cost e_i also varies from node to node depending on equipment capacity for the node. Fibre capacity u_{ij} is assumed to be large and not a limiting factor and a value of 1,000 is used. Equipment capacity q_i varies depending on the equipment use on the nodes. a_{ij} is the usable matrix. Commodities are from all nodes to randomly generated destination nodes. Three cases were simulated.

We then study three cases with increasing number of different number of commodities for two 12-location networks as shown in Fig 2. This is a subset of a real China network. Flow size remains at 0.6Gb/s and flow cost at 1. Each network is divided into 4 ring sub-networks. The capacity of the network is also shown in Fig 2. 24 to 32 randomly generated commodities were being simulated.

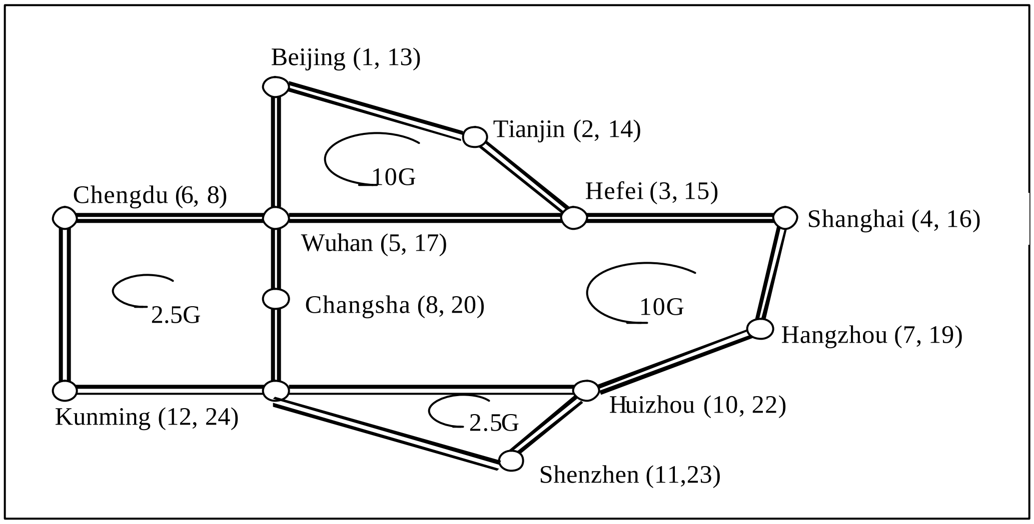

Fig 2. Two 12-location Fibre Optic Network
(*i*, *j*) = node *i* in network A and node *j* in network B.

5. Result and Discussion

We first examine the simulation result of the two four-location identical networks. As we increase the number of commodities (8 in case 1 to 16 in case 3) as per Table 1a, more fibre link is needed. Simulation results show that fibre links 1-5, 13-17 are not needed in case 1 and 2 and fibre link 1-5 is not needed for case 3 as shown in Table 1b. Note that link *i-j* denotes the fibre link between node *i* and node *j*. Saved fibre links lead to reduction of total operating cost for the operator. It is also found that interconnection locations remained to be two in node location 1-13 and 5-17 for the 4-location network as shown in Table 1c. It is therefore concluded that under the present assumption and conditions, only two interconnection locations are needed for this moderate flow of traffic for the 4-location merged network.

Table 1a Cases with Various Commodities and Objective Function Results for 4 Location Network

Case	Flow Cost	Flow Size	Allowable Inter Connect Location	Number of Commodities	Objective Function (e +05)
1	1	0.6	4	8	1.159
2	1	0.6	4	12	1.159
3	1	0.6	4	16	1.159

Table 1b Fibre links used and unused

Case / Fibre links *(i-j)*	1-2	2-3	3-5	1-5	13-14	14-15	15-17	13-17
1	v	v	v	X	v	v	v	X
2	v	v	v	X	v	v	v	X
3	v	v	v	X	v	v	v	v
v required X not required								

Table 1c Interconnecting Locations

<u>*Case/ Interconnect locations*</u>	1-13	2-14	3-15	5-17
1	v	X	X	v
2	v	X	X	v
3	v	X	X	v
v required X not required				

Next, we study the three cases with different number of commodities for two 12-location networks. Again some fibre links are not needed. Link 1-5, 14-15, 17-18 are not needed for case 1 with 24 commodities; fibre links 2-3, 6-12 are not needed for case 2 with 28 commodities; fibre links 6-12, 13-17, 17-18 are not needed for case 3 with 32 commodities (not shown in Table). The value of objective function increases as the commodities increase as shown in Table 2a. As more traffic flow through the network, cost increases as shown in Table 2a. Due to the commodity size and the computation time required, programme is run to the respective error percentage in order to save computation time. Table 2b shows the interconnections needed for the 12-location network. In all three cases, fibre links can be saved and only two interconnecting locations are needed as noted.

Table 2a Case with various Commodities and Objective Function Results for 12 Location Network

Case	Flow Cost	Flow Size	Allowable Inter Connect Location	Number of Commodities	Objective Function (e+05)	Error (%)
1	1	0.6	12	24	2.6305	4
2	1	0.6	12	28	2.6330	12.6
3	1	0.6	12	32	2.9803	17

Table 2b Interconnecting Location

Case \Interconnect locations	1-13	2-14	3-15	4-16	5-17	6-18	7-19	8-20	9-21	10-22	11-23	12-24
1	v	X	X	X	v	X	X	X	X	X	X	X
2	X	X	v	X	v	X	X	X	X	X	X	X
3	X	X	v	X	v	X	X	X	X	X	X	X
v required X not required												

As the number of commodities increases, the locations of the interconnection change as depicted in Table 2b. It is reflected by higher traffic flow and flow patterns changes. Commodities seek alternative routing to arrive at their destination. Link requirements shift. However fibre links are still saved in a merged network situation.

As noticed in our simulation that in both Fig. 1 and 2 regardless of the flow pattern changes, fibre links can be saved in all situations for a merged network. There is a definite advantage of merging two existing identical networks from a resource optimization point of view. In addition, saving from fibre link and equipment can be better re-deployed and a more optimal solution can be achieved for the newly merged network. It is founded that only two interconnection nodes were required. To further validate this result, we simulate moderate traffic load with traffic flow of various commodities up to 32 and with flow size of 0.4Gb/s, 0.5Gb/s and 0.6Gb/s each. It is shown that under the aforementioned assumptions, two interconnections are sufficient for the above operation range. Therefore, network planner can focus on the simulation for two interconnected nodes and derive the two interconnecting locations that can provide the most optimal solution for the operator. Much computation time can therefore be saved, especially for the consideration of large network size, as a result of this finding.

7. Conclusion

We have developed a framework to investigate, using CPLEX programme, the optimal strategy of merging two identical networks to see how fibre links can be saved by merging. It is interesting to find that only two interconnected nodes are needed for the simple 4-location ring networks and the more complex real 12-location networks (a subset of a China network), for less than 32 commodities and flow size less than 0.6Gb/s. In all cases, fibre links can be saved in the whole network as a result of merging. Interconnection is needed to achieve optimized situations. Network planners therefore can focus on analysis based upon two interconnection locations. Much computation time can be saved. Substantial saving in interconnection and fibre link cost can be achieved.

Further analysis and studies can be performed for the effect on different traffic pattern and traffic size of commodities in relationship to the interconnection locations. Changes in capacity of equipment at locations may have influence to the resulted cost objective and flow pattern. These results will be reported.

NThE5.pdf

8. Reference

1. The Officer of the Telecommunications Authority, “Draft Merger Guidelines for Hong Kong Telecommunications Merchants”, (Aug 2003)
2. J. Chan, M. Gertler, “Major Mergers involving US & European Telecom Firms (1997-99)”, in Workshop Presentation: Strategic Alliances and Joint Ventures in Asia, (Jan 2000)
3. Ouida Taaffe, “Does it do what it says on the tin?”, in Telecommunications International, (Aug 2003) pp. 12-14
4. D. Bienstock etal, “Minimum cost capacity installation for multicommodity network flows”, 177-199 (Elsevier Science B.V., 1998)
5. Nevil Brownlee, “Understanding Internet Traffic Streams: Dragonflies and Tortoises”, in IEEE Communications. (Institute of Electrical and Electronics Engineers, New York Oct 2002), pp. 110-117
6. J. Chan, M. Gertler etal, “Strategic Alliances and Joint Ventures in Asia” in Workshop Presentation by Paul, Weiss, Rifkind, Wharton & Ganison, (Pacific Telecommunication Conference, Jan 2000)
7. Christelle Wynants, Network Synthesis Problems (Kluwer Academic Publishers, 2001), Chapter 2
8. Ouida Taaffe, “An urge to merge?”, Telecommunications International, (Sept 2004) pp. 18-22