TREATMENT OF SOME IMPORTANT ASPECTS OF DATA NETWORK PLANNING

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ABSTRACT

Network planning is the analysis and design of a network to achieve the optimum use of resources while providing the desired services at acceptable quality and cost. It is a complex area which can be simplified by breaking it down into different aspects for more or less separate study. Major aspects treated in this paper include optimizations of nodal hierarchy, network topology and configuration. A special algorithm was designed to carry out the optimization process based on heuristic considerations. This algorithm is used to cover a wide range of applications relating to leased line data services. Several examples are given to illustrate these applications.

1. INTRODUCTION

A data network must be designed so that the service provided to the user meets his requirements of performance and is at an acceptable cost. The nature of data, the multiplicity of current services and the variety of network techniques presently in use, complicate the design problem. Furthermore, large networks which provide public multi-user service are considerably more complex than small, private, single-user networks.

Planning complements the implementation and engineering activities by providing the analysis and design of the network on which these are based. Fundamental aspects of planning are concerned with the user environment, dimensioning and placement of the nodes, provision of inter-node links and other related problems involving economics and sensitivities.

Data is a relatively new service area and has little historical precedent on which to base demand projections and thus the future can not be well defined. The design of the network must be sufficiently flexible to reduce the future exposure to cost penalties due to unforeseen changes in demand and services. Planning provides invaluable assistance in this area by analysing the causes and effects on different designs produced by changes, thus enlarging the scope on which to base design selection.

Planning also lays the groundwork for orderly expansion to meet increased demand and provide new services, both for new or existing networks and for those in the transition stage from experimental to fully operational status.

In this paper there are treated the optimization of the important network areas of configuration, topology and nodal hierarchy, carried out using a specially designed algorithm.

The following key words are defined below to provide a common understanding of the terminology used throughout the text.

Configuration. Conceptualizes the method of interconnection of nodes. This will be basically in mesh and tree forms, and other common variations such as ring, simple and compound star. There exist intrinsic requirements for nodal hierarchy in each of these methods.

Hierarchy. The classification of the nodes in different levels thus strictly defining their relative interdependence.

Topology. Relates the geographical parameters of terminal/computer locations with those of the network nodes and links. The use of the telephone network infrastructure is an example of a network, imposes certain topological constraints.

Layout. Defines the arrangement of nodes and links resulting from a particular configuration and its inherent hierarchy. The number of nodes and associated links are limited to those possibilities allowed by the telephone network infrastructure.

Structure. Describes the network for a particular configuration, nodal hierarchy and topology, all relating to a specific example. Inherent in this is the aspect of dimension, relating to traffic volumes and characteristics.

2. INVESTIGATION OF NETWORK PROBLEMS

2.1 Points of analysis

The overall objective for planning activities is to identify suitable designs for the network to achieve the desired cost effectiveness of the services provided. It is necessary to analyze the different aspects which have particular influence on this. The following aspects have been selected for study, as being of prime importance:

Network topology " hierarchy " configuration

In addition, subsidiary factors of nodal interconnection, centralized organization and growth are also analyzed, being closely related to the former.

At the same time, it was desired to investigate the basic factors influencing network design, propose methodologies of analysis, prepare tools and where possible apply the results to practical examples. This leads to basing the investigation on the leased line services which would simplify some problems, and later to consider switched services as necessary.

2.2 User-network relationship

The network is intended for use by the user and becomes an integral part of his business operation. For correct design it is necessary to assess the user-network relationship. The network provides the means by which the user can connect his remote terminals to his computer and transport data between them. The traffic flow of a user will be based on the source/sink...
The terminals may be conventional teletypes, computer terminals, or computer. These normally form a closed user group because there is little or no requirement for connection outside of this group. As several terminals will be working with a single computer, the user group traffic pattern will be asymmetric (see Figure 1).

The terminals will be working with a single computer, their normal traffic pattern will be asymmetric. There are several services available such as switched, point-to-point and multipoint.

The number of data users on a network is as yet relatively small compared to telephony, though the coverage will still be nationwide. The resulting low density will have an effect on the composition of the network. Fewer nodes will be required, which will prolong the local loops; in consequence the relative proportion of network cost represented by these will be higher. The topology of the telephone network will strongly influence that of the data network, because part of the latter's plant facilities will be provided by the telephone network infrastructure. Local loops will be from cables of the telephone network, which will be used. If the nodes are collocated in exchange buildings, the maintenance and administrative organizations may also be allied. In practice, the degrees of freedom for varying the network topology are limited by these constraints.

Economic considerations of location and dimensioning of nodes is closely related to the design. The modularity obtainable from current technology provides for improved linearity of the cost/capacity relation and lower start-up costs. Similarly the amount of intelligence which can now be made available economically permits greater freedom to allocate the functions at each node.

The user requires an adequate level of service performance, high enough not to perturb his business operation. For network design purposes, such as dimensioning of links and nodes, failures and failure rates of the data network, a new performance requirement is translated into a series of quality and grade of service parameters which specify the limits permitted for outages, delays, errors, repair and repair time. As these all have an effect on cost, it is necessary in the design phase to establish acceptable values.

2.3 User-network environment

In order to investigate the planning problems, it is necessary to assemble the information which permits a full description of both the user, his location and characteristics, and of the requirements and constraints which will affect the network (see Figure 2).

To give full coverage to the problem, the general case has been treated of creating a new network and starting from the fundamental information sources on which to base the study parameters. In practice, a service demand must already exist, which may be being served over alternative facilities which are inadequate for reasons of cost, quality, lack of services, problems of expansion, etc.

The areas which are of concern are listed below:

A. User oriented:

1. Socio-economic information:
   a. Geographic concentration of government and industry.
   b. Penetration of teleprocessing data processing.

2. Market survey information
   a. Profile of users' data-processing applications.

3. Terminal and computer distributions:
   a. Geographical locations.
   b. Terminal speed types.
   c. Terminal operational types.

4. User traffic characteristics:
   a. Transaction rate.
   b. Transaction duration and message length.
   c. Volume per user type and application.
   d. Busy hour activity profile.

B. Network oriented information

1. Network descriptors:
   a. Signalling and control procedures.
   b. Quality and grade of service.
   c. Operational structure.
   d. Fallback and recovery strategies.
   e. Telephone network bearer infrastructure.

The connection matrices which are basic to the analysis, are prepared from the user oriented information; they can be extended to include interconnection nodes. The user terminal model is not already sufficiently well defined in terms of speeds, traffic characteristics, etc. It will be necessary to build up this information from the fundamental factors related to the user's business activities (AI). From the geographical information concerning the location of users, sources and sinks, these can be allocated to discrete geographical areas which may be made to coincide with regions, provinces or other political boundaries. The initial connection matrices will define the aggregate traffic flows between these areas.

3. PLANNING ANALYSIS

The particular planning studies treated here are cost oriented, identifying the effects on cost brought about by changes in the network design. Capital cost is taken as the principal item, with running costs and user tariffs being assumed to be directly related. The principal variations of cost are studied here under alternative conditions of design reflected by changes in network topology, nodal hierarchy and configuration.

To simplify the analysis the fundamental approach adopted treats separately each of these areas and by combining the individual results the overall solution obtained. As each step can use results from previous steps, a good approximation to the ideal of simultaneous optimization of all factors, will be achieved. In the initial stage only leased line services have been considered and in consequence described here.

Users and Administrations are concerned mainly with their national environments where costs can be specified in local currency. However for general analytical applications these specific values may be avoided by expressing costs in terms of equipment quantities, route-kilometers or other currency-independent units. This is considered adequate for use in analyses involving relative comparisons when examining trends and sensitivities.

3.1 Optimization

Because the transmission aspect of the network is fundamental and common to the provision of both leased line and switched services, the detailed analysis of this area becomes specially important. The facilities which provide the internode links will be made up of bearer circuits with data
multiplexing applied to obtain economic benefit from the economies of scale. The users' connections will use dedicated multiplexer channels up to a switching node for switched service access or 2) continue on through to the destination in the same service. A multi-link connection may be provided by a single end-to-end multiplexer channel or made up from tandem combinations of multiplexer channels connected at baseband at intermediate points. If the demand is large enough it will be possible to separate out sufficient connections to fill one or more through multiplexer systems leaving a residual quantity. This latter group of connections may be served on an ad-hoc basis by providing multiplexers on an end-to-end basis with no tandem connections (non-optimized method), or by combining the various demands running over common links of the network, in such a way that maximum use is made of the multiplexer and bearer plant (optimized method).

For the analysis of leased line, point-to-point service, the starting point for the optimization process is the Connection Matrix which defines the aggregate traffic flows between specific geographical areas. It should be noted that the optimization is carried out each time over a fixed network topology and layout which has been previously defined and set by the specific ordering of nodes in the connection matrix. The calculation of results for alternative network designs hinges on this optimization process. The end-to-end connections run through the network, ascending and descending the hierarchical levels. Over common internode links it will be possible to combine the parallel circuits participating in these connections, for application to multiplexer systems. Optimization is applied so that the selection of these circuits is done according to predetermined rules which permit the use of the multiplexers to be maximized, simultaneously minimizing the number of multiplexer systems, their bearers and therefore aggregate cost.

Allowance is made for operational conditions requiring a margin of unassigned in-service channels for maintenance purposes.

4. ANALYTICAL TOOLS

Modern planning methods benefit from the application of computer tools. One of the essential tasks undertaken consisted of identifying suitable tools and where best these could be applied. As a requirement for optimization was encountered in many stages of the planning process an algorithm was designed for common application to meet this need. The computational requirements associated with the process were reduced by programming the algorithms for computer application.

The algorithm on which the optimization process is based, is described in detail below.

4.1 Optimization Algorithm

The cost of the communication network can be estimated as follows:

\[ C = \sum_{i=1}^{N} \sum_{j=1}^{N} C_{Mi,j} + C_{BW} \times \sum_{(i,j) \in E} S_{i,j} \times I_{i,j} \]

where

- \( C_{Mi,j} \) = Cost of a multiplexer terminal.
- \( C_{BW} \) = Cost of a "bandwidth unit" per unit of distance between nodes i and j.
- \( S_{i,j} \) = Number of multiplexed digital "streams" between nodes i and j.
- \( I_{i,j} \) = Set of links between any two consecutive nodes.
- \( S_{i,j} \) = Number of multiplexed "streams" of unit bandwidth between the i and j consecutive nodes.
- \( D_{i,j} \) = Distance between i and j consecutive nodes.
- \( N \) = Number of nodes.

\[ \text{Cost of a "bandwidth unit" per unit of distance.} \]

\[ \text{Allowance is made for operational conditions requiring a margin of unassigned in-service channels for maintenance purposes.} \]

\[ \text{The concept of optimization applied here, consists in dividing connections into two sections in such a way that the combination of demands in one section "fills" more efficiently the multiplexers providing the channels (see Figure 5). In explaining the algorithm used, the following definitions are given:} \]

Longest route = The physical route with the greatest number of intermediate nodes.

Section = Component part of a route which may have or not intermediate nodes.

\( \mathcal{G}_o \) = Set of all the connections which appear in the connection matrix.

\( \mathcal{G}_p \) = Set of those connections which completely fill multiplexer systems (i.e. point-to-point through systems).

\( \mathcal{G}_r \) = Set of those residual connections which are insufficient to completely fill multiplexer systems.

Such that: \( \mathcal{G}_i = \mathcal{G}_o + \mathcal{G}_p \) For all possible partitions of the connections \( \mathcal{G}_o \), the ideal algorithm should attempt to combine in each section the corresponding channel requirements, in order to fill the multiplexers. The desired solution will be the one which is derived from the economical partitioning of connection requirements which result in any minimum plant. As the number of possible combinations is large, a heuristic method was adopted which is reflected in our algorithm, reducing the number of combinations to a manageable amount.

The user demand characteristics are specified in connection matrices, these are analyzed, element-by-element, commencing with the longest routes. The model hierarchy, network topology and layout have been predetermined. The connection (i,j) being analyzed, is divided into 2 sections, one of which has the maximum length possible. The demand of this connection is satisfied by the "point-to-point" demand already existing in that maximum section, in order to fill further multiplexers. For each example of the partitioning there will be two possible solutions for the "longest" section, i.e. (i,Mj) and (Mi,j), each with its own basic demand (see Figure 6). The algorithm makes the decision at the node Mj or at node Mi, or partially at both nodes Mi and Mj, in such a way that the combination of the existing and partitioned demands, over these sections, will be most favourable for filling the multiplexers. It should be noted that this algorithm used for the optimization process takes into account the cost of the equipment while the second covers the cost of the bearer circuits. There is no conflict when minimizing these terms (1 multiplexer system is equivalent to 1 "stream" plus 2 multiplexer terminals) because if the number of systems is reduced then also the number of bearers required will be correspondingly reduced.
account the existing demand on both "longest sections" in order to make the partitioning, this represents an improvement over the algorithm given in Bibliography 1.

Optimization effectiveness: The unit of comparison used to measure the "effectiveness" of optimization, is expressed in terms of the plant required under non-optimized conditions. This will be the equipment and bearers necessary to provide the connections $\mathcal{S}_0$, in straight point-to-point application without tandem interconnections. Those multiplexers which correspond to the residual demand $\mathcal{S}_r$, will be inefficiently utilized. The comparison is made considering the total cost $C$ even though in some cases it would be advantageous to treat each of the terms separately.

Optimization of equipment: (This is computed in equipment units, M)

$$\theta_{eq} = \frac{M_{nop} - M_p}{M_{nop}} x 100\%$$

$M_{op} = (M_p + M_t + M_r)$

$M_{nop} = M_p + M_p'$

where $\theta_{eq}$ = Optimization effectiveness when considering equipments

$M_{op}, M_{nop}$ = Equipment units for optimized and non-optimized cases.

$M_p$ = Completely filled point-to-point multiplexers (these remain unaltered in the optimization).

$M_p'$ = Partially filled multiplexers (carrying the residual demand in the non-optimized case).

$M_t$ = "Through" multiplexers (these have been filled to capacity by the optimization process).

$M_r$ = Partially filled multiplexers (these carry the residual demand after optimization).

Note: As $M_p \to 0$, then $\theta_{eq} \to 0$

Examination of the results obtained from using optimization methods reveals several interesting aspects:

a) In reducing the requirement for multiplexer systems and bearers, some connections will result being made up of two or more multiplexer channels connected in tandem. The ratio of channels to (demand) connections is termed Multiplication Factor (MF). It will be an indication of the effect of applying optimization.

$$MF = \frac{C_1}{C_2}$$

where $C_1$ = Number of channels used in the optimized case.

$C_2$ = Number of connections, this corresponds to the number of used channels in the non-optimized case.

b) In practice it is usual to install fully equipped multiplexer systems even though the channel requirement may be less. The relation between the used and unused capacity is termed multiplexer Fill Efficiency ($\phi$).

$$\phi = \frac{C_1}{C_3}$$

where $C_1$ = Number of channels used.

$C_3$ = Number of channels installed.

c) The channels in the overall network should be arranged to satisfy the connection demand to with minimum unused capacity. The optimization process is applied to secure this objective. There will be a relative Improvement (R) in efficiency when comparing the fill efficiencies for both optimized and non-optimized cases.

$$R = \frac{\phi_1}{\phi_2} - 1$$

where $\phi_1$ = fill efficiency in optimized conditions.

$\phi_2$ = fill efficiency in non-optimized conditions.

Optimization of bearers: (This is computed in bearer-kilometers BK)

$$\eta\{BK\} = \frac{BK_{nop} - BK_{op}}{BK_{nop}} x 100\%$$

where $\eta\{BK\}$ = Optimization effectiveness when considering bearers.

$BK_{nop}, BK_{op}$ = Bearer-km for non-optimized and optimized cases.

For multiplexers of the type using a fixed frame, in this case, with fixed capacity for each of the user classes (CCITT Rec. X50/51), the algorithm must be applied separately for each user class to fill the individual first stage multiplexer "phases". Subsequently the algorithm is applied again to the second stage higher rate multiplexers.

For multiplexers of the type with a programmable frame (CCITT Rec. R101, R111), it is necessary to work with all user classes simultaneously. In this case, the multiplexer capacity is expressed in bits per second instead of channels.

The computer programs used to implement the algorithm differ for these two cases each of which considers different equipment types.

For the programmable multiplexer case, the above mentioned factors will be as follows:

Multiplication Factor (MF):

$$MF = \frac{K_1}{K_2}$$

where $K_1$ = capacity (bps) used, optimized case.

$K_2$ = capacity (bps) used, non-optimized case (capacity required)

Fill Efficiency ($\phi$):

$$\phi = \frac{K_1}{K_3}$$

where $K_1$ = capacity (bps) used.

$K_3$ = capacity (bps) installed.

Improvement (R):

$$R = \frac{\phi_1}{\phi_2} - 1$$

where $\phi_1$ = fill efficiency in optimized conditions.

$\phi_2$ = fill efficiency in non-optimized conditions.

4.2 Level of Accuracy

It is recognized that approximations are introduced by using this heuristically based algorithm which departs somewhat from the ideal. This solution was adopted as simplifying the complexity associated with the ideal solution. Although no direct comparison is possible, the accuracy of the actual algorithm can be evaluated qualitatively on basis of reviewing the Multiplication Factors (MF) and Fill Efficiencies ($\phi$) typically obtained, these range from 1.02 to 1.11 for MF and from 0.82 to 0.97 for the average fill ($\phi$). While the ideal solution would locate the exact optimized balance in the effect of channel equipment requirements and bearer-kilometers, the

x See Bibliography No.5 for Details of CCITT references.
above range of values indicate small room for improvement either decrease in MF or increase in fill factor. It is felt that this situation represents a very good degree of approximation to the ideal solution.

4.3 Range of Application

The algorithm has a wide field of usage as shown by the areas of application:

- Independence of the bearer network technique makes for equality of application to analogue, digital or mixed environments.
- Type of multiplexer (e.g. X50/51, R101, etc.) is not a criterion of application. These can be used alone or in mixed systems.
- Future changes from analogue to PCM environments will not invalidate results or change the application.

5. APPLICATION AND EXAMPLES

The optimization algorithm mentioned earlier has been successfully applied to the analysis of different network planning problems. Some examples are given below to illustrate this, these being directed towards determining the final choice of the network structure. This will ultimately be expressed in the following terms:

- number and geographical location of the nodes
- nodal interconnecting arrangement
- node and link dimensions
- aggregation of network core

By way of achieving this goal the basic factors which govern the composition of the network have been analyzed, these being:

- distribution of terminals/computers and traffic characteristics
- configuration alternatives
- topology
- hierarchy

Manipulation of these factors in various combinations will produce a series of structures which can be evaluated in cost; by comparing these, the best choice can be selected. In each case the alternative structure will be the result of separately optimizing the nodal hierarchy, topology and configuration.

Various references are made to particular multiplexer equipment types specified by CCITT Recommendations, details of these can be found in Bibliography No. 5.

5.1 Minimizing Plant Requirements

Problem: To determine the minimum quantity of equipment systems and bearers required to implement the network with predetermined topology and nodal hierarchy, to meet a given demand and using a specified multiplexer equipment defined by its modularity, capacity, etc.

The demand has to be quantified in connection matrices whether these have been determined from a precise terminal model or elaborated from general fundamental sources.

Using the algorithm, the minimum number of multiplexer terminals is calculated, together with the physical location of each and the minimum bearer-km required to interconnect them. If more than one kind of multiplexer is to be used, the method may be sequentially applied according to the ranking of the multiplexers, lower order first and higher orders later. In each case the multiplexed bit stream that results from the optimization process is treated in the next stage as a "new user" with a higher transmission rate and no additional bearer cost, repeating the optimization process.

Example: For the Model 1 specified in Appendix 1, the following results have been obtained for a specified network topology and nodal hierarchy, using multiplexer equipment according to CCITT Rec. X50/51.

Reduction in equipment from optimization: 7.1%
Reduction in bearer-km from optimization: 44.4%

In both cases the reductions are relative to the non-optimized requirements, as described in Section 4.

The computer program which applies the algorithm to the calculation also prints out the number of multiplexer systems needed, their locations, the number of bearers between consecutive nodes and the aggregate bearer kilometers.

5.2 Equipment Selection

Problem: To determine which of various alternative multiplexer types will require the least plant (equipment and bearers), to implement a network which will satisfy a given demand, using a specified topology and nodal hierarchy.

The algorithm is applied for each of the equipment types, permitting the comparison between the respective minimum solutions for equipment and bearers.

Example: Based on Model 1 of Appendix 1, the following results were obtained for a given topology and hierarchy. Both the equipment types CCITT Rec. X50/51 and Rec. R111 are compared.

Relative equipment saving using type X50/51 over R111: 12.8%
Relative bearer savings using type X50/51 over R111: 29.5%

5.3 Optimization of Nodal Hierarchy

Problem: To determine the nodal hierarchy which will correspond to a minimum plant requirement for a given demand, preset data network topology and configuration, and specified multiplexer equipment. Use is made of the telephone network infrastructure.

The number of nodes and their locations are set once the particular network topology has been chosen. The general requirement for nodal hierarchy is specified by the network configuration desired. The assignment of each node to a specific hierarchical level will result in a particular layout. Therefore, by varying this assignment, changes will be introduced in the layout and corresponding changes will occur in the quantity requirements of equipment and bearers.

Although the general requirement for nodal hierarchy is set by the particular network configuration chosen, various criteria are possible for determining the actual category of each node; for example, the relative importance of the node in terms of the number of connections passing through it, or based on factors relating to the PTT administrative or maintenance organizations, or geopolitical considerations. In some cases it is possible that two neighboring nodes of disparate size will be required to home on each other because of or their proximity and telephone network topology, even though this may mean contravening the particular hierarchy homing rules. To solve this difficulty, the concept of fictitious nodes has been introduced. In this case, a fictitious node would be collocated with the lower ranking node; its demand would be null and the category assigned to it would permit homing on the neighboring node of the next higher level as the rules require.

The algorithm is applied to different examples...
in which the hierarchy assigned to the nodes differs, or in using different layout. In each case the minimum plant requirements are calculated and comparisons made to determine the optimum hierarchical arrangement.

Example: Three different hierarchical arrangements have been compared, using Model 2 in Appendix 1, with a given topology, configuration and equipments specified according to CCITT Rec. X50/51.

Case A: with 10 primary nodes and 3 secondary nodes.
Case B: with 2 primary nodes, 9 secondary nodes and 2 tertiary nodes.
Case C: with 2 primary nodes, 6 secondary nodes, 3 tertiary nodes and 2 quaternary nodes.

Equipment saving, case B over A: 3.5%
Equipment saving, case C over A: 8.2%
Bearer saving, case B over A: 21.3%
Bearer saving, case C over A: 40.7%

5.4 Optimization of Network Topology

Problem: To determine which topology corresponds to a minimum plant requirement, for a given demand, specified equipment type and a preselected data network configuration. The method used is that of the telephone network infrastructure.

In practice, although the topology for the data network is constrained by the use of the telephone network infrastructure in which the number of node locations and their links are limited and preselected, there is still room for variation when choosing the actual locations for the data network nodes, from amongst those possibilities offered by the telephone network infrastructure (see Figures 3a & 3b).

The particular network configuration is selected which also implies a specific form of nodal hierarchy. A topology is set by choosing the appropriate nodes, locations and links. These nodes are assigned to hierarchical levels according to the configuration requirements, resulting in a particular network layout. The different topologies produced by alternative choices for the nodes are analyzed by optimizing the hierarchical arrangement of the nodes. Each nodal arrangement for each case of topology will result in a different network structure.

The algorithm is applied to all these alternative cases of hierarchies and topologies, and the minimum plant requirement is calculated for each. The optimum topology will be that associated with the structure requiring minimum equipment.

5.5 Optimization of Configuration

Problem: To determine the configuration which will result in a minimum plant requirement for a given demand and specified equipment type. Use is made of the telephone network infrastructure.

There are a variety of methods for the interconnection of the nodes such as mesh, tree, simple and compound star network configuration. The method used is that of the telephone network infrastructure.

Example: The Model 1 of Appendix 1 has been used for calculating the plant requirements associated with centralization. The demand was specified and configuration, topology and layout predetermined. Equipments of the type CCITT Rec. X50/51 have been considered.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Operation</th>
<th>Mux Systems</th>
<th>Bearer-Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Decentralized</td>
<td>164</td>
<td>59700</td>
</tr>
<tr>
<td>B</td>
<td>Centralized</td>
<td>194</td>
<td>80330</td>
</tr>
</tbody>
</table>

In both cases optimized solutions for the alternatives have been utilized. It should be noted that this example is used to illustrate the application of the algorithm to other network problems. The actual results shown above are derived from unequal terminal bases and require further elaboration in the corresponding trade-off studies.

5.6 Centralized Operation

Problem: To determine the effect of imposing the constraint that all connections must pass through specific principal nodes, in order to implement a particular centralized organizational requirement.

So far in the previous examples the routing of traffic through the network has been node by node, dictated by the interconnection arrangements of the particular configuration used. However in some cases there may be the requirement that all traffic must pass via specified high level nodes. This could be the case where the planned network enters into initial operation with a leased-line point-to-point service and subsequently switched services are introduced by locating the appropriate switching equipment at specified high level nodes. Routing of the leased-line service traffic via these nodes would permit the easy conversion of this service to the other where desired, or, alternatively, allow passing the leased line connections through the switch as "permanent call" connections permitting common use of the maintenance and diagnostic capabilities internal to the switching machine.

Normally the switching centres will coincide with the nodes of highest category. Concentrators may be located in lower categories without ability to switch locally. Local connections within the service area of a node, which previously were not required to pass up through the network, must now be "tromboned" via the appropriate primary centre. Connections running between adjacent nodes whose relative geographical position does not normally require the intervention of an intermediate primary node, will also be affected over part of their route.

All the problems of plant requirement, topology, equipment selection, etc. treated earlier, can be analyzed for this case using the same algorithm with a variation in the computer program to perform the accounting of the tromboned requirements separately from direct channels between two nodes. This will permit estimation of the additional equipment and bearers required for centralized purposes, the cost of which is an integral part of the overall trade-off calculations involved in the evaluation of these alternative service methods.

Example: The Model 1 of Appendix 1 has been used for calculating the plant requirements associated with centralization. The demand was specified and configuration, topology and layout predetermined. Equipments of the type CCITT Rec. X50/51 have been considered.

5.7 Optimization of Newly Added Plant

Problem: To minimize the additional equipment required to satisfy growth, taking into account the spare capacity already resident in the network, accumulated from previous expansions.

At this stage the network is related to a fixed point in time corresponding to the particular...
The necessity to accommodate growth of this demand.

Overall in the network, if the demand is assumed satisfied at the base planning date, there will be spare capacity in excess of the actual demand. For the next network expansion required to cover a growth of demand, this spare capacity should be used before additional equipment is added. The optimization algorithm used in the calculation, outputs details of the unused channel in addition to that used, identified for each link. This detail of unused capacity is then set against the gross new demand to produce the net requirement which can now be optimized separately.

The previous network design in topology, etc., can be maintained for the next planning period or changed if necessary. In both cases the optimization algorithm is applied in the way according to this decision.

In this way the minimum plant required to satisfy an increment in demand for an existing network, can be determined, thus assuring minimum investment over each period.

Example: Using the Model 2 specified in Appendix 1 and demand specified over a period of 5 years, the plant requirements have been calculated corresponding to the beginning of each planning period (year 0 and year 5) and taking into consideration the unused plant available during the first period. Applying the algorithm permitted the minimum requirements to be calculated for CCITT Rec. X50/51 type multiplexers.

Year 0. A demand of 6871 connections is satisfied with 410 multiplexer systems. Unused plant amounts to 452 channels.

Year 5. The growth in demand over the planning period represents 7984 additional connections. Using up the existing spare plant, the net increment in demand remaining to be served will be 7532 connections. The new plant for this is estimated at 453 multiplexer systems.

6. CONCLUSIONS

The complexity encountered when attempting to carry out network planning, has been successfully reduced by separating the different aspects of the problem and analyzing them more or less independently. By using the specially designed algorithm each of these factors were optimized separately and the overall solution represented by combining these results. Based on experience in general network problems it is felt that inaccuracies resulting from this approach have only negligible effect, taking into consideration the general lack of precision in the base statistical planning data.

The resulting reduction in plant using the algorithm described earlier is especially significant for networks of magnitude about ten thousand terminals and up to 50 nodes which is about that currently encountered in present conditions.

The heuristic application of this algorithm to each of the distinct areas comprising the overall problem described above, results in an easy, manageable and practical method of analysis which commends the approach taken.

APPENDIX 1

Network Models

Several network models have been elaborated for distinct uses, two of these are detailed below. The examples given in Section 5, have been selected from amongst the various studies carried out using these models.

Model 1. This represents an actual case study for a proposed leased line network. The number of nodes at which multiplexing, patching, etc., could be located, was set in relation to the particular PTT administrative areas. Similarly a terminal speed mix was given. The principal aspect for analysis was to compare the network requirements engendered by two different multiplexing techniques. A certain freedom was permitted in choosing configuration and setting the nodal hierarchy in order to determine the best structures.

The pertinent details of the model are given below:

Model 1

Number of network nodes: 13

Number of terminals: 1141 (1336 for centralized operation)

Terminal speed mix:

<table>
<thead>
<tr>
<th>Speed</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 bps</td>
<td>20.6</td>
</tr>
<tr>
<td>1200 &quot;</td>
<td>24.4</td>
</tr>
<tr>
<td>2400 &quot;</td>
<td>41.2</td>
</tr>
<tr>
<td>4800 &quot;</td>
<td>11.1</td>
</tr>
<tr>
<td>9600 &quot;</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Alternative nodal hierarchies:

Case A: 10 primary nodes, 3 secondary.

Case B: 2 primary nodes, 9 secondary, 2 tertiary.

Case C: 2 primary nodes, 6 secondary, 3 tertiary, 2 quaternary.

Model 2. This was specially created to provide the basis for investigation into the factors influencing network analysis methodology. To serve this end the model was made purposely complex to cover many hypothetical situations. The user details on which the model is based, were elaborated from fundamental statistical information instead using a "a priori" model. The applications of the computer programs relating to the optimization algorithm were tested using this model, the outline details of which are given below:

Model 2

Number of network nodes: 42

Number of terminals: 6871 (9363 for centralized operation)

Terminal speed mix:

<table>
<thead>
<tr>
<th>Speed</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4600 bps</td>
<td>19.7</td>
</tr>
<tr>
<td>12004800 &quot;</td>
<td>74.2</td>
</tr>
<tr>
<td>4800 &quot;</td>
<td>4.0</td>
</tr>
<tr>
<td>9600 &quot;</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Alternative nodal hierarchies:

Case A: 6 primary nodes, 32 secondary, 4 tertiary.

Case B: 2 primary nodes, 19 secondary, 21 tertiary.

BIBLIOGRAPHY


3. "Computer Communication Networks - The parts make up the whole" Chou, W.
   CCITT Orange Book Vol. VII-2, X50 pp 113-118 and X52 pp 118-123.

FIGURES

Traffic Volume

Term. Input

Figure 1. Asymmetry of the user's source/sink traffic pattern.

Figure 2. Multiuser network, defining the general user environment.

Figure 3a. Typical form of the Telephone Network.

Figure 3b. Example of Data Network Topology showing overlay on the Telephone Network.

Figure 4. A typical network structure of four hierarchical levels showing mesh and tree connected subnets.

Figure 5. Average multiplexer fill distribution after optimization, typical values.

Figure 6. Criteria for splitting connection i-j: Compare the existing residual demands between i-Mj and Mi-j and break i-j residual demand all at node Mi, or node Mj, or part in each, such that the combination of demands represents improved mux channel fill over longest sections.