

Assessment of Cross-connect Systems in Transmission Networks

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ABSTRACT

Introduction of synchronous multiplexers (or digital cross-connect systems) requires thorough studies on transmission network topology, as well as circuit routing. In this paper, transmission network designs related to cross-connect systems are discussed. An assessment result is presented on the application of digital cross-connect systems and add-drop type multiplexers (ADMs).

1. INTRODUCTION

With the development of digital transmission technologies and the introduction of digital switches, digital transmission systems are being introduced in virtually all parts of telecommunications networks. They are taking the place of conventional analog carriers in long-distance networks, and of voice-frequency systems transmitted over pair-cables in short-distance networks. When multiplexed transmission systems are used point-to-point, the multiplexers are acting merely as circuit bundlers. However, when they dominate the network, multiplexers play an important role as circuit cross-connectors. To terminate and cross-connect circuits more efficiently and economically, synchronous multiplexers (i.e., digital access and cross-connect systems) have been developed. Cross-connect systems were first introduced by NTT in 1980. They have DS2 (6.3Mb/s) interfaces with line facilities. The minimum unit of cross-connection with timeslot interchange (TSI) techniques is 384Kb/s, or six telephone channels. Cross-connect systems with DS4 interfaces are now being developed. They bring about more efficient circuit handling, and also require a more complicated transmission network design.

2. DIGITAL CROSS-CONNECT SYSTEMS

In analog networks, each circuit transmitted over a multiplexed system has to be demultiplexed to a voice-frequency baseband signal when switched. Test access and cross-connection on per-channel basis can be achieved at any appropriate distributing frame. In digital networks where the interface between transmission and switching is performed at the multiplexed stage, digital cross-connect systems (i.e., synchronous multiplexers) performs the

operations of multiplexing and operation. At NTT, the first cross-connect system, the M20, was developed in 1977. It was put into commercial use in 1980. Presently, M40, having a DS4 line interface, is being developed (1), (2). It is expected to contribute to network cost reduction as well as an increase in operational flexibility.

In the cross-connect systems, circuits can easily change transmission lines using timeslot interchange (TSI) techniques. Cross-connection between any two lines is possible. Besides these cross-connect type multiplexers, add-drop type multiplexers (ADMs) with lower cost and limited functions are applicable. Introduction of these multiplexers requires studies on circuit routing as well as on transmission network topology.

The main purpose of transmission network optimization has been to minimize the total transmission line cost, with little considerations given to multiplexers. This is because most transmission facility expenditures were for outdoor plants, and, in many cases, terminal equipment could be dealt with as additional cost required at both ends of the line. However, the assessment of both the cost and functions of multiplexers is becoming more important because of the following circumstances.

One is the recent development in transmission line technologies. The recent advances in transmission technologies, such as fiber optics, has contributed to the reduction of line cost. Larger capacity transmission systems have lower system cost, with lower line cost per channel, but higher multiplexer cost. Thus, the development of line technologies results in an increases in multiplexer cost

The other is the wide-spread use of digital systems. Digital carriers have been used in networks, in a point-to-point manner, as economical alternatives to analog carriers. However, they are now to be used as main transmission systems everywhere in long- and short-distance networks. The shorter the transmission length becomes, the larger the relative cost of the multiplexers becomes. If conventional outdoor plants (such as conduits) are available when the new system is introduced, multiplexer cost may be much larger

than the line cost, especially in short-distance networks.

3. CROSS-CONNECTION SCHEME

Given the geographical conditions at transmission nodes, and, technical conditions of the transmission systems and multiplexers, there should be many choices of transmission network topology and cross-connection schemes. Transmission network topology is designed so as to minimize the total investment on transmission facilities, such as conduits, fiber cables, repeaters, and multiplexers. In many cases, the topology may be determined mainly by the geographical constraints and the already-built conduits routes for analog carriers. Given the topology, the main problem is determining (a) the routing of each point-to-point circuit, and, (b) the cross-connection schemes at intermediate nodes.

As the number of nodes involved becomes large, the ratio of intermediate multiplexers to terminating multiplexers becomes large. For example, let us assume a network as shown in Figure 1. If the inter-node distance is long enough, it is more economical to cross-connect each circuit at a fairly low digital stage in most intermediate nodes. This will improve the circuit fill rates in the transmission lines. The resultant decrease in the number of required transmission lines makes up for the increase in the number of the multiplexers required for cross-connection. In actual networks, where the balance between invests on transmission lines and multiplexers is one of the important concerns, the choice of cross-connection schemes becomes increasingly important.

The design of cross-connection schemes for an entire network requires optimization algorithms that deal with combinatorial problems(3). The aim is to find the best cross-connection scheme that minimizes the total cost of the transmission lines and multiplexers. In general, cross-connection at a lower digital stage results in excessive multiplexer cost. Contrarily, cross-connection at a higher digital stage results in excessive line cost, as shown in Figure 2. An example of a cross-connection scheme is shown in Figure 3. In this example, a group of point-to-point circuits between Nodes 1 and 14 through Nodes 2, 4, 5, 12, and 13, is demultiplexed and cross-connected at the proper stage at each intermediate node. The cross-connection scheme for all point-to-point circuits at each node is optimized in terms of the total network cost. In figure 3, stuff multiplexers are assumed. Whenever digital cross-connect systems are used, the same design algorithm can be applicable with some modifications of the parameters. The selection of a cross-connection scheme depends on the inter-node circuit demands, circuit routing, transmission length, applied transmission systems, multiplexers, and so on.

4. HIERARCHICAL STRUCTURE

The complexity in designing digital paths or cross-connection schemes drastically increases as the number of nodes involved increases. Although it is possible to design digital paths in large networks with computer assistance, the simplicity of the network is another important objective of designers. In some cases, a large network can be hierarchically structured, as shown in Figure 4.

A transmission network is divided into some subnetworks, or intra-area short-distance networks, and an inter-area long-distance network that connects the gateway nodes of individual subnetworks. If the network is divided into too many subnetworks, the cost of the inter-area network becomes excessive, even though the cost of each intra-area network decreases. Consequently, there is an optimal number of subnetwork division. In actual networks, each area is determined taking into account the geographical conditions, administrative areas, switching hierarchy, and so on.

In a transmission link between an intra-area node and a gate node, all out-of-area circuits can be packed, assuming cross-connection at the gateway nodes. If the number of circuits in the link sum to a large number, no cross-connection at the intermediate intra-area nodes may be necessary. At the gateway node, circuits are cross-connected and bundled into higher-order digital stages according to the area for which they are headed. At the destination gateway nodes, they are cross-connected again and forwarded to their final destination nodes. In this scheme, a large number of circuits can be bundled with less cross-connection points. This contributes to a reduction in the number of multiplexers, but at the expense of an increase in the circuit length. The detailed digital path design, mentioned previously is necessary for an inter-gateway network and for each individual subnetwork. Thus, the number of nodes involved is much less than that of the original large network.

Besides the design of each network, the interaction between these networks is another problem.

In a long-distance network that connects gateway nodes, the number of circuits that traverse an inter-gateway link is generally larger than that of intra-area links. Cross-connection systems applied to gate nodes will have higher-speed bit-rate interfaces with transmission lines. Cross-connect systems can be realized economically if the cross-connection unit is set to a larger circuit group. However, in most networks, cross-connection at each node need to be executed at a smaller circuit group. This is because the number of point-to-point

circuits is usually fairly small. To enlarge the cross-connection unit for the multiplexers at gateway nodes, circuit pre-grouping with a small unit in each intra-area network is necessary.

One solution is to define a set of nodes for the circuit pre-grouping. They form a circuit group that is cross-connected at the gateway nodes without segregation. The segregation of circuits for each node is executed by cross-connect systems applied at the destination subnetworks. Other concerns are the choice of transmission network topology, circuit routing, cross-connection scheme, and multiplexer type.

5. CROSS-CONNECTION ASSESSMENT

From the viewpoint of allocation of cross-connection nodes, there are several configurations. Some of which are shown in Figure 5. In the hub configuration, the cross-connection function is centralized at a specified node. In this scheme, the trade-off between multiplexer reduction and circuit-length increase determines the economics. In loop configurations, add-drop type multiplexers (ADMs) can be applicable. These contribute to network cost reduction, because the the ADMs are less expensive. However, in actual networks, some nodes have more than two links with different destinations, as shown in Figure 5(c). ADMs are not applicable for these nodes. The use of a cross-connection system for all the node is the conventional idea. The joint use of ADMs and cross-connect systems may provide practical solution.

Another idea to cope with this problem is to synthesize the required connection using a set of loops, as shown in Figure 5(d). These loops are not necessarily formed at the rate of transmission. They may be formed at a certain digital stage in large-capacity transmission systems. In each loop, ADMs are applicable. The first process in synthesizing a network is to find a set of logical loops that can provide all point-to-point circuits. There are a large number of sets that meet this condition. The next problem is to find the best set that minimizes the network cost, or minimize the sum of multiplexer and line costs. That includes determining the loop for which each point-to-point circuit should be provided. A heuristic algorithm for this problem has been developed.

A simple nine-node network model, shown in Figure 6, is assumed to be able to evaluate the following three schemes:

Scheme 1: Tandem of cross-connect systems.

Circuits are bi-routed over the shortest paths, and cross-connected at every intermediate node.

Scheme 2: Hub with a cross-connect systems.

Circuits are bi-routed through the central node.

Scheme 3: Combined logical loop with ADMs.

Circuit are bi-routed over one of loops.

For each scheme, the circuit routing and a cross-connection scheme is designed, and the total network cost is evaluated. Figure 7 shows which scheme is most economical, with respect to inter-node distance and the amount of demand for inter-node circuits. As a general trend, Scheme 1 becomes most economical when the line length become longer. This is because it gives the highest fill rate in the lines and the shortest total circuit length.

On the other hand, Scheme 3 becomes economical as the inter-node distance becomes shorter. This is because cost increase due to the long circuit length becomes less critical. The most economical area of Scheme 2 is small, as shown in Figure 7(a), when the ADM cost is assumed to be the same as that of cross-connection type multiplexers. However, since the ADM cost is assumed to be cheaper, the area grows and Scheme 2 could be most economical (except when the inter-node distance is fairly long, or inter-node circuit demand is fairly small). These maps depend on the number of nodes involved and other detailed parameters. In an actual network, it is necessary to base the detailed design on actual parameters and constraints, such as point-to-point circuit demands, node allocation, transmission network topology, line length, and so on.

6. CONCLUSION

Recent developments in transmission line technologies and multiplexing technologies present a necessity of thorough study on transmission network configurations. Introduction of cross-connect systems gives us a wide variety of possibilities in network planning and operation. Since cross-connection schemes can not be assessed at each node independently, studies on an entire network are necessary.

In this paper, a few network configurations related to cross-connect system and ADM application are evaluated.

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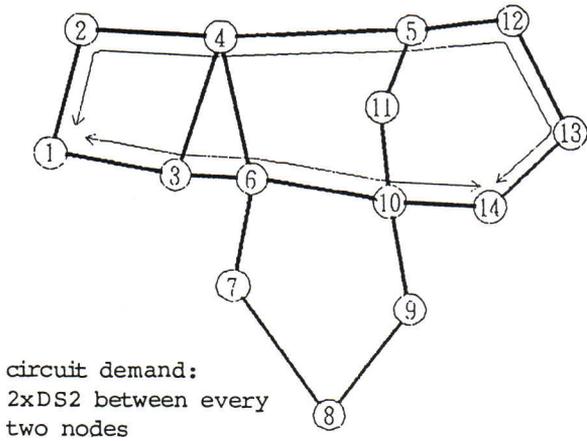
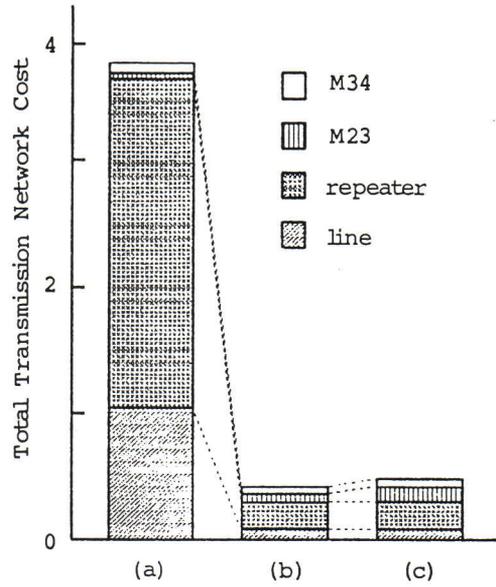


Fig.1 Transmission network model



- (a) Cross-connection at DS3 at every intermediate node
- (b) Cross-connection designed by the algorithm
- (c) Cross-connection at DS3 at every intermediate node

Fig.2 Cross-connection assessment

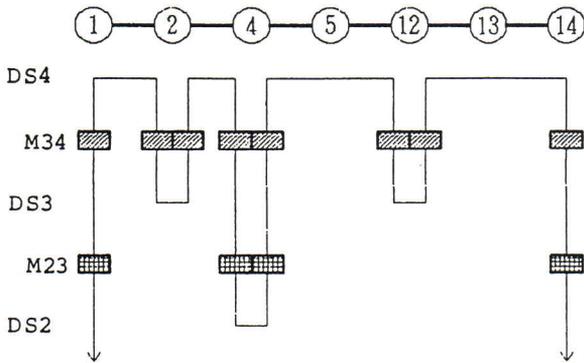


Fig.3 Example of cross-connection

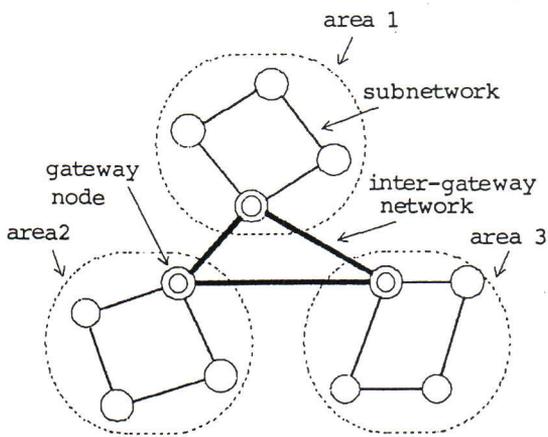
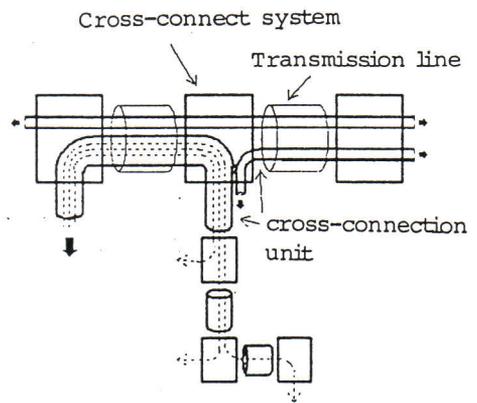


Fig.4 Hierarchical structure and cross-connection



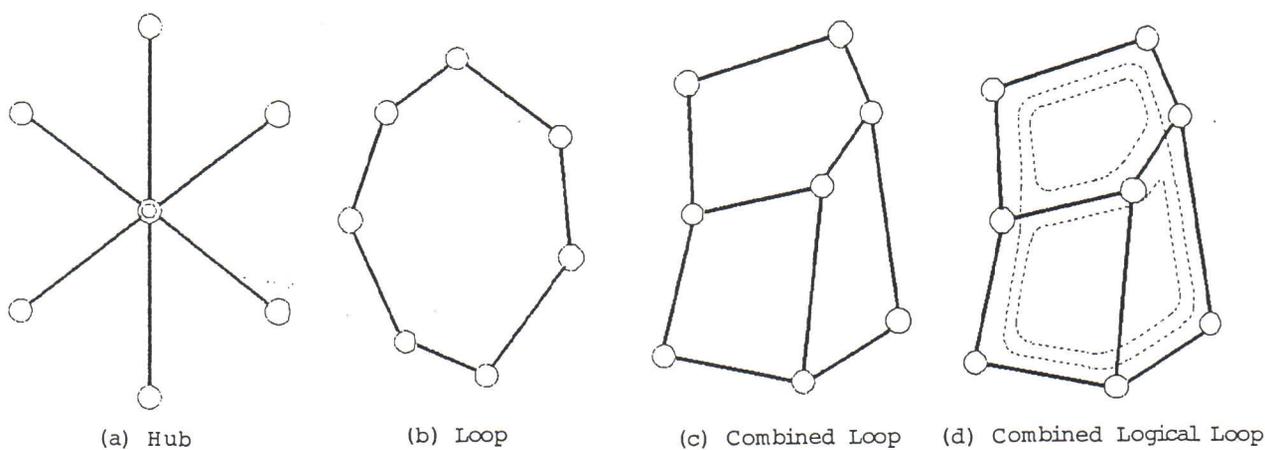


Fig.5 Cross-connection and topology

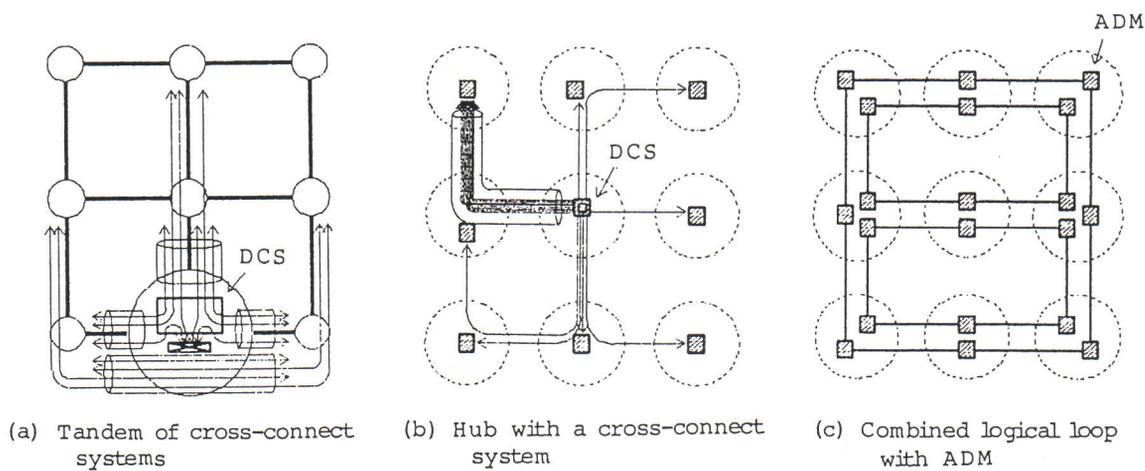


Fig.6 Cross-connection assessment model

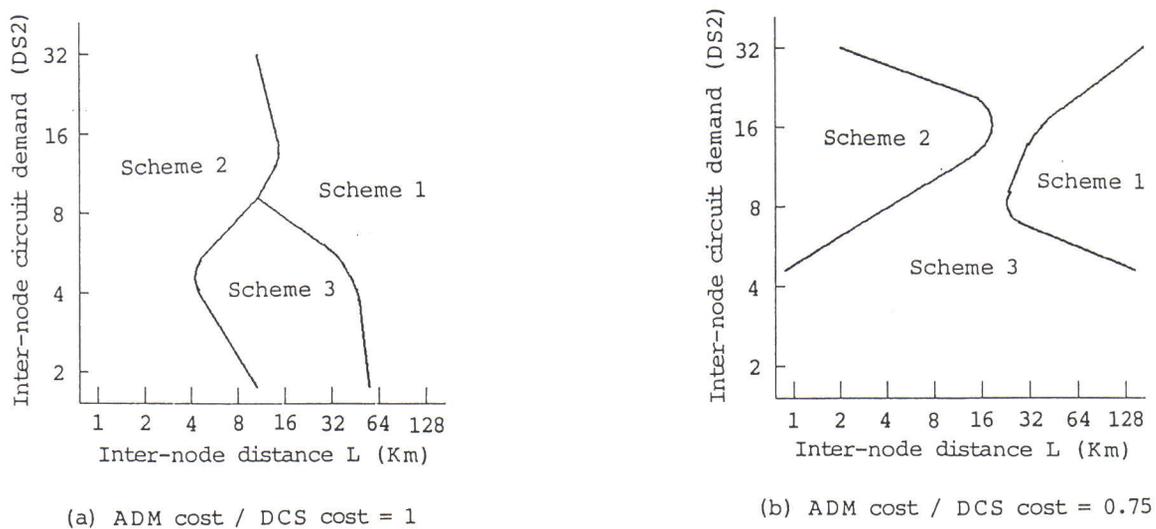


Fig.7 Application map

