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Traffic Design Method for Large-Scale Switched Telecommunication Networks

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SUMMARY

With the widespread telephone service and the introduction of various services, the scale of the switched telecommunication network is expanding. The adequate traffic design of the switched telecommunication network is important in improving the efficiency of the use of the communication network facilities.

This paper considers the large-scale switched telecommunication network with various local structures and proposes a method for the traffic design. First, it is intended to simplify the design of the large-scale switched telecommunication network without introducing the network partitioning or the unrealistic concept. For this purpose, the hierarchical concept composed of the traffic network and the circuit network is introduced. Then, the methods for the network structure design and the traffic assignment are presented for the traffic network and the circuit network, respectively. For the former, the design is considered with the specification by the designer as the minimum requirement for the locally inhomogeneous network structure. A method is shown to realize the whole network as a combination of basic elements. For the latter, the minimization of the number of additions in traffic counter is considered. A detailed algorithm is presented, and the effectiveness is shown through numerical examples.

Key words: Network structure; multiunit; switched telecommunication network; traffic design; large-scale; hierarchical network.

1. Introduction

Recently, there has been remarkable widespread use and development of the communication services based on the telephone. At present, the number of telephone subscribers in Japan is approximately 60 million and the number of subscriber telephone switching units is several thousand. Along with this situation, the number of units in the trunk switches is now several hundred and the number of links (circuit groups) connecting the switching units is several tens of thousands. In other words, the trunk switching network is now very large-scale and complex.

The adequate traffic design of the switched telecommunication network is very important in improving the efficiency of the use of the telecommunication network facilities. The large-scale switched telecommunication network usually has the composite network structure where the switches are placed hierarchically in multistages. For the switched network, various methods have been proposed for traffic design [1-8], most of which, however, consider the relatively small-scale network with a homogeneous network structure.

It has been considered difficult to consider directly the large-scale telecommunication network with various network structures according to the local characteristics. The usual approach is to partition the switched network and design the individual subnetwork or to simplify the problem using various assumptions. The top level of the network is separated, for example, or the part of the

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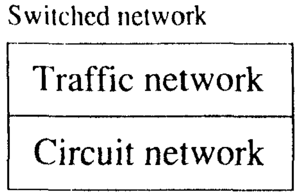

Fig. 1. Hierarchical representation of switched network.

network above a certain layer is separated from another part or the network is partitioned into local subnetworks. Another approach is to ignore the limit of the switch capacity and to introduce an unrealistic assumption that one unit is provided in each switching node.

By applying such a simplification, the strict traffic calculation among subnetworks is made difficult which deteriorates the accuracy of the traffic design. In addition, the following essential problem arises. There may be a change of the generation of the switching or transmission system, a change in the traffic flow or a change in the framework in telecommunication administration. Those will be accompanied by the change of the network structure or, more precisely, the number of layers, the connections among switches and the circuit modularity. Then, it becomes necessary to remodel the whole network from the viewpoint of the traffic design. This may invalidate the network design system corresponding to the past network structure or make it necessary to reconstruct the traffic design procedure.

This paper aims at the direct design of the large-scale switched telecommunication network with locally diversified structures. A new concept is proposed where the switched telecommunication network is decomposed hierarchically into the traffic network and the circuit network. The design for the network structure and the traffic assignment algorithm are given for both the traffic networks and the circuit network.

2. Hierarchical Model for Switched Network

The switched telecommunication network is decomposed hierarchically into two layers, which are the traffic network and the circuit network (Fig. 1). The traffic network represents the macroscopic flow of the traffic among the subscriber line-switches (LS). More precisely,

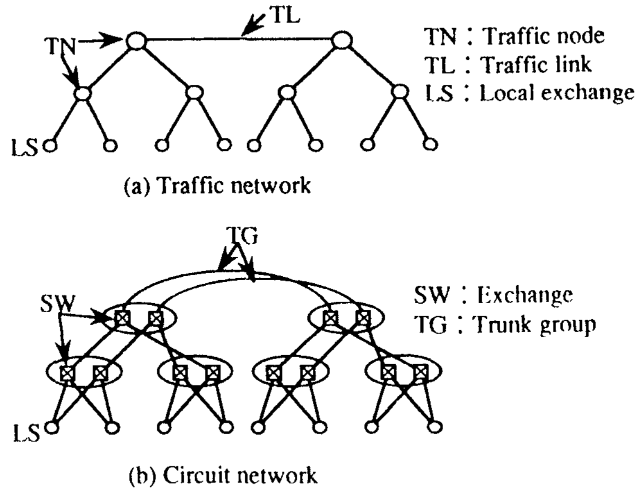

Fig. 2. Examples of a traffic network and a circuit network.

the network is composed of the network topology, consisting of the traffic nodes (TN) and the traffic links (TL), and the routing table that specifies the traffic flow for each TN.

The circuit network represents the macroscopic flow of the traffic among LS and specifies the realization configuration of the traffic network. More precisely, the network is composed of the network topology, with the trunk switch (SW) as the node and the trunk group as the link, as well as the routing table specifying the traffic flow for each SW. Figure 2 shows examples of the traffic network and the circuit network. As is shown in the figure, one or more SWs are provided corresponding to each TN in the traffic network. Similarly, one or more TGs are provided corresponding to each TL in the traffic network.

As discussed in the following, the traffic design is started from the traffic network, which is the upper layer, and is continued to the circuit network (Fig. 3).

(1) Design of traffic network

The network structure of the traffic network (the topology and the routing table for each TN) is generated, and the traffic is assigned. Those procedures determine the traffic through each TN, and the results are passed to the design of the circuit network.

(2) Design of circuit network

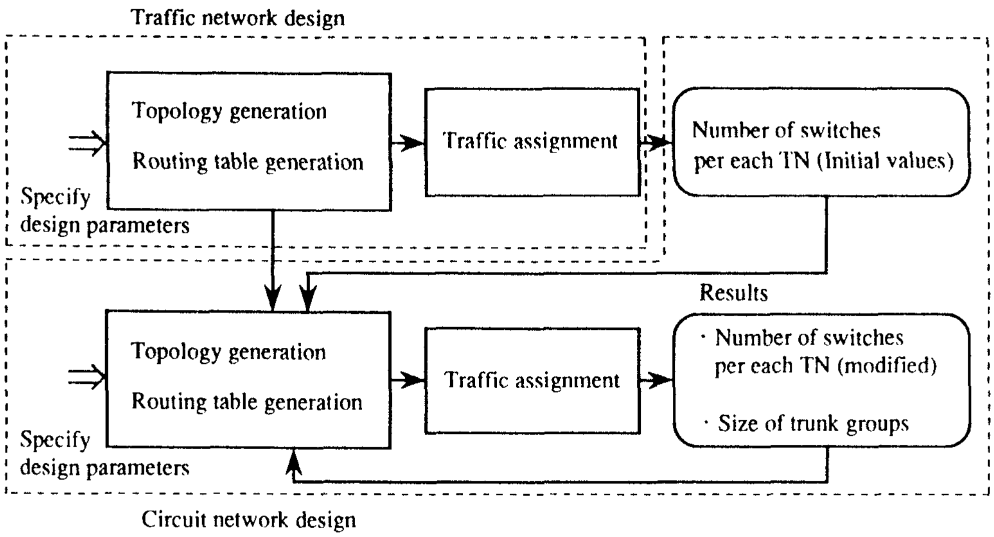

Fig. 3. Network design flow.

Based on the traffic through each TN and the capacity of SW, the number of SW in each TN is determined as the initial value. Then the network structure (the topology and the routing table of each SW) is generated, and the traffic is assigned. The result is used in the calculation of the number of circuits in each TG, and the calculation of the number of ports in each SW.

There may be detailed conditions, such as the partition of the traffic among SW and TG or the number of ports, which have not been considered in the design of the traffic network. If it becomes necessary to increase or decrease the number of SW in each TN in this process, the number of SW is newly defined and the circuit network is redesigned. If multiple kinds of SW with different capacities are available, there must be the condition for the selection of SW type. Assume, for example, that there are available SW with a large capacity and SW with a small capacity. For TN with too many SW with small capacity, SW with a large capacity can be applied.

By the hierarchical modeling, the design parameters of the lower layer (circuit network) are concealed in the design stage of the upper layer (traffic network). The design parameters for the upper layer are inherited by the lower layer. In other words, in the design of the lower layer, the design parameters determined in the upper layers are fixed and the design parameters inherent to the lower layer are determined. This reduces the complexity of the traffic design. Another point is that the change of the design parameter in the lower layer does not affect the upper layer and the redesign can be restricted to the lower layer. Thus, the traffic design can be simplified by the hierarchical representation of the switched telecommunication network.

3. Generation of Network Structure

3.1. Traffic network

(1) Configuration of nationwide network

Assume that the traffic flow is specified for the nationwide subscriber line switches (LS). When the nationwide network is considered, such conditions as the density of LS and the traffic flow characteristics differ depending on the local character. Consequently, the network configuration cannot be homogeneous over the whole country. An approach in this paper is to realize the whole network as a combination of basic elements, just as a system is constructed from a number of components. By such an approach, it is possible to generate to some extent automatically the locally inhomogeneous large-scale switched network, with the specification by the designer as the minimum requirement.

First, the nationwide network is constructed as overlaid subnetworks (SNW). SNW is constructed for a specified area (a set of LS). More precisely, the procedure is as follows. An SNW is constructed for the whole national area. In addition, SNW can be constructed for any local area. It is possible also to define a smaller local area within a local area to construct an SNW.

LS belonging to more than one SNW is connected directly to TN in each of SNW (Fig. 4). The traffic between any two LS is carried by the SNW corresponding to the smallest area containing those two LS. In the case of the Japanese nationwide network, the long-distance trunk network corresponds to the nationwide area SNW and the urban trunk network corresponds to the local area SNW.

(2) Configuration of SNW

Each SNW is composed of a combination of a number of element networks (ENW); ENW is a network with a homogeneous structure. There are hierarchical, mesh, originating tandem, and terminating tandem networks, from which the designer can select appropriate networks. By combining those networks, various network patterns can be generated efficiently which helps to represent easily the network such as urban trunk network, which can have diversified configurations according to the local characteristics.

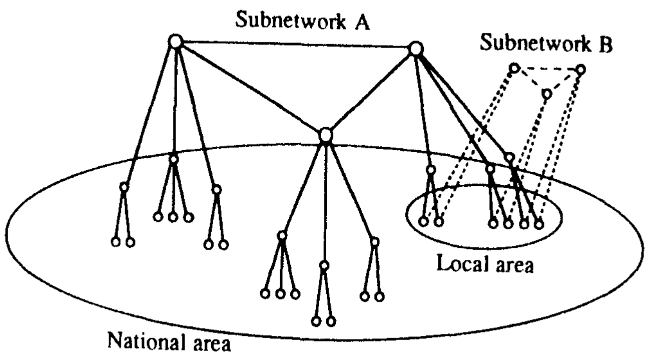

Fig. 4. Network configuration with overlaid subnetworks.

As to the routing method, the simplest nonalternate routing is assumed in this paper. This is considered as one of the sensible approaches to simplify the large-scale network. The method shown in this paper can be applied even if the alternate routing is considered, which, however, is not discussed in this paper in order to avoid complex descriptions.

ENW has a homogeneous network structure. Consequently, the network topology and the routing table of each TN can be generated automatically when the designer specifies particular design parameters. In the case of the hierarchical network, for example, it suffices to specify the number of layers and the traffic area. By traffic area is meant the set of LS belonging to one upper-level TN. In the case of the three-layered hierarchical network, for example, there exists a traffic area (HTA) corresponding to the top level TN (HTN), and the traffic area (LTA) corresponding to the next level TN (LTN) (Fig. 5). The topology is represented by the TN-TN incidence matrix. The routing table is composed of the destination column and the next TN column, and all LTA in ENW are registered in the destination column.

It is assumed that the direct TL can be set between any TN in ENW. The designer specifies the originating

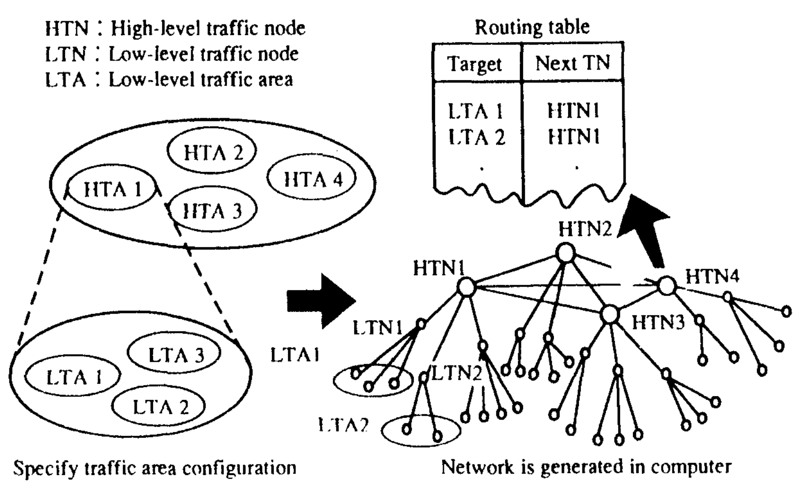

Fig. 5. Generation of a network component.

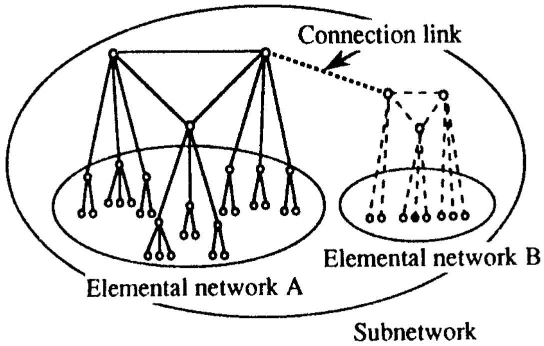

Fig. 6. Connection of network components.

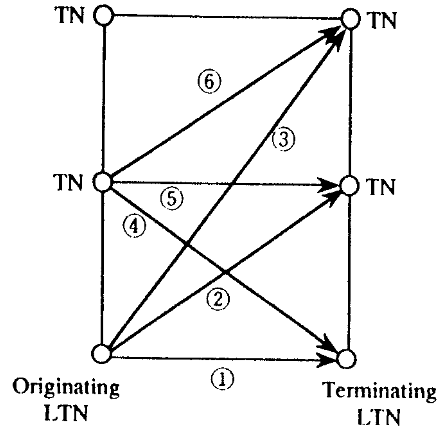

Fig. 7. Direct route classes in a hierarchical network.

and the destinating TN for the direct TL, which makes it possible to modify automatically the corresponding network topology and the routing table. The derivation of the candidates for the direct TL will be discussed in the following section.

As shown in Fig. 6, it is assumed that TL (called connection link) can be set between any ENW composing an SNW. The designer specifies the originating and the destinating TN to define the connection link, which helps to modify automatically the network topology and the routing table for each TN. In this process, all LTA of SNW are to be registered in the destination column of the routing table. By this scheme, the network structure can be constructed by a combination of relatively simple manipulations even if the structure is inhomogeneous, according to the traffic flow characteristics, etc.

(3) Derivation of candidates for direct TL in hierarchical network

The hierarchical network is the most general configuration as ENW. There is known the LTC method, which assumes the alternate routing as a method to set the direct TL in the hierarchical network. In this method, however, the route in which the traffic between TN exceeds a certain value is extracted as the candidate for the direct TL. With the use of the large-capacity transmission system, the cost structure for the network has changed recently. At present, it is more economical as a whole network to simplify the design rule for the network rather than to optimize locally with the utmost strictness [9]. From such a viewpoint, it is sensible from a practical viewpoint to prepare the forementioned simple criterion for setting the direct TL.

When a direct TL is set from a TN (originating TN) to another TN (terminating TN), the traffic of the direct TL from the upper level TN to any terminating TN is decreased due to the property of the hierarchical network. Consequently, the candidate extraction and setting of the direct TL are executed according to the order of the route class shown in Fig. 7. To calculate the traffic of the route, the LS-LS traffic matrix in the hierarchical network is prepared as follows.

First, for the route class ①, the traffic flows between LS in the traffic area of the originating TN (LTN in this case) and LS in the traffic area of the terminating TN (LTN in this case) are summed. The result is the traffic flow between the originating and the terminating TN. The candidates for the direct TL are extracted based on the condition that the traffic flow exceeds a certain value. Referring to these data, the designer determines and sets the direct TL. The elements in the LS-LS traffic matrix corresponding to the route with direct TL are set as 0.

Then, for the route class ②, the direct TL is extracted and determined. The procedure is iterated down to the last route class. For each route class, the traffic flow of the route for which the direct TL is set is deleted from the LS-LS traffic matrix. Thus, the traffic flow matrix between the originating and terminating TN can easily be calculated for each route class.

(4) Connection to service network

A configuration is considered in the following where the nationwide network is connected to the service

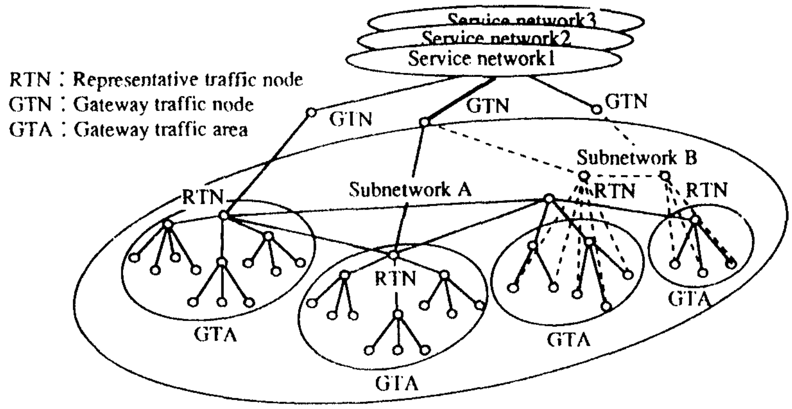

Fig. 8. Connection with service networks.

network through the gateway traffic node (GTN). By service network is meant the node which executes the communication processing services, such as the message dialing, the packet switching, and the facsimile, or other carrier networks. There can be more than one GTN, or a GTN can be shared by multiple service networks or multiple SNW.

For each service network, the designer specifies the GTN (more than one, in general), the service area (GTA) to correspond to each GTN, and the representative traffic node (RTN) to be connected to GTN.

As GTA, one of the areas already defined in constructing the nationwide network, i.e., the whole SNW, the whole ENW in SNW, HTA or LTA in an ENW is selected. As RTN, one or more are specified from TN that belong to the SNW in which GTA is defined so that the whole GTA is covered. Figure 8 shows an example. In this process, the network topology and the routing table for each TN concerning the service network can be modified automatically. In this way, the complex network structure in the multiservice environment can easily be represented.

3.2. Circuit network

Assume that the number of SW for each kind to be assigned to each TN of SNW is already specified as the initial value. The initial values are determined based on the result of the traffic assignment for the traffic network, as is discussed in item (2) of section 2.

When more than one SW corresponds to one TN, it is a problem in the design to which SW of another TN

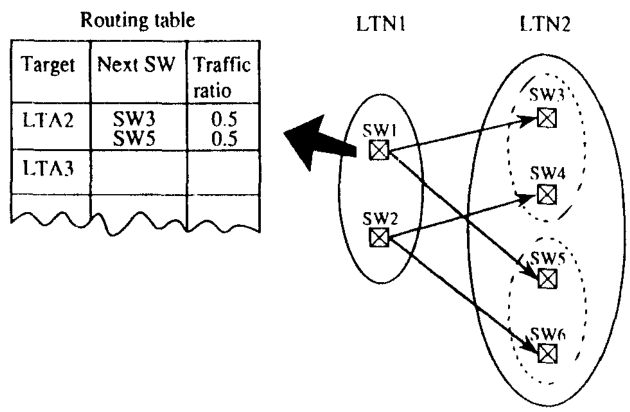

Fig. 9. Generation of a circuit network.

(terminating TN), TG should be defined from each SW of a TN (originating TN). The same problem also arises in defining TG in the up-direction, from LS to the set of SW in LTN. TG can always be set in the down-direction, i.e., for each LS in LTA from each SW in LTN.

If TG are set to multiple SW in the terminating TN from each SW in the originating TN, the effect of the fault in terminating SW can be reduced. In addition, if SW of TN are contained in multiple buildings, the concentration of the damage to a particular TN can be avoided in the case of an earthquake, etc.

From such a viewpoint, it is designed that more than one TG is set from each SW in the originating TN to the set of SW in the terminating TN. The number n of latter SW is specified by the designer. SW in the terminating TN is divided into two groups. The groups are composed so that the numbers of SW in the groups are equal for each kind of SW; $n/2$ each TG are set from each SW of the originating TN to each group in the terminating TN (Fig. 9). When the number of SW in the terminating TN is less than n, the maximum number that can be set is selected automatically. By this scheme, if two groups of SW in each TN are contained in separate buildings, 50 percent of the traffic can be retained when a building has a fault. The value of n may not be homogeneous in SNW. Different values can be used, for example, in the cases of origination from LS and the origination from SW in TN.

Then, TG are set either uniformly or in proportion to the capacity, so that the traffic does not concentrate to a particular SW. By uniform setting is meant the scheme where the total number of TG accommodated by each SW is made uniform in each TN. By the capacity-proportional setting is meant the scheme where the total number of TG accommodated by each SW is made proportional to the capacity of SW. In the uniform setting, the traffic is assigned to TG in proportion to the capacity of SW. The traffic is assigned uniformly in the case of the capacity-proportional setting. Then, the traffic assigned to SW is made proportional to the capacity of SW.

More precisely, a counter is provided in each SW, which is counted up each time TG is set in the SW. When a TG is to be set for a TN, SW with the minimum count in the TN is selected. Then, the uniform setting is realized. If the counter value is normalized by the capacity of SW, the capacity-proportional setting is realized similarly.

The topology of the network realized in this way is represented by the SW-SW incidence matrix corresponding to TN-TN with TL in the traffic network. The routing table in each SW has essentially the same structure as that of the corresponding TN. In other words, the routing table is composed of the destination column, the next SW column, and the ratio column. The destination column contains the list of LTA in SNW, as in the case of TN. The next SW column contains SW of the next TN, which is the termination of TG (more than one, in general). The ratio column contains the assignment ratio of the traffic for each SW (Fig. 9). For LS, the destination column is not necessary but the next SW column and the ratio column are provided. The designer has only to specify the parameter n and to select between the uniform and the capacity-proportional settings. Then, the network topology and the routing table for each SW are generated automatically.

4. Traffic Assignment

4.1. Traffic assignment in traffic network

It is assumed that the nationwide traffic matrices are given for LS-LS as well as between LS-service network. The part of the traffic flow carried by the considered SNW is extracted. The traffic is assigned for each SNW. The traffic offered on each TN and TL is calculated. When a GTN is shared by multiple SNW (GTN at the center of Fig. 8), the traffic offered on GTN and TL between GTN and service network is calculated individually in the traffic assignment to each SNW. By summing up the results, the final traffic is determined.

The method of traffic assignment in each SNW is shown in the following. Assume that ENW composing the SNW is a hierarchical network. To simplify the description, the LS-LS traffic assignment is considered. The idea is the same for the traffic assignment for LS-service network.

The traffic counter is provided corresponding to each TN and TL. The traffic assignment is executed in principle by summing up the originating LS-terminating LS traffic in the corresponding traffic counter of TN and TL in the network, according to the routing table of each TN (this is called the direct method). In this method, however, the number of additions in the traffic counter becomes tremendous.

This problem becomes more serious in the traffic assignment in the circuit network where SW in each TN as well as TG between SW are considered. In the following, an algorithm is proposed which assigns the traffic efficiently from the viewpoint of minimizing the number of additions in the traffic counter (called aggregating method). The aggregating method can also be applied to the traffic assignment in the circuit network as is discussed in section 4.2. The effectiveness of this algorithm is discussed in section 4.3, combined with the case of the circuit network.

(1) When the originating and the terminating LTA are the same

① The traffic from an LS (originating LS) in LTA to each LS (terminating LS, not including the originating LS) in the same LTA is added to the traffic counters of TL from originating LS to the same LTN, and TL from LTN to each terminating LS.

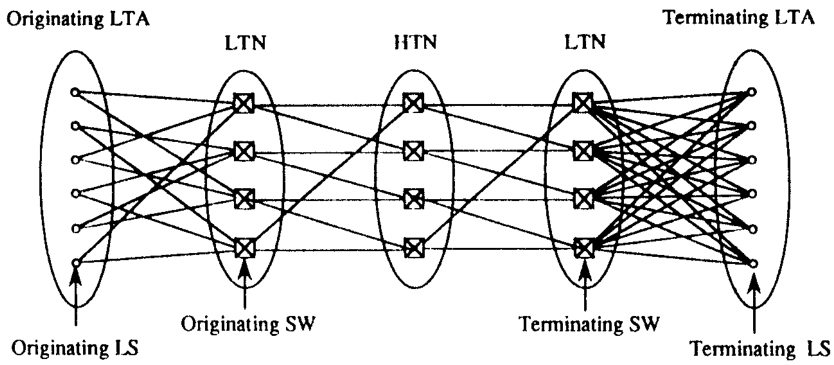

Fig. 10. Traffic flow between originating and terminating LTAs.

② The traffic summed up in the counter of TL from originating LS to LTN is added to the traffic counter of LTN.

③ The foregoing process is applied to all LS in LTA. The process is then applied to all LTA in SNW.

(2) When the originating and the terminating LTA are different

① The traffic from an LS (originating LS) in the originating LTA to each LS (terminating LS) in the terminating LTA is added to the traffic counter for TL from the originating LS to the originating LTN, and for TL from the terminating LTN to the terminating LS.

② The traffic summed up in the counter of TL from the originating LS to the originating LTN is added to the traffic counter of the originating LTN.

③ The foregoing process is applied to all LS in the originating LTA.

④ The traffic summed up in the counter of the originating LTN is added to the traffic counter of TL and TN (including the terminating LTN) on the route to the terminating LTN according to the routing table.

⑤ The foregoing process is applied to all originating LTN and terminating LTA in SNW.

4.2. Traffic assignment in circuit network

As in the case of the traffic network, the traffic assignment is described for LS-LS. The traffic counter is provided corresponding to each SW and TG. In the following description, the same number is assigned to the item corresponding to the traffic assignment in the traffic network.

(1) When originating and terminating LTA are the same

① The traffic from an LS (originating LS) in LTA to each LS (terminating LS, not including the originating LS) in the same LTA, is added to the traffic counter for TG from the originating LS to SW, and TG from SW to each terminating LS, according to the ratio given in the routing table.

② The traffic summed up in the counter of TG from the originating LS to SW is added to the traffic counter of SW.

③ The foregoing process is applied to all LS in LTA. Then, the process is applied to all LTA in SNW.

(2) When originating and terminating LTA are different

Figure 10 shows, as an example, the traffic flow from an originating LTA to the terminating LTA. The traffic is assigned for three sections, i.e., from the originating LS to originating SW, the originating SW to the terminating SW, and from the terminating SW to the terminating LS.

① The traffic from an LS (originating LS) in the originating LTA to each LS (terminating LS) in the terminating LTA is added to the traffic counter of TG from the originating LS to the originating SW, according to the ratio given by the routing table of the originating LS.

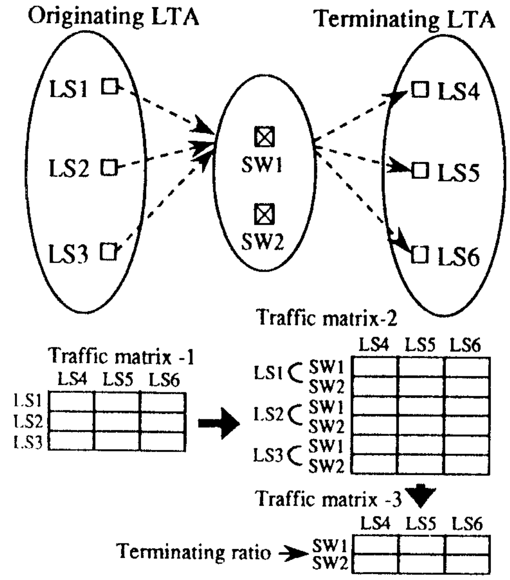

Fig. 11. Computation of terminating ratio.

② The traffic summed up in the counter of TG from the originating LS to the originating SW is added to the traffic counter of the originating SW.

③ The foregoing process is applied to all LS in the originating LTA.

Next, the LS-LS traffic matrix-1 for the originating and terminating LTA is divided by the ratio given by the routing table of the originating LS, as is shown in Fig. 11. The result is the traffic matrix-2 representing the content for each of the originating SW. By summing the result for each originating SW, the traffic from the originating SW to the terminating LS is determined (traffic matrix-3). In this process, the ratio of the traffic to each terminating LS (called terminating LS ratio) is determined for each originating SW. This value is used in the traffic assignment to TG from the terminating SW to the terminating LS, as will be discussed later.

④ The traffic summed up in the counter of one of the originating SW is added to the traffic counter of TG and SW (including the terminating SW) on the route to each terminating SW, according to the routing table. It may happen that there exist more than one route from the originating SW to each terminating SW, which may pass through the same SW on the way. Then, a problem arises as to by what order the traffic assignment should be executed to achieve the highest efficiency.

For this problem, the depth-first search [10] algorithm can be applied (called conditional depth-first search algorithm, shown in Appendix 1). By this algorithm, the traffic assignment of the outgoing TG can be made at once, even if there exist more than one incoming TG to an SW. The number of additions in the traffic counter is minimized.

By the foregoing process, the traffic is assigned to the terminating SW. The forementioned traffic is from one originating SW. At SW on the way, the routing is made with the terminating LTA as the destination and the terminating LS is not considered. Consequently, by partitioning the traffic of each terminating SW according to the previously defined terminating LS ratio, the traffic of TG from the terminating SW to each terminating LS can be determined.

By applying the foregoing process to all originating SW, all of the traffic assignment is completed for TG and SW (including the terminating SW) from the originating SW to the terminating SW as well as TG from the terminating SW to the terminating LS for the corresponding originating LTA and terminating LTA.

⑤ The foregoing process is applied to all originating LTA and terminating LTA in SNW.

4.3. Evaluation of number of additions in traffic counter

As an example, assume the case where SNW is composed of a single ENW, and ENW is a hierarchical network. The numbers of additions in the traffic counter are compared between the direct method and the aggregating method in the following. Let the number of HTA in the hierarchical network be p, the number of LTA in HTA be q, the number of LS in LTA be r, the number of SW in each TN be k, the distribution of TG be d, and the number of trunk lines from the originating LTN to the terminating LTN be s. When the originating and the terminating LTN belong to the same HTA, $s = 2$. When they belong to different HTA, $s = 3$.

Two cases are considered: ① the case where the originating and the terminating LTA are the same, and ② the case where they are different. Let the numbers of countings in the traffic counter be x and $y(s)$, respectively. Then, the number of additions C of the traffic counter for the whole SNW is given as follows:

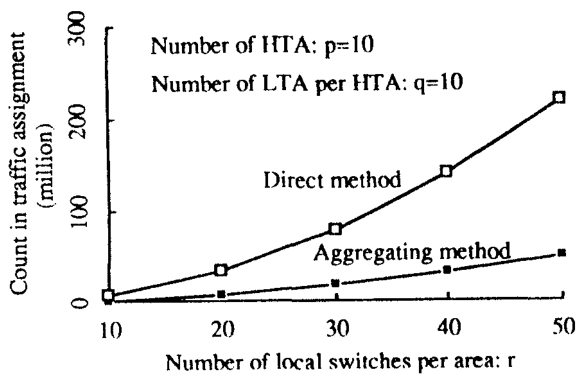

Fig. 12. Count in traffic assignment for a traffic network.

$$C = pqx + pq(q-1)y(2) + p(p-1)q^2y(3) \qquad (1)$$

The calculation of x and $y(s)$ in the traffic network and the circuit network is shown in Appendix 2.

Figure 12 shows a numerical example for the traffic network. It is seen that the number of additions in the traffic counter in the aggregating method can be reduced to a fraction of the direct method. Figures 13(a) and (b) are numerical examples for the circuit network of the same condition. It is seen that the number of additions in the traffic counter is reduced greatly by the aggregating method, as in the traffic network. Especially, the following situation is observed. When the number of distributions d of TG is increased, the number of additions in the traffic counter increases in proportion in the direct method, while it increases with a smaller rate in the aggregating method.

5. Conclusions

This paper considered the nationwide large-scale switched telecommunication network and proposed a systematic traffic design, aiming at an easy handling of the large-scale network with an inhomogeneous structure based on the general local characteristics. It is intended to simplify the design of the large-scale switched telecommunication network without introducing the network partitioning or unrealistic assumption. A method is proposed to model the network as a hierarchical network composed of the traffic network and the circuit network. Methods of the design for the network structure and the traffic assignment are shown for each of the layers.

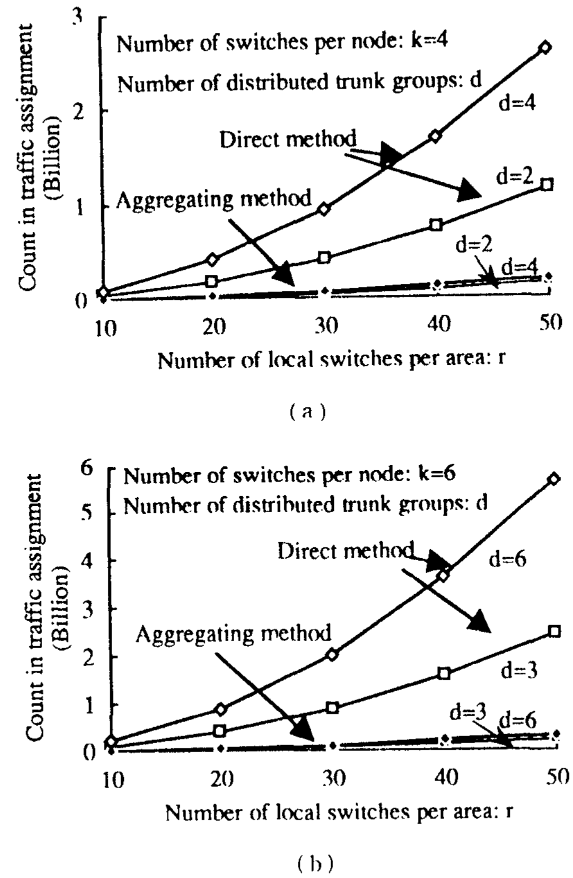

Fig. 13. Count in traffic assignment for a circuit network: (a) $k = 4$ and (b) $k = 6$.

As to the design of the network structure, a method is shown to construct the network in the form of building blocks, which has the inhomogeneous and complex structure from the viewpoints of the traffic characteristics and connections to other carrier networks and service networks. As to the traffic assignment, detailed algorithms are shown from the standpoint of minimizing the number of additions in the traffic additions corresponding to the nodes and links in the network. It is shown through numerical examples that the number of additions can greatly be reduced.

This paper provided a method to design an inhomogeneous network structure, which is usual in the large-scale network. It is a proposal to specify the interface between the designer and the design system so that the designer is burdened least. Such an approach will also be useful in the design of the transmission network, in addition to the switched network. By extending the idea, the advanced network design method will be realized, integrating the switched and transmission networks. In the future development toward the construction of B-ISDN and other networks, it is becoming more important to establish a practical telecommunication network design technique. This paper is a trial to move a step forward, and it is expected further to construct and develop the algorithm and theory for the systematic network design.

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APPENDIX

1. Traffic Assignment Algorithm for Circuit Network

Assume that a subnetwork is extracted where the traffic flows from an SW (originating SW) of the originating LTA, to the set of SW (terminating SW) of the terminating LTA. By corresponding SW to node and TG to edge, the subnetwork can be considered as a directed graph G; G does not contain a cycle. The node corresponding to the originating SW is called the start node, and the node corresponding to one of the terminating SW is called the end node. Other nodes of G are called internal nodes.

The start node is assigned a traffic beforehand and is marked as "assigned." All other nodes are marked as "unassigned." When more than one edge comes out from a node, it is assumed that the traffic ratio is predetermined for the edges. By the conditional depth-first search is meant the depth-first search [10] with the condition that the node other than marked as *assigned* cannot be visited.

In the conditional depth-first search, the start node is defined as the first visited node. Then, by tracing the edges of G, the adjacent nodes marked as *assigned* are visited. At the visited node (node v), the mark is altered to *visited*. At the same time, the traffic assigned to v is assigned to the edges coming out from v, according to the traffic ratio. If traffic is assigned to all incoming edges at node w adjacent to v, the sum of the incoming traffic to w is defined as the traffic assigned to w. The mark of w is altered to *assigned*.

If there exists a node adjacent to v marked as *assigned*, it is visited and the same processing is applied. If there exists an adjacent node that can be visited from the node visited as in the foregoing, the visit is continued along the line of progress (depth-first search). If there does not exist a node adjacent to v marked as *assigned*, the trace returns to the node visited previously and the visit to the adjacent node is started again. If there does not yet exist a node that can be visited, the trace further returns to the one more previously visited node. By continuing the forementioned process, all internal nodes of G eventually are visited. As a result, the traffic is assigned to all edges, all internal nodes and the end nodes of G.

2. Number of Additions in Traffic Counter

(1) Traffic network

(a) When originating and terminating LTA are the same

Aggregating method. For each LS, $(r - 1)$ additions are required for TL from the originating LS to LTN, one for LTN, and $(r - 1)$ for TL from LTN to the terminating LS. Consequently, the number of additions x is given as $r(2r - 1)$.

Direct method. For each originating LS and terminating LS, one each addition is required for TL from the originating LS to LTN, for LTN and for TL from LTN to the terminating LS. Consequently, the number of additions x is $3r(r - 1)$.

(b) When originating and terminating LTA are different

Aggregating method. For each LS, r additions are required for TL from the originating LS to the originating LTN, one for the originating LTN, and r for TL from the terminating LTN and the terminating LS. In addition, $2s$ additions are required corresponding to TL and TN (including terminating LTN) between the originating and the terminating LTN. Consequently, the number of additions $y(s)$ is $2s + r(2r + 1)$.

Direct method. One each addition is required corresponding to passed TN and TL for each originating LS and terminating LS. Consequently, the number of additions $y(s)$ is $(3 + 2s)r^2$.

(2) Circuit network

To calculate the number of additions in the counter in the circuit network, the topology of the circuit network must be assumed. In the following, the simple case is considered as in Fig. 10 where TG are placed regularly between SW (for simplicity, grouping of SW described in section 3.2 is not considered). In other words, serial numbers are given to SW of each TN and TG is placed from SW_i to $SW_i \sim SW_{i+d-1}$ of the adjacent TN. From each LS to the set of SW of LTN, TG are placed so that the traffic is assigned equally, as is shown in Fig. 10. Figure 10 is the case of $k = 4$ and $d = 2$.

In the following, one SW in the originating LTN is considered. Let the number of SW in the j ($j = 0 \sim s$)-th TN which is reachable from that SW be α_{j+1}. $j = 0$ corresponds to the originating SW itself, and $\alpha_1 = 1$. Then, one of the LS is considered. Let the number of SW in the j ($j = 1 \sim s + 1$)-th TN, which is reachable from that LS be β_j.

(a) When the originating and terminating LTA are the same

In both aggregating and the direct methods, the number of additions is d times that of the traffic network.

(b) When the originating and terminating LTA are different

Aggregating method. For each LS, d time larger number of additions of the traffic network is required corresponding to TG between the originating LS and the originating SW. Then, consider one of SW in the originating LTN. One each addition is required corresponding to TG and SW (including the terminating SW) passed by the traffic from that SW to the terminating LTN. The total number of additions is given as $2d(\alpha_1 + \cdots + \alpha_s)$. To assign the traffic flowing into α_{s+1} SW of the terminating LTN to the terminating LS, there must be $\alpha_{s+1}r + r^2$ additions. In the foregoing, the second term is needed for the calculation of the terminating LS ratios described in section 4.2. Thus, the number of additions $y(s)$ given by

$$r(r+1)d + k\left(2d\sum_{j=1}^{s}\alpha_i + \alpha_{s+1}r + r^2\right)$$

Direct method. For each originating and terminating LS pair, one each addition is required corresponding to the passed SW and TG. Consequently, the number of countings $y(s)$ is given by

$$\left(2d + 2d\sum_{i=1}^{s}\beta_i + \beta_{s+1}\right)r^2$$

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