Fundamental Plans for Toll Telephone Plant

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This paper covers the general switching plan and fundamental plant layout proposed for handling telephone toll messages throughout the United States and Canada using automatic toll switching.

There has been rapid growth in the number of telephones and in the volume of toll traffic, particularly long haul. Toll facilities are provided under fundamental plans, an essential part of which is a toll switching plan for setting up connections quickly between any two telephones. The introduction of mechanical operation and the general improvement in the transmission performance of the communication plant over a period of years make the introduction of certain modifications in the fundamental plans possible and advantageous at this time. The important new features and the service improvements which are provided by the proposed plans are outlined in this paper. The principal types and characteristics of circuit facilities available for use in the intertoll network are also described.

GENERAL ASPECTS OF TOLL SWITCHING PROBLEMS

Switching plans providing for the systematic routing of toll telephone traffic have been employed by the communication industry for many years. These plans have contributed directly to the high quality of long distance telephone service enjoyed by the public in the United States and Canada. This generally excellent service is the result of the cooperative work of many organizations including the Bell Operating Companies, many independent connecting Companies and others in the United States as well as in adjoining countries. The techniques employed today reflect a great amount of research and engineering and improvements in manufacturing skill and in construction, maintenance and operating methods developed over a period of many years.

Throughout the United States and Canada there are approximately 20,000 different places – cities, towns, and villages – that serve as toll connecting points. The telephone offices in each of these places have access through the toll network to practically all of the 50,000,000 telephones in the United States and Canada and also to most of the telephones in the rest of the world. Currently the Bell Operating Companies are handling toll calls at an average rate of over 7,000,000 during a business day. The many millions of different connection possibilities which this number of calls involves require a definite and comprehensive switching plan.

Whenever practicable and economical direct circuits are used to handle toll message traffic between two given points. Much of the traffic in the country is handled this way. However, a substantial volume of business, about 20 per cent, is handled as a matter of economy, by switching toll circuits together. Although the volume of traffic between different points may vary over a wide range, it is nevertheless important that adequate service be provided for all possible connections. For example, there are about 110 circuits from Chicago terminating in the toll office serving Minneapolis and St. Paul. These handle about 5500 calls per day. On the other hand, only a few calls a year may be involved between some point in Western Minnesota and a point in Florida. The switching plan described in this paper is devised for the purpose of efficiently and effectively establishing connections between any two points regardless of their separation and regardless of whether traffic volume be a few calls per year or many calls per hour.

ELEMENTS OF THE PROBLEM

In order to illustrate the problem a specific example may be useful. Fig. 1 is a map of Wisconsin and Minnesota on which nearly 1200 circles indicate points at which exchange facilities may be connected to the toll network. The extent of the coverage in this area is typical of that found throughout the country.

The 150 odd larger circles represent existing offices known as "toll centers" – that is, places where operators record toll calls and perform other operations necessary to establish toll connections. These places have switching arrangements of various types depending on how they fit into the switching plan. Some may operate as control switching points in the nationwide plan as described later.

More than 1,000 smaller circles on the map represent "tributaries" – that is, towns where little or no toll operating is done. Toll connections to and from these points are completed at the toll centers which in general do the toll operating required.

In the United States and Canada as a whole, there are approximately 2,600 toll centers. The remainder of the toll connecting points—about 17,500—are tributaries.

Fig. 2 gives an idea of the variety and complexity of the network of circuit groups required to interconnect the toll centers in one area. Here each line represents a group of circuits, known as "intertoll trunks," between two toll centers. Each group may contain anywhere from one to several dozen trunks. The location of the lines on the map is unrelated to the geographical routing of the trunks, and only a part of the circuit groups are shown. To get a complete picture one should visualize that a cluster of relatively short circuit groups radiates from each toll center to its tributaries, of which there may be up to 15 or more.

Physically, the plant consists of a network of open wire lines, cables and radio systems. On these, voice frequency or carrier operation is employed in each section as required to provide the necessary intertoll trunks. The routes of the lines in Minnesota and Wisconsin are shown by Fig. 3. In this area there are no radio routes carrying telephone circuits, but a radio system between Chicago and Minneapolis is in the planning stage.

Areas like Wisconsin and Minnesota must, of course, be connected together, and Fig. 4 shows the major Bell System toll routes that accomplish this. On a map of this kind it is not possible to include anything like the detail shown in Fig. 3. One must visualize, therefore, that each state contains a network of routes generally comparable to those shown for Wisconsin and Minnesota.

This then represents the interconnection problem to be met by an orderly switching plan that will provide efficient, reliable and fast toll telephone service between any two points.

EARLIER TOLL SWITCHING PLANS

Very early in the telephone industry it became evident that: (1) There must be a plan for connecting circuits together. (2) Switching centers with suitable equipment must be established in accordance with this plan. (3) Trunks must be provided in adequate numbers to connect every place to one or more switching centers and to interconnect the switching centers. (4) All this must be done in a way that makes it possible to provide good service at reasonable cost.

As time went on, early plans crystallized into what became known as the General Toll Switching Plan. A paper presented at the summer convention of the A.I.E.E. in Toronto in 1930 by Dr. H. S. Osborne outlined the principles of this comprehensive plan for handling telephone toll traffic in the United States and Eastern Canada.[1] It involved two classes of major switching centers – Regional Centers and Primary Outlets – and some classes of less important centers. It also set up methods of designing toll trunks to give adequate transmission efficiency on all possible toll connections. In use for the last two decades this basic plan has been of great value in accommodating the tremendous growth of telephone toll business during this period.

SWITCHING PLAN FOR NATIONWIDE TOLL DIALING

The earlier general switching plan was based on manual switching and on a toll plant made up for the most part, of voice frequency circuits. The probability of operating irregularities and delays increases with the number of manual switches in tandem. Likewise, the transmission problem of operating many voice frequency trunks in tandem was so formidable that the number of intertoll trunks in tandem had to be limited to five. In practice, switching was avoided where practicable and economical.

Impact of Mechanization and Improved Transmission Facilities

On the other hand, mechanical switching is very fast and is designed to be practically free of operating irregularities. Delays can be minimized by fast switching to alternate routes. Also, in the last two decades the use of carrier has grown from a relatively minor place in the toll plant to the point where it is now commonplace.[2] Carrier provides superior transmission performance. Limitations on switching are thus greatly reduced and economies are achieved under many conditions.

In addition, mechanization of local switching systems has proceeded rapidly. With mechanized toll switching, it is becoming possible to establish many toll connections with only a single toll operator and in some cases by customer dialing, without the assistance of any operator.[3, 4]

Along with these developments has come tremendous growth in traffic. Since 1930 toll messages in the Bell Operating Companies and the Bell Telephone Company of Canada have more than trebled, growing from an annual volume of about 650 million to about 2 billion. Intertoll trunks over 25 miles in length have increased in number from about 28,000 to about 100,000. This continuing growth in traffic volume has required a large scale development of plant facilities and has permitted a more extensive use of carrier than would have been practicable with a slower rate of growth.

Consideration of these factors which offer an opportunity to improve service has led to the gradual reorientation of the fundamental plans for the intertoll trunk plant which is now under way.

The New General Toll Switching Plan

Mechanization of switching and the use of improved transmission instrumentalities permits the design of the switching plant to be controlled primarily by the balance between the costs of transmission facilities and of switching facilities.

The new general toll switching plan contemplates as many as eight intertoll trunks in tandem on the most complex connections to be established. These eight trunks can be interconnected at switching points as described later. The plan further contemplates that wherever possible, the traffic will by-pass intermediate switching points. The number of switches that can be avoided depends on the volume of traffic between the two points concerned and on the traffic load at the time the connection is established.

The proposed plan provides a systematic grouping of switching points. Under this arrangement, each ordinary Toll Center (TC) serves a cluster of nearby tributary points and has trunks to a "home" Primary Outlet (PO) which serves a cluster of toll centers. In some cases it appears practicable to utilize a simplified switching system at a PO, and in order to distinguish this type of center it has been designated a Tandem Outlet (TO). In turn, each PO or TO has trunks to a "home" Sectional Center (SC) which serves a section of the country varying in size from part of a state to all of several states depending on the density of the population. Similarly, The United States and Canada are divided into nine regions, each having a Regional Center (RC) serving as a central switching point for all sectional centers in the region. One of these RC's (St. Louis) is termed the National Center (NC). All of the higher orders of switching centers also act in the capacity of each of the lower centers. For example, any specific SC also acts as a PO and as a TC.

This arrangement is illustrated in Fig. 5, which covers approximately the same area as Fig. 1, portraying the toll connecting routes. Hibbing, Minnesota, is shown as a representative toll center with the tributaries it serves. It is in the service area of the Duluth Tandem Outlet, the approximate boundaries of which are indicated. Duluth lies in the Minneapolis "section," which includes a large portion of Minnesota, and is

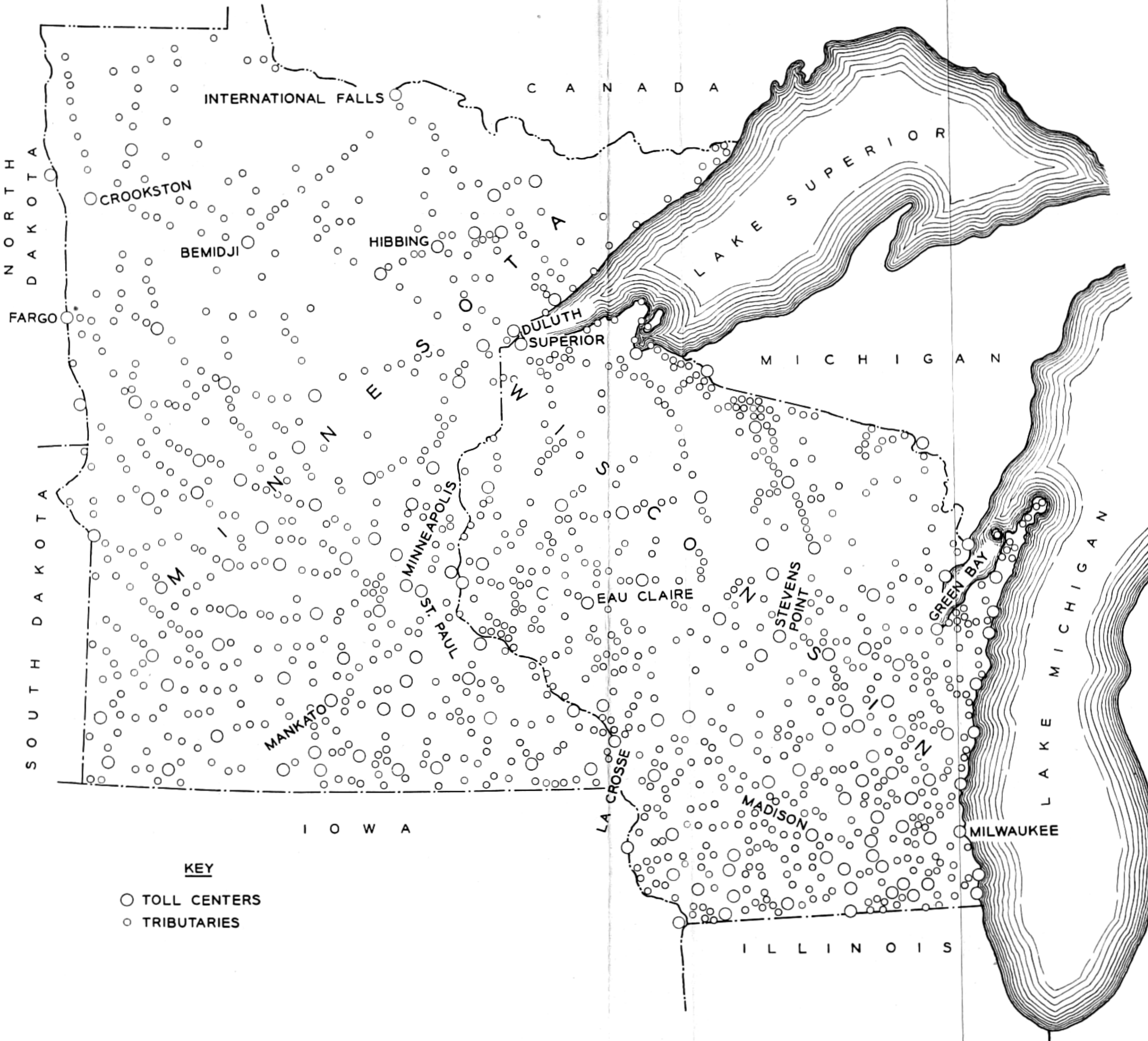

Fig. 1—Toll centers and tributaries in Minnesota and Wisconsin.

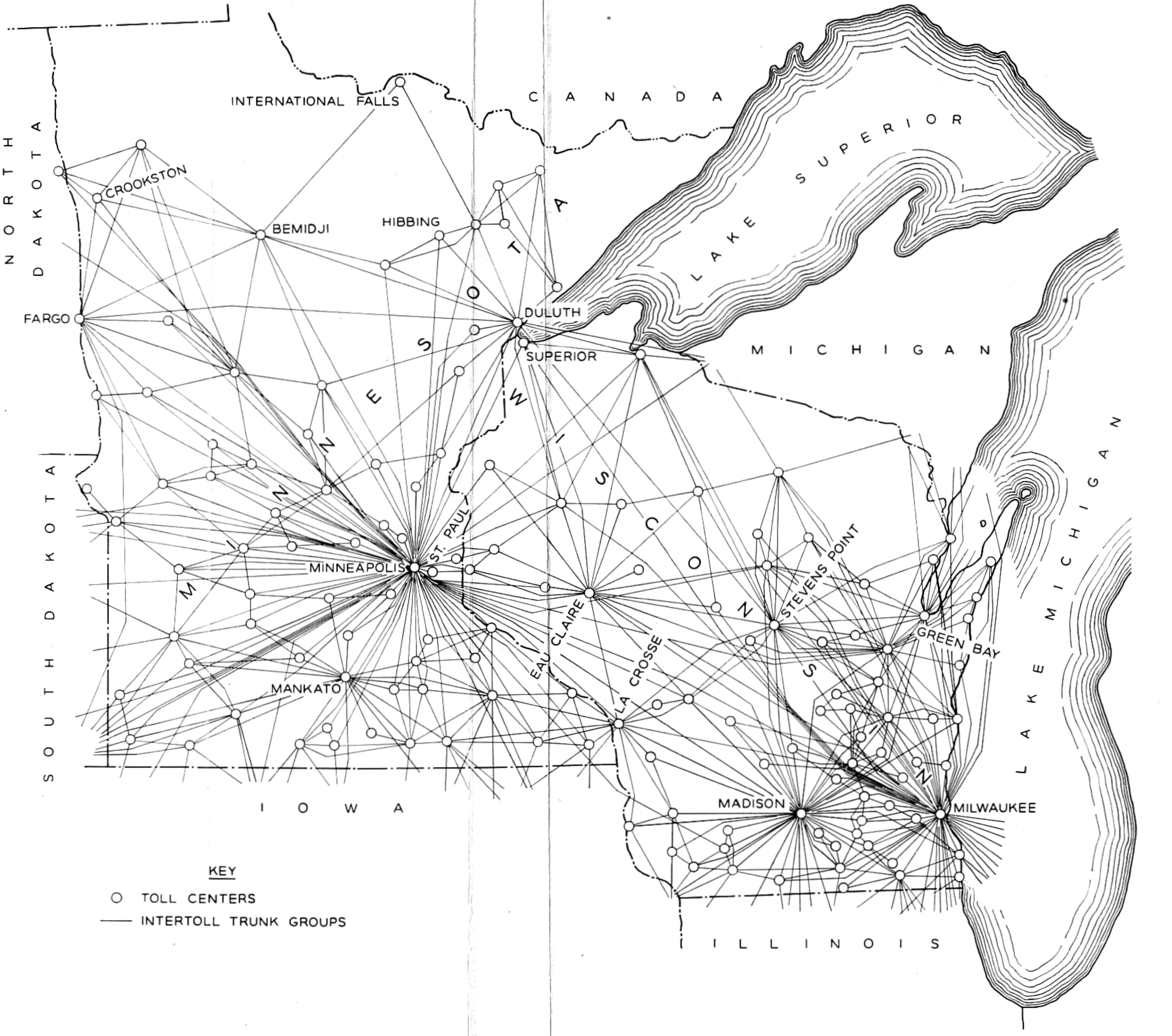

Fig. 2—Principal intertoll trunk groups in Minnesota and Wisconsin.

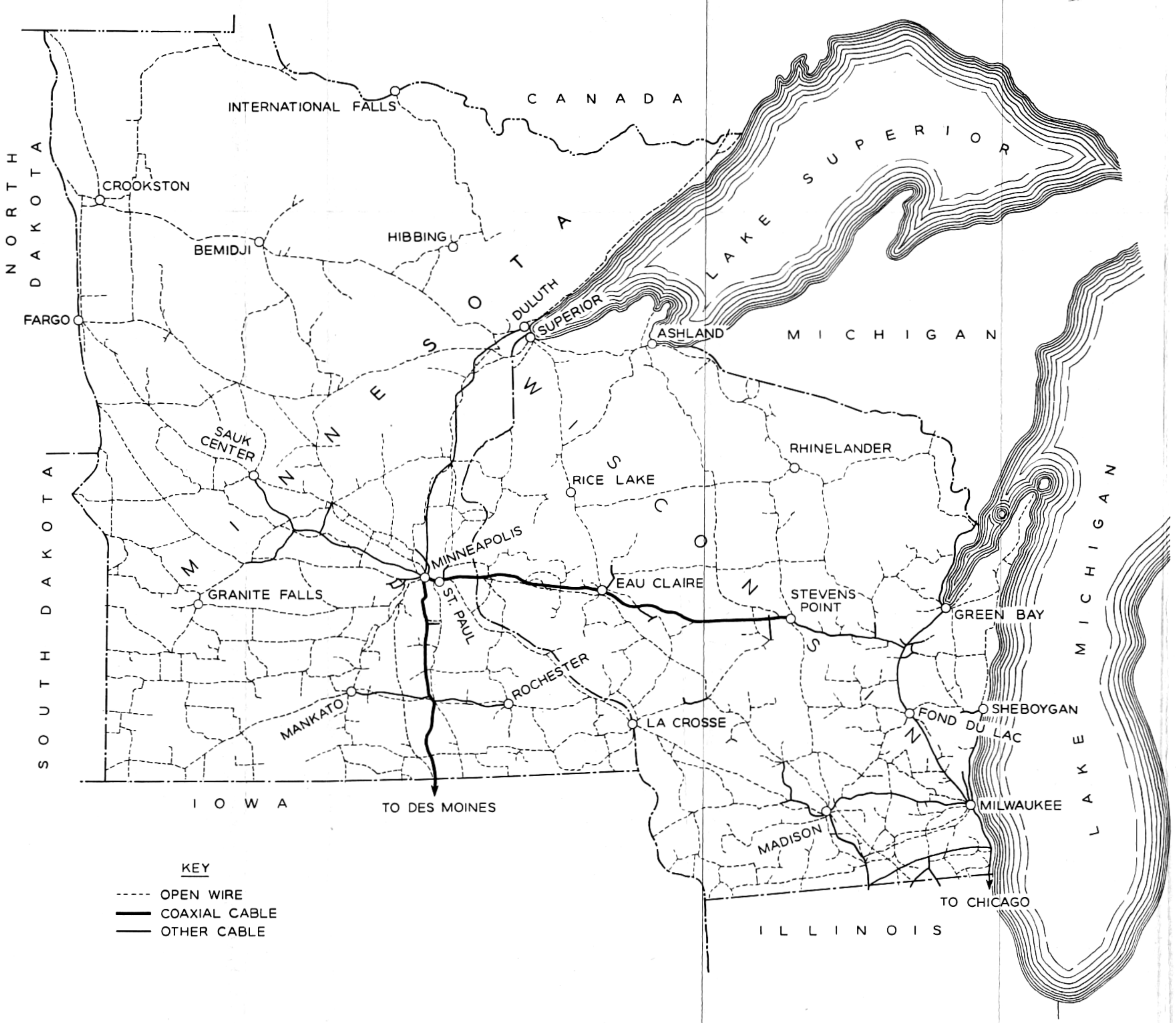

Fig. 3—Bell System telephone toll routes in Minnesota and Wisconsin.

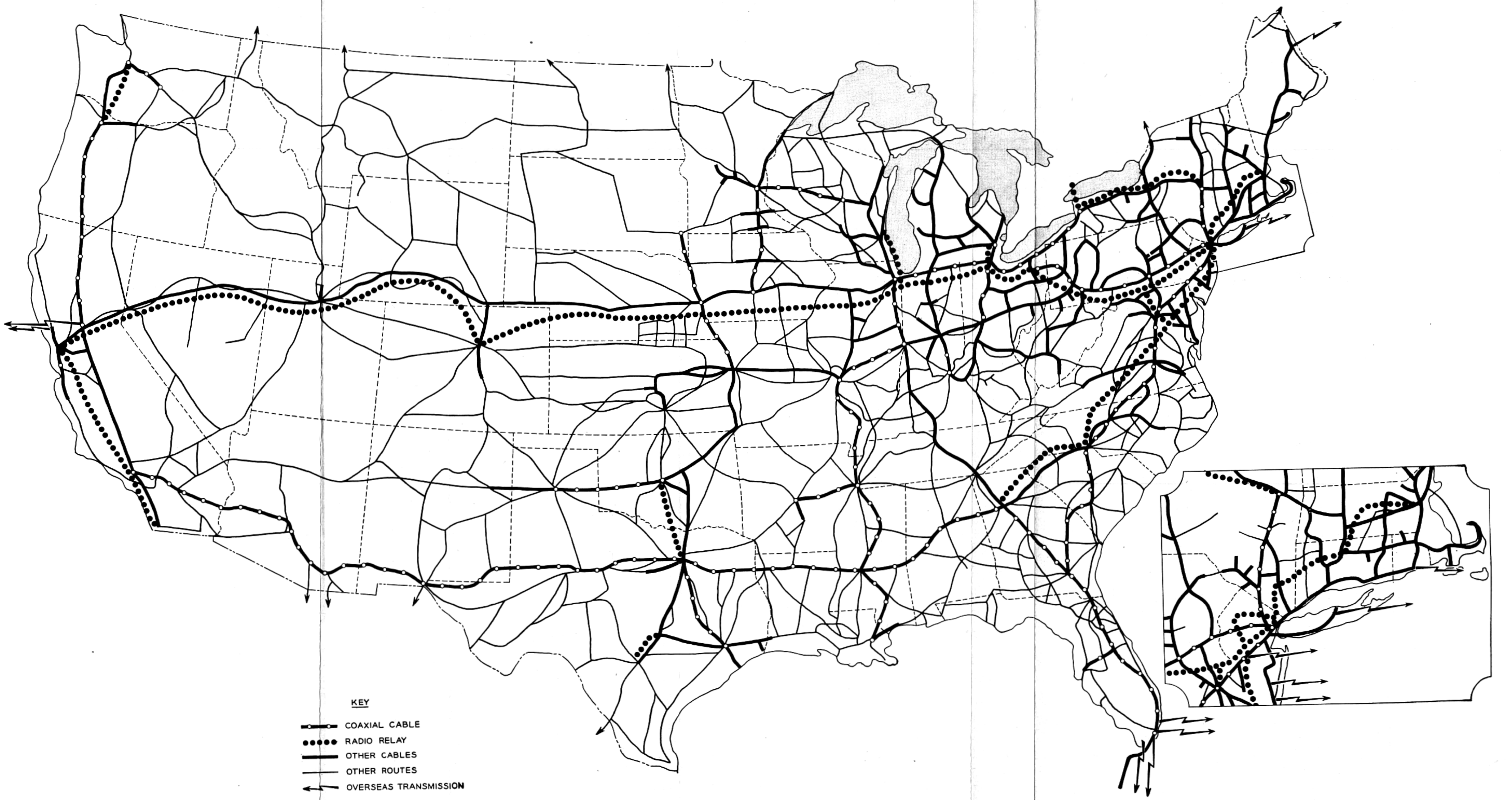

Fig. 4—Principal toll routes of the Bell System.

in turn one segment of the Chicago "region" which serves a somewhat larger area than shown by Fig. 5.

Under this arrangement, toll calls between two tributaries in the Hibbing toll center area can be completed by switching at the toll center. In a similar manner, any two points within the Duluth tandem outlet area can be served by switching at Duluth. The same treatment also applies for connections between any two points in the same sectional center area or in the same regional center area. For example, a connection from Hibbing to any point within the Chicago region (which involves more than six states as shown in Fig. 7) requires no more intertoll links than Hibbing to Duluth, Duluth to Minneapolis and Minneapolis to Chicago, and a corresponding number of links on through to another sectional center, and primary or tandem outlet to the toll center destination. Circuits between the toll center and tributaries are not referred

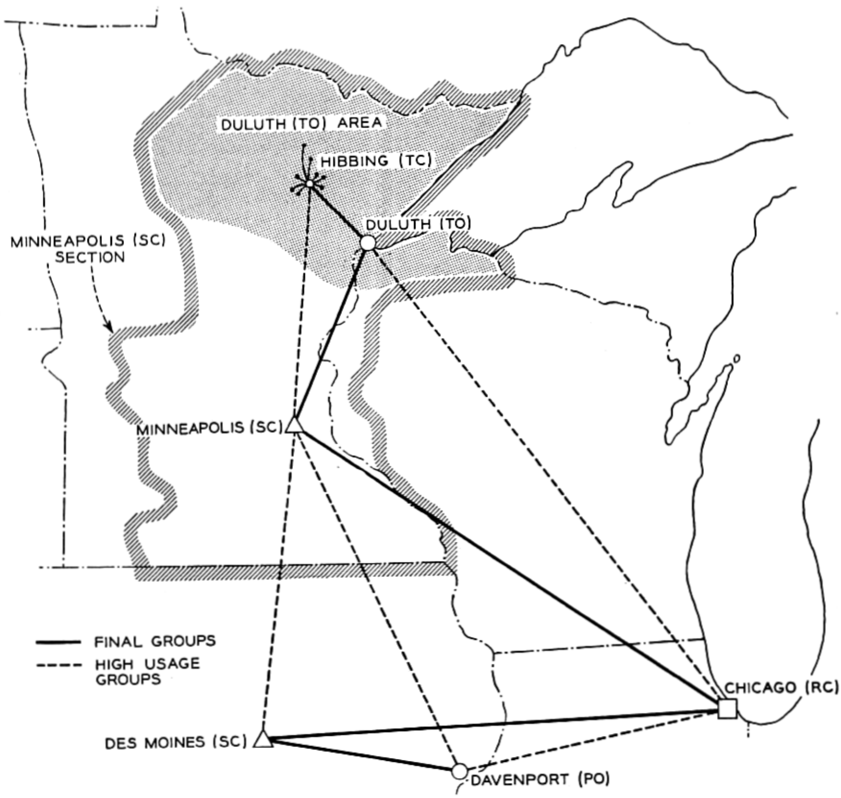

Fig. 5—Intertoll trunks between Davenport, Iowa and Hibbing, Minnesota, showing alternate routing possibilities.

to as intertoll trunks or lines but are classed as toll connecting trunks.

Where the volume of traffic warrants, direct circuits may be provided to by-pass the intermediate switching points included in the preceding example. Once such direct circuit groups have been established, it is economical and advantageous from a switching standpoint to take advantage of their existence, using routes that involve a minimum number of switches. The basic routing plan is used when the more direct circuit combinations are busy.

These routing arrangements contemplate the application of "high usage" and "final" trunk groups as an integral part of the plan. The "high usage" groups are direct groups which by-pass the higher order switching points wherever the routing of the call permits. These "high usage" groups can be engineered to carry high loads per circuit, with an adequate number of circuits in the "final" groups to take care of prac-

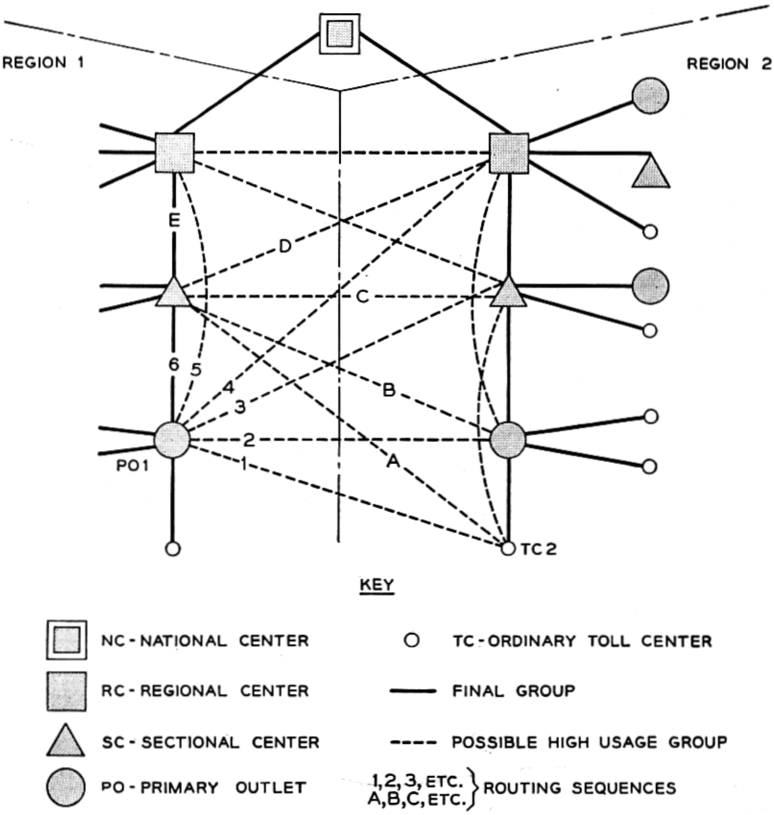

Fig. 6—Illustration of intertoll routing pattern between two regions.

Fig. 7—Tentative locations of control switching points in United States and Canada.

tically all overflows from the high usage groups during the heavy traffic periods. The "high usage" and "final" groups which could be used for routing calls between Hibbing, Minnesota and Davenport, Iowa are shown by Fig. 5.

Generalization of the Toll Switching Plan

The generalization of the arrangements discussed for the Chicago region is illustrated in Fig. 6. This shows diagrammatically all types of switching points in two regions and also indicates the relative position occupied by the National Center in the switching plan. On this chart, the solid lines represent the "final groups" of trunks, and the dotted lines represent "high usage" trunks. Examination of this chart will indicate that the mechanical switching system need perform only relatively simple toll switching operations at the toll centers. At other points the system must attempt to complete the call over the most favorable routes, in planned sequence, until the "final" route is selected.

For example, from a given primary outlet such as PO1 on a call destined for a toll center in the other region such as TC2, the switching equipment would attempt to complete the call, in sequence over the routes marked 1 to 6.

Should Route 6, which is the "final" route, be selected because all of the trunks in the "high usage" groups marked 1 to 5 were busy at the time, the switching equipment at the SC would in turn try routes marked A, B, C, etc., in attempting to complete the call. A fairly complete pattern of circuit groups is indicated in this illustration. Depending on the relative locations of the points concerned and the traffic load requirements, certain of the "high usage" groups shown may not exist. It is expected, however, that most TC's will have high usage groups to points other than their "home" PO's. Also each PO can be expected to have high usage groups to sectional centers other than its "home" SC. All regional centers will be interconnected with direct trunks, regardless of geographical location.

Control Switching Points

Because of rapid and complex switching operations required by the automatic equipment at PO's and higher order switching points, (SC's, RC's and the NC) these switching centers are called Control Switching Points (CSP's).

As covered by a companion paper,[5] the switching equipment required at the CSP's is quite complex. This equipment must have a high degree of built-in capability to perform quickly the circuit selection work associated with the alternate routing features of the switching plan. In addition, to help provide the transmission margins needed for satisfactory operation of the plan as contemplated, it must be arranged to connect circuits on a four-wire basis rather than on a two-wire basis, the latter being the arrangement used at most toll centers. The switching equipment at a CSP must not only provide for connecting one toll circuit to another; it must also perform the very important function of tying the toll networks which serve limited local areas together so that collectively they work as a smoothly functioning nationwide system. This becomes practicable when there is coordination between the design of the individual limited networks and the design of the overall system.

The location of control switching points indicated by the nationwide plan is shown in Fig. 7. This also indicates the home switching center of higher order associated with each switching point. As the number of CSP's increases, the cost of the toll circuit plant decreases because each CSP can then be located closer to the cluster of ordinary toll centers which it serves. However, because of the cost of the CSP equipment, it is necessary to weigh the cost of circuit facilities with the equipment costs in a way that will result in the minimum overall cost. Certain of the smaller Primary Outlets are being studied with the view of reclassifying them as Tandem Outlets (TO's). A Tandem Outlet occupies the same relative position in the switching plan as a Primary Outlet but is not a control switching point. The switching equipment employed is less complex than that used at control switching points and therefore provides for only limited alternate routing and does not have all the advantages of four-wire transmission.

Effects of Customer and Operator Toll Dialing

Customer dialing of short-haul toll calls has been in use, particularly in metropolitan areas, for some years. A trial of long-haul customer dialing over the intertoll trunk network and through the switching equipment provided for operator toll dialing was instituted at Englewood, New Jersey, in the Fall of 1951. The local equipment includes automatic message accounting and permits Englewood customers to dial directly to about eleven million telephones in ten metropolitan areas across the country. A trial installation of customer toll dialing, utilizing automatic message accounting equipment on a centralized basis rather than at each local office, is planned for Washington, D. C., in the Fall of 1953. Initially customers will dial toll calls within the Washington metropolitan area and to such points as Baltimore and Annapolis. The favorable results and general acceptance of the trial at Englewood indicate extensive application of customer dialing of toll calls as conditions warrant.

The general introduction of customer toll dialing as this becomes desirable will affect the number and location of ordinary toll centers since calls handled by operators may be limited to assistance calls and to person-to-person, collect and others which cannot be customer dialed. Indications are that toll operation for a number of smaller centers can be combined as the local service is converted to dial operation with operator toll dialing.

Studies now in progress indicate that the number of toll centers may be reduced by one half or more over a period of years in many areas.

Reactions on Toll Plant Layout

The expanded general toll switching plan for nationwide dialing contemplates a degree of alternate routing far in excess of that used with the former switching plan designed for manual operation. This change along with the reduction in toll centers will have a marked effect on the normal flow of many traffic items through the intertoll network. As a result the arrangement of the present intertoll trunks will be significantly modified both in number, routing and terminating points. It is necessary to take these facts into account in engineering toll plant additions so that they will lead toward an advantageous layout for future nationwide dialing as well as meet the needs of the more immediate future. Fortunately, the effect is in the direction of greater concentration of circuits in main routes so that with the new cable and radio facilities available, over-all economy and better service should result.

TYPES OF TRANSMISSION FACILITIES USED AND INCLUDED IN SWITCHING PLAN

The domestic toll network is an outgrowth of the demands of the business and the advance in communication technique over many years. At present, about 100,000 intertoll trunks over twenty-five miles in length and many thousand shorter toll trunks are in service throughout the country. They are provided generally by voice frequency or carrier frequency facilities. The choice of transmission facility on a given route is dependent on a number of factors, such as cost, length of haul, number of trunks in the cross-section, numbers of trunks to be terminated at intermediate points, the types of terrain to be transversed, storm and

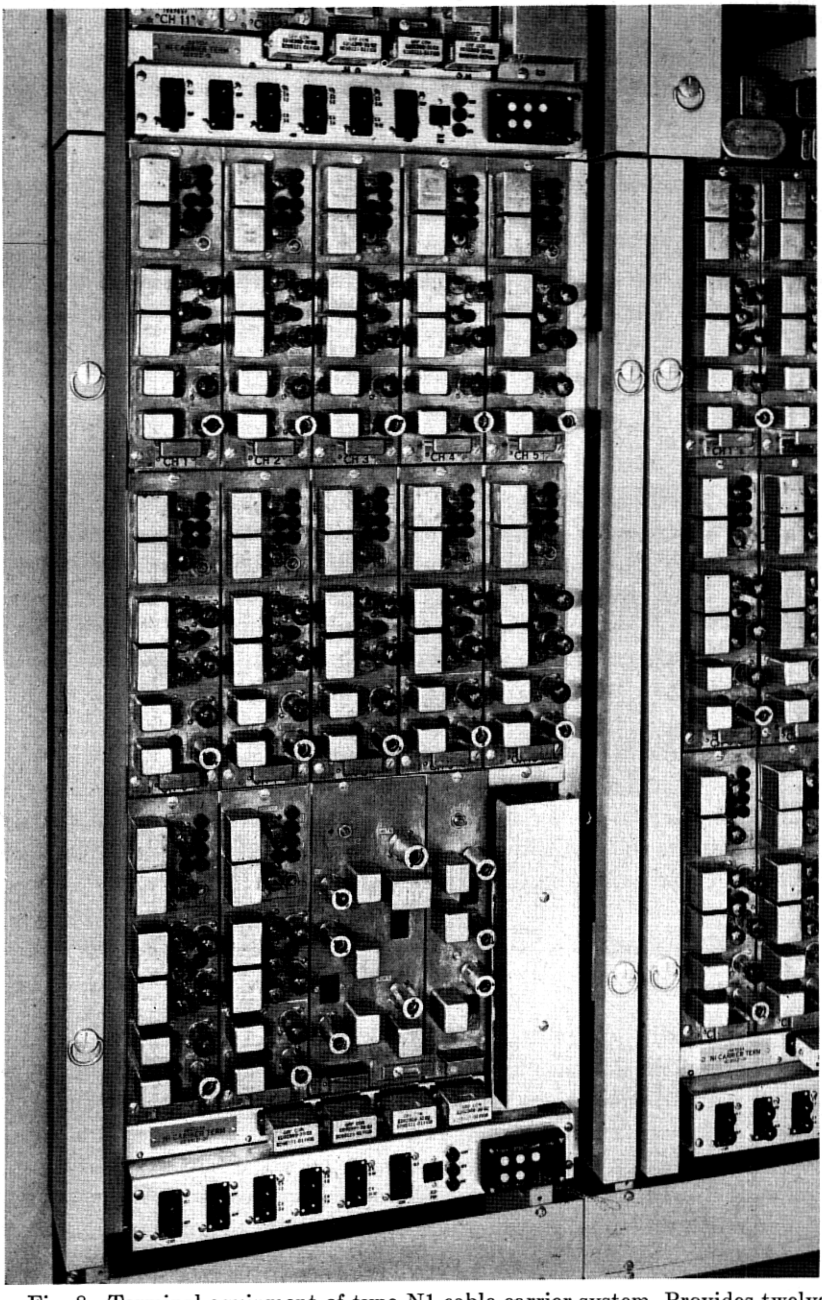

Fig. 8—Terminal equipment of type-N1 cable carrier system. Provides twelve message channels with self contained signaling equipment over two pairs of cable conductors in same sheath.

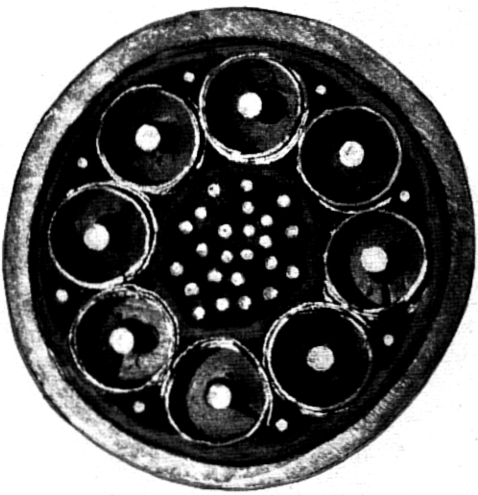

Fig. 9—Coaxial Cable. Cross section of cable containing four pairs of coaxials. Each pair can accommodate one two-way coaxial carrier system.

other conditions affecting service continuity and the transmission requirements of the circuits to be provided.

Voice frequency facilities equipped with repeaters as required are used on both open wire lines and cables. At voice frequencies it is customary to derive three trunks known as a phantom group, from two pairs of open wires or from one "quad" (two pairs) of loaded cable conductors. In general the use of voice frequency facilities is now limited to shorter circuits.

Considerations of economy and service improvement led to the introduction of carrier operation into all types of toll plant as rapidly as the state of the art permitted. This directly affects the toll switching plan from the standpoint of routing and location of switching centers.

At present, carrier systems use four broad categories of facilities: open wire, conventional paired or quadded cables, coaxial cable and radio.

Several types of open wire carrier systems permitting from one to fifteen telephone channels above the frequency band of the voice channel are now in use. In general these systems are used where trunk cross-sections are relatively small and where the terrain and weather conditions make open wire lines economical.

Cable carrier systems at present permit the operation of up to twelve telephone channels on two pairs of cable conductors. These conductors may be in one cable or divided between two separate cables, depending

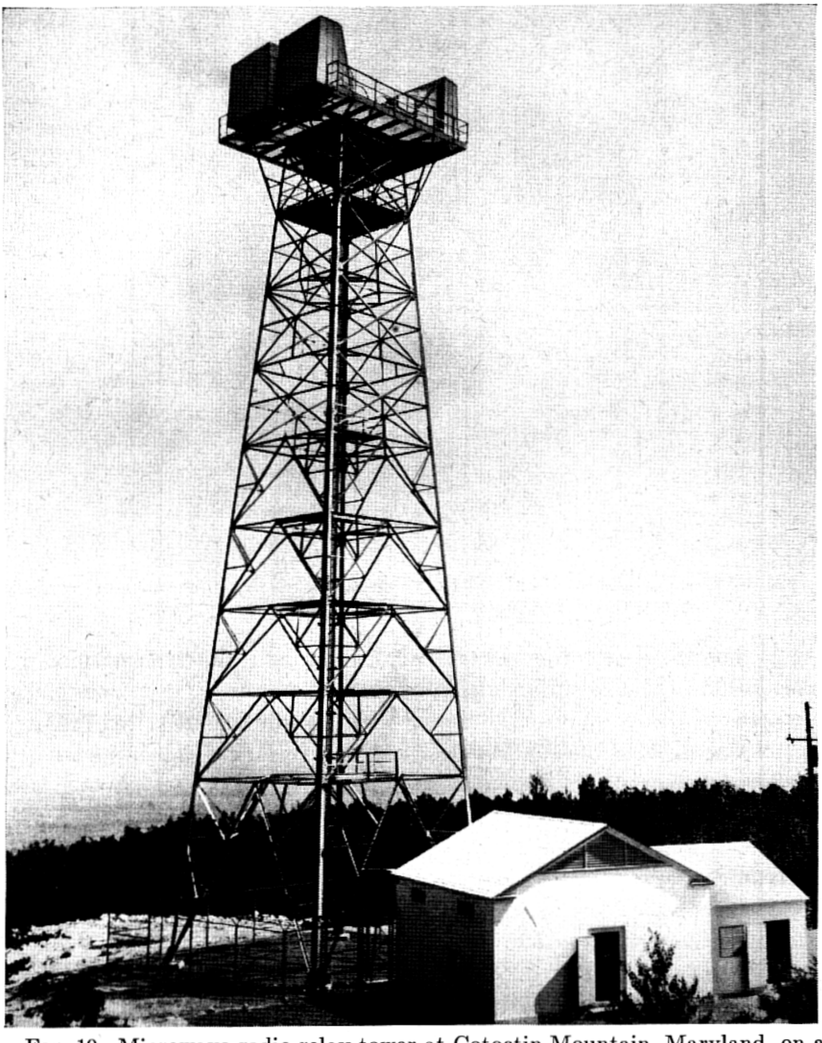

Fig. 10—Microwave radio relay tower at Cotoctin Mountain, Maryland, on a New York–Washington radio route. There are 300 message circuits in service with more planned.

on the type of carrier system (Fig. 8). Coaxial cable transmission systems currently provide up to 600 telephone channels per pair of coaxials (Fig. 9). A new coaxial system, under development, is expected to produce about 1,800 telephone channels per pair of coaxials.

Most of the applications of radio for toll telephone service now contemplated, involve the use of point-to-point microwave systems. By employing channeling equipment at the terminals of these systems similar to that used for the present coaxial system, each pair of radio channels may provide up to 600 telephone channels. Several pairs of such radio channels may be operated through the same antennas (Fig. 10).

Radio systems are also useful in some cases where the number of toll trunks required is moderate, where diversity is desired or where water or other natural barriers make the provision of wire circuits difficult or impracticable.

The type of facility to be used on a particular route is sometimes affected by requirements for other services such as teletypewriter, television network facilities, program facilities, private lines and other factors.

Trend to Carrier Type Facilities and Advantages to Toll Switching Plan

About 70 per cent of the long haul toll message mileage in Bell Operating Companies is provided on carrier type facilities as contrasted with 7 per cent in 1930 (Fig. 11).

From the transmission standpoint, carrier facilities offer marked ad-

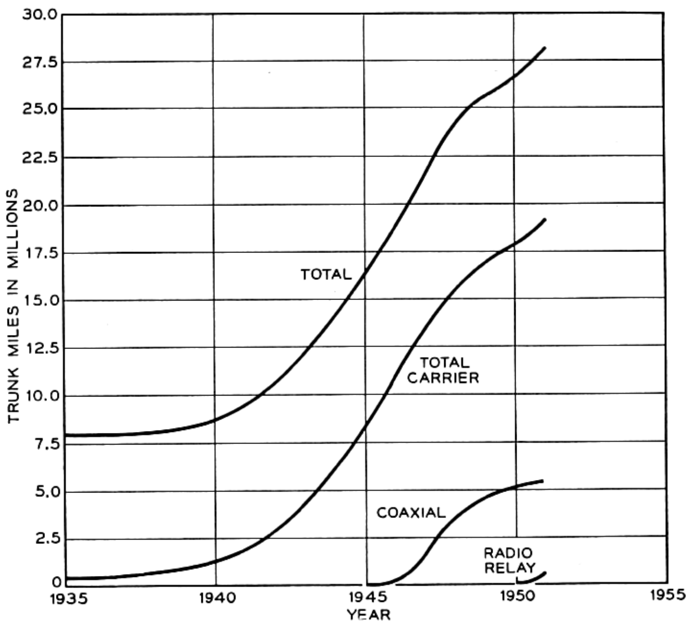

Fig. 11—Growth in Bell System intertoll trunk mileage showing trend toward more extensive use of carrier type facilities.

Fig. 12—Toll switchboard position with key set used for toll dialing.

vantages. They are inherently of the "four-wire" type which minimizes the number of possible singing and echo paths on a circuit. Also, the speeds of propagation over carrier systems are generally higher than over voice frequency systems thereby further minimizing the echo problem. These features are of great advantage in reducing limitations on circuit design and layouts of the general toll switching plan.

Signaling Systems

In addition to the ability to carry messages, intertoll trunks must be provided with suitable signaling facilities.[6, 7] These must provide a means of: first, attracting the attention of the distant point, either an operator or automatic equipment, to the fact that a connection is to be established; and second; in the case of dial operation, transmitting coded information in the form of pulses for establishing the connection; and third, transmitting a general class of supervisory signals including connect and disconnect signals, on and off switch hook signals, recall signals and busy signals which are essential to the efficient operation of the switching plant. The circuit design contemplated in the overall plan must take into account this requirement for transmitting signals as well as speech, to obtain accuracy and speed in setting up and taking down connections.

TRANSMISSION DESIGN ASPECTS OF CIRCUITS FOR NATIONWIDE TOLL DIALING

The more extensive use of alternate routing together with the increase in maximum possible number of trunks in tandem associated with nationwide toll dialing, tends to increase the problems of assuring adequate transmission of speech and signals on all possible connections. On the other hand, the use of four-wire switching at important points and the definiteness of the routing patterns permit more effective use of the available facilities and thus tend to simplify the problem. Extensive studies indicate that on the whole, the new toll switching plan will make feasible still further improvements in transmission. This is, of course, a desirable objective.

Transmission Design of Trunks

With dial operation, the number of trunks in tandem in a given toll connection may vary on successive calls. To avoid undesirable transmission contrasts and other adverse effects, it is important that every trunk be designed to operate as closely as possible to the theoretically correct transmission loss. The problem is complicated by the fact that the extent to which the echo, noise and crosstalk will limit the performance of an individual link is not directly proportional to the length of the circuit. In fact, the minimum loss at which a particular circuit used singly or in various built-up combinations can theoretically be operated depends on the number, length and characteristics of the other circuits connected in tandem with it. Arrangements for precisely adjusting the loss in the individual trunks for each call would be complicated. Adequate performance can be achieved however by compromise methods which provide for automatic adjustments in the loss of each trunk in accordance with the following:

1. When a trunk is switched to other intertoll trunks at both ends it is operated at the minimum loss practicable. This loss is known as "via net loss." (VNL)
2. When the trunk is switched to another intertoll trunk at one end only, the loss is increased two db.
3. When the trunk is not switched to another intertoll trunk at either

end a further loss of two db is added. This loss which is four db greater than the via net loss is known as "terminal net loss." (TNL)

The data and methods used in the derivation of the via net loss are rather complex and not within the scope of this paper.

Assignment of Facilities Among Trunks

The definite routing patterns established for the toll machine switching operation impose more severe transmission conditions on certain classes of circuits than on others. For example, a trunk in a "final" group between a TC and a PO can become involved in an eight-link connection, whereas a trunk in a "high usage" group, say, between a PO and another PO will not be involved in more than a three-link connection.

This creates a need and provides an opportunity for allocation of the available facilities among the various trunk groups in a way that will provide the best overall service. For example, to the extent practicable it is desirable to assign carrier grade facilities to trunks in "final" groups that may be involved in connections with the maximum number of links. Facilities with less favorable transmission characteristics may then be reserved for trunks in groups that are used for connections involving fewer links.

TRANSMISSION PERFORMANCE

Table I shows the approximate range of transmission losses between toll centers under the manual plan compared to ranges that appear practicable under the proposed fundamental plan, which, of course, permits more links in tandem.

Trunk Transmission Stability

It is as important that the transmission loss of a trunk used in the contemplated toll dialing network be maintained at or close to its assigned value at all times as that the assigned value be right. On multi-switched connections even a relatively small consistent excess or deficiency in the loss in the individual trunks can accumulate to overall excesses or deficiencies in loss large enough to cause difficulty – by making it hard for people to hear if the attenuation becomes too great or by creating excessive echo, crosstalk or noise if the loss becomes appreciably less than normal.

This subject has been extensively studied for the past several years and it appears that some changes in practices and the introduction of

TABLE I—APPROXIMATE RANGE OF LOSSES BETWEEN TOLL CENTERS IN DB

No. of Links in Intertoll Connection	Manual Plan	Proposed Plan
1	4–12	4–8
2	8–14	5–12
5	9–20	6–13
8	—	7–13

new methods of measuring results will lead to marked improvements. It is of some interest that one of the major factors in securing improvement appears to be the application of a statistical method of evaluating performance along somewhat the same lines as the "quality control" methods used in other fields of industry.

Since, with operator toll dialing only one operator is involved in many connections and with customer toll dialing there is no operator on the connection it is extremely important that everything be right. This is typical of the requirements of any large scale "push button" operation (Fig. 12).

CONCLUSION

The fundamental plans proposed for Telephone Toll Switching provide a basis for the progressive mechanization of toll service. The installation of suitable switching mechanisms at Control Switching Points and the provision of toll trunks utilizing the new instrumentalities will implement the toll switching plan. The plan is sufficiently flexible to adjust for changes in the telephone art as they develop. Also, the plan can fit in with the requirements of those Companies whose plants connect with the Bell operating network should they desire to arrange for operator or customer toll dialing.[8]

Average speed of service will be improved. The flexibility in plant design inherent in the new toll switching plan will increase service security and improve the utilization of the entire toll plant. In addition, adequate provision is made for the progressive introduction of customer toll dialing as this becomes practicable and desirable.

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