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Common Channel Interoffice Signaling:

Implementation Planning

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To introduce Common Channel Interoffice Signaling (CCIS) into the toll network as rapidly and economically as possible, a great deal of planning had to be done. An analysis was performed to determine which 4A-ETS (Electronic Translation System) offices should be converted to CCIS and the order of this conversion. Practical feasibility constraints also had to be considered. This analysis was followed by coordination with AT&T and the operating companies which resulted in a plan to convert about thirty 4A-ETS switching offices per year to CCIS in 1977, 1978, and 1979. In addition, all No. 4 ESS offices are CCIS-equipped and No. 1(A) ESS will be CCIS-equipped by 1978. The result is that by 1980 more than a hundred toll offices will have CCIS capability.

I. INTRODUCTION

Common Channel Interoffice Signaling (CCIS) is being rapidly introduced throughout the toll network of the Bell System. At present, CCIS is part of every No. 4 ESS office, and many existing 4A crossbar offices with Electronic Translation System (ETS) are being converted to CCIS. In addition, CCIS is being developed for No. 1 ESS and No. 1A ESS toll switching offices, and development is under way to extend CCIS to Traffic Service Position Sytems (TSPS). Exploratory studies are also in progress to extend CCIS to No. 1 ESS and No. 1A ESS local switching offices and to No. 5 crossbar-ETS, No. 2 ESS, and No. 3 ESS as well as to *DIMENSION®* PBXs and other PBXs.

In addition to CCIS, another closely related signaling system, CCITT No. 6, is being developed for No. 4 ESS. This latter signaling system will be used exclusively for signaling for overseas calls. It will be available in 1978 and, over the next few years, will be introduced into the international switching centers, which will all be No. 4 ESS offices.

CCIS is based on the CCITT No. 6 signaling system, and hence there exists a great deal of similarity. Modifications have been made to make CCIS more flexible for domestic use and allow new capabilities and features to be introduced.

CCIS affects many systems and its introduction will take many years. The topic of this paper is the strategy employed in obtaining a near-optimal and practical CCIS implementation schedule.

II. PLANNING PHILOSOPHY

The advantages of CCIS can be realized only if a great deal of connectivity exists among CCIS-equipped switching offices. The savings associated with CCIS are to a large degree proportional to this connectivity as expressed in terms of the number of CCIS trunks in the network.

All No. 4 ESS systems come equipped with CCIS signaling capability. However, at the present time, the bulk of the Bell System toll traffic is handled by 4A crossbar systems and crossbar tandems. For any reasonable deployment of No. 4 ESS, it will be many years before No. 4 ESS handles a significant fraction of the toll traffic. It was therefore imperative to develop a strategy that converted a number of existing toll switching offices for CCIS. It is practical to provide CCIS capability only on processor-controlled switching systems. The 4A-ETS is processor controlled, but the crossbar tandem and the 4A crossbar card translator are not.

Initially, the planning objective was to maximize the net savings in switching equipment. These savings are due to new CCIS trunk circuits on the 4A ETS systems which are cheaper than the conventional SF/MF trunk circuits. Also, no in-band single frequency (SF) signaling sets (used to transmit and receive supervisory tones on analog carrier trunks) are required with CCIS. However, there are also considerable costs associated with modifying a 4A switching office for CCIS operation.

The type of office that would tend to be converted to maximize equipment savings would be a small office with large projected growth. Those offices that are at full capacity (exhaust) at the time of CCIS conversion will contribute little to direct switching equipment savings. This is because considerable costs will have to be incurred to modify existing trunk circuits for CCIS operation. These costs are only partially offset by savings that can be obtained from reusing SF sets. Consequently, few 4A offices at exhaust would have CCIS capability and there would be low CCIS connectivity in the network.

The potential economic benefit from features and services made possible by CCIS will eventually far outweigh the equipment savings directly attributable to this new form of signaling. The sensitivity of the direct switching equipment savings to different conversion schedules was found to be small. The sensitivity of connectivity, however, is considerably greater. Since savings related to CCIS features and services are directly related to connectivity, the CCIS schedule for 4A offices was based on maximizing connectivity subject to constraints on the number of offices that could be modified in any year, due to limitations in manufacturing and installation capability and capital availability.

III. PROBLEM FORMULATION AND SOLUTION

An algorithm was constructed in 1973 to select a predetermined number of 4A-ETS offices for conversion to CCIS each year, beginning in 1977, so that CCIS connectivity is maximized each year. The problem was formulated separately for each year, starting with the first, and the connectivity is maximized subject to a constraint on the number of modifications in that year. For the following year, it is assumed that the switching systems modified in the previous year remain CCIS and a new schedule developed for this year. The process is repeated until all CCIS candidate offices are modified for CCIS capability. This method effectively decouples the problem into a separate problem for each year.

It is necessary to define the notation for a specific year y in order to describe the mathematical formulation of the problem. For year y, let:

M_0 = the set of 4A-ETS offices that are candidates for CCIS conversion in year y.
M_0' = the set of all offices, not members of M_0, which are CCIS in year y. These include No. 4 ESS offices and 4A offices modified to CCIS in previous years.
T_0 = the set of trunk groups having both ends of the trunk groups in offices of the set M_0.
T_0' = the set of trunk groups having one end of the trunk group in an office from set M_0 and the other end in an office from set M_0'.
$T = T_0 \cup T_0'$ = the set of all candidate CCIS trunk groups.
T_m = the set of trunk groups $t \in T_0$ that have one end of the trunk group in office m.
T_m' = the set of trunk groups $t \in T_0'$ that have one end of the trunk group in office m.
M_t = the set of offices $m \in M_0$ at the ends of trunk group t.

$$x_t = \begin{cases} 1 \text{ if trunk group } t \text{ is CCIS} \\ 0 \text{ if trunk group t is conventional (non-CCIS)} \end{cases}$$

$$z_m = \begin{cases} 1 \text{ if office } m \text{ is CCIS} \\ 0 \text{ if office } m \text{ is conventional} \end{cases}$$

p_t = the number of trunks in trunk group t.
n^y = the number of 4A-ETS offices to be modified in year y.

Ignoring for the moment the integrality requirements, the problem can be formulated as the linear program:

$$
\text{(A)} \qquad \left\{ \begin{array}{ll}
\multicolumn{2}{c}{\text{Maximize } \sum_{t \epsilon T} p_t x_t} \\
\multicolumn{2}{l}{\text{subject to the following sets of constraints:}} \\
(i)\ x_t - z_m & \leq 0 \text{ for each } t \epsilon T, \text{ each } m \epsilon M_t \\
(ii)\ \sum_{m \epsilon M_0} z_m \leq n^y & \\
(iii) \qquad z_m \leq 1 \text{ for each } m \epsilon M_0 & \\
(iv) \qquad z_m \geq 0 \text{ for each } m \epsilon M_0 &
\end{array} \right.
$$

If we let $f(n^y)$ be the maximum value of the objective function as a function of n^y, it is easy to show that $f(n^y)$ is a concave function of n^y. In fact, the variation of $f(n^y)$ with n^y will be given by a plot like one of those shown in Fig. 1.

The sheer size of the problem in terms of the number of constraints involved necessitates a method other than the simplex method. One method of solving this problem is by using a Lagrange multiplier for constraint (ii). The formulation of the problem using Lagrange multipliers is then:

$$
\text{(B)} \qquad \left\{ \begin{array}{ll}
\multicolumn{2}{c}{\text{Maximize } \left[\sum_{t \epsilon T} p_t x_t - \lambda_1 \cdot \sum_{m \epsilon M_0} z_m \right]} \\
\multicolumn{2}{c}{\text{subject to the sets of constraints:}} \\
(i) & x_t - z_m \leq 0 \text{ for each } t \epsilon T, m \epsilon M_t \\
(ii) & \qquad z_m \leq 1 \text{ for each } m \epsilon M_0 \\
(iii) & \qquad z_m \geq 0 \text{ for each } m \epsilon M_0
\end{array} \right.
$$

Of course, the value of λ_1 used will have to be chosen such that

$$\sum_{m \epsilon M_0} z_m = n^y$$

[Even though constraint (ii) in formulation (A) is an inequality, the equality will always hold in the optimum solution.]

It can be proved that formulation (B) of the linear program is the dual formulation of a problem of maximizing the flow through a network.[1] A computerized algorithm similar to the one described in Ref. 2 was developed to determine rapidly the maximized flow for the dual problem and thereby obtain the solution of the primal problem (B). The primal is a problem of determining the minimum cut of the network. This solution for any value of λ_1 will therefore always be integer valued.[2] At the nonextreme points of the function $f(n^y)$, the value of λ_1 has to be equal to the slope of the function at that point. The interpretation of λ_1 is discussed in more detail later in this section. However, the solution technique described will only pick up, for each value of λ_1, the extreme points of the constraint set defined in formulation (B). The solution to the linear program (A) for a specific value of n^y that is not an extreme point of (B) has to be obtained by taking a convex combination of the two extreme points of (B) around n^y. However, this will give rise to noninteger solutions to the original problem and these, of course, are not acceptable.

To determine an integer solution to the problem, we have to generate cuts to the constraint set by means of new constraints which do not eliminate any of the original integer solutions to formulation (A) of the problem. However, before we proceed to attempt this, let us look at the nature of the solutions to the problem for different values of n^y.

In the final solution of the linear programming problem represented by formulation (A) or formulation (B), the value of $\sum_{t \epsilon T} x_t$ is strictly increasing for increasing values of n^y. This particular fact suggests an interesting method of generating an integer cut. If the solution of the problem with formulation (B) results in a noninteger solution, introduce a constraint of the form $\sum_{t \epsilon T} x_t \leq k$, but only integer values of k need to be considered. If a solution to formulation (B) yields a solution for a particular value of n^y which results in a noninteger value of $\sum_{t \epsilon T} x_t$, then it is clear that the value of k that should be considered is the largest integer less than $\sum_{t \epsilon T} x_t$. However, this results in the same kind of problem as that with constraints on the number of offices that can be converted to CCIS. This constraint will therefore have to be considered by introducing another Lagrange multiplier λ_2. This results in another formulation of the problem:

$$
\text{(C)} \qquad \left\{ \begin{array}{ll} \multicolumn{2}{l}{\text{Maximize } \sum_{t \epsilon T} (p_t + \lambda_2) x_t - \lambda_1 \cdot \sum_{m \epsilon M_0} z_m} \\ \multicolumn{2}{l}{\qquad \text{subject to the constraint sets:}} \\ (i) & x_t - z_m \leq 0, \; t \epsilon T, \; m \epsilon M_t \\ (ii) & z_m \leq 1 \; m \epsilon M_0 \\ (iii) & z_m \geq 0 \; m \epsilon M_0 \end{array} \right.
$$

It is interesting to note that the value of k does not appear explicitly anywhere in the formulation. As a matter of fact, it is not even necessary to know what value of k is being considered. The only consideration should be to keep λ_2 as close to 0 as possible.

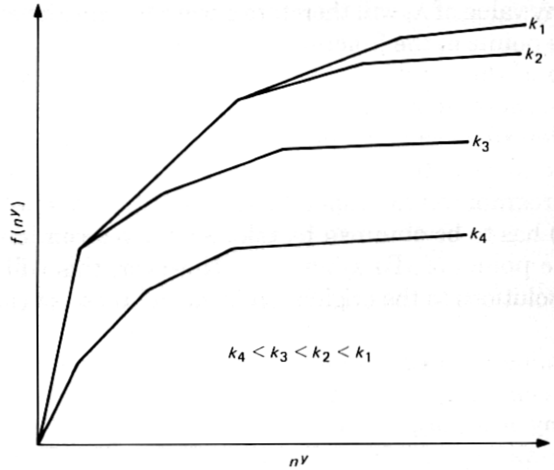

Fig. 1—Linear programming optimal value [$f(n^y)$] as a function of the number of CCIS office conversions n^y and trunk group conversions k.

The effect of changing the value of k is shown in Fig. 1. Reducing the value of k lowers the maximum CCIS connectivity as indicated. Let us see the effects of changes in the values of λ_1 and λ_2. The objective function represents a plane which for a value of λ_2 equal to 0 is perpendicular to the plane of the paper. The different curves representing different values of k are the projections, on the plane of the paper (the third dimension, perpendicular to the plane of the paper, represents the value of k), of the section of the surface for that value of k. With λ_2 equal to 0, increasing the value of λ_1 amounts to rotating, in an anticlockwise direction, the objective function plane about an axis perpendicular to the surface of the paper. The solution that is obtained for a particular value of λ_1 is the extreme point of the surface at which the objective function plane is supported. Decreasing the value of λ_2 rotates the objective function plane about a horizontal axis in the plane of the paper. (Only negative values of λ_2 should be considered.) By rotating the plane about this axis, new extreme points are available at which it can be supported. At the nonextreme points of the surface, the objective function plane is supported by an edge of the surface. For a given value of λ_2, the value of λ_1 is equal to the slope of the projection of the surface on a plane parallel to the surface of the paper.

However, this method is not exact. Examples can be constructed to show that this method does not always work. In some cases, there does not exist a value of λ_2 such that the integer cut generated does not exclude the optimal solution.

The question naturally arises as to how good this approximation is. One way of judging the "goodness" of this method is to compare it with the linear programming solution for formulation A. It should be noted that the best solution that this method will give is obtained with the smallest value of λ_2 that gives an integer solution. It has been our experience that, except for the first 1 or 2 years, the linear programming solution and the integer solution coincide. Even for the years where they did not coincide, the integer solution has at most only 15 percent fewer trunks than the linear programming solution. For all practical purposes, therefore, the solution was as close to the optimal as one could expect.

A constraint of 30 4A-ETS conversions per year (n^y) was imposed on the solution as a result of Western Electric manufacturing and installation loads and Bell System capital constraints. Within this limit, a trial schedule was determined by the above algorithm, and modifications to the schedule were made by the operating companies, coordinated by AT&T, according to more detailed information about each candidate machine. Since the objective function is fairly flat in the region of the optimal solution the modifications did not significantly affect the connectivity. Finally, a Bell System-wide schedule was agreed to for each year, beginning in 1977, with approximately 30 machines to be converted each year.

IV. PRESENT IMPLEMENTATION PLANS

The first two offices to use CCIS for signaling communication were the Chicago 7 No. 4 ESS, installed in January 1976, and the Madison 4A-ETS, installed in May 1976. Madison was the last new 4A-ETS switch to be installed in the Bell System. Later in 1976, No. 4 ESS switching offices in Kansas City; Jacksonville, Florida; and Dallas were installed with CCIS capability, and the 4A-ETS in Waukesha, Wisconsin, was converted to CCIS operation. Figure 2 shows the switching offices deployed at the end of 1976.

Early in 1976, before the Chicago 7 and Madison offices could communicate via CCIS, the first two pairs of signal transfer points (STPs) were put into operation in Indianapolis, Omaha, Dallas, and Oklahoma City. These STPs, described in another article,[3] consist of the processors from 4A-ETS switching offices that will not be converted to handle CCIS trunks. Generally, these locations were chosen from among those scheduled for early replacement by No. 4 ESSs. By the end of 1977 the remaining 16 STPs were cut over so that each of ten switching regions into which the continental United States is divided now has two STPs to which the switching offices will be connected, as shown in Fig. 3. In 1977, 27 4A-ETS switching offices were converted to CCIS operation, and eight new No. 4 ESSs were installed. By year-end 1979, plans call for about 70 converted 4A-ETS offices and 32 No. 4 ESS offices. The offices will be located approximately as shown in Fig. 4. Also, by year-end 1979, many No. 1 ESS

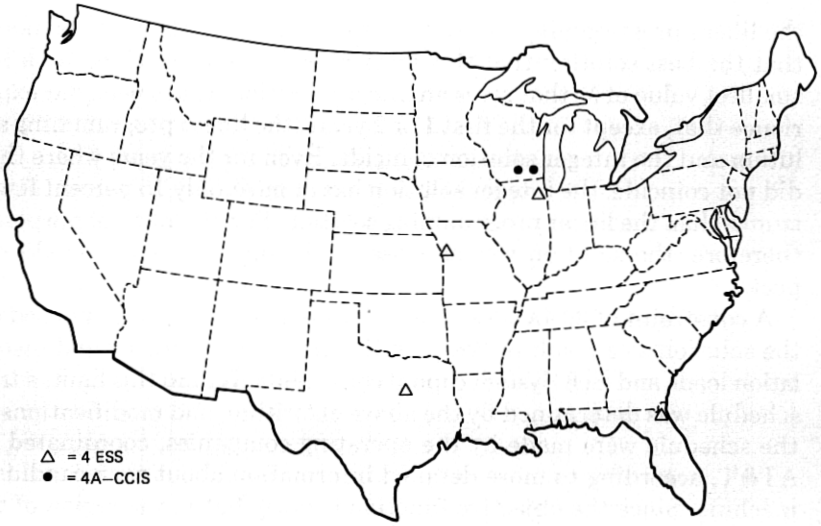

Fig. 2—Deployment of CCIS switching offices by year-end 1976.

toll offices are expected to have CCIS capability. (The first No. 1 ESS toll office with CCIS will be cutover in 1978.)

The number of trunks that will use CCIS for call control grows along with the number of switching offices that are deployed. The offices at both ends of each trunk group must be capable of CCIS before that trunk

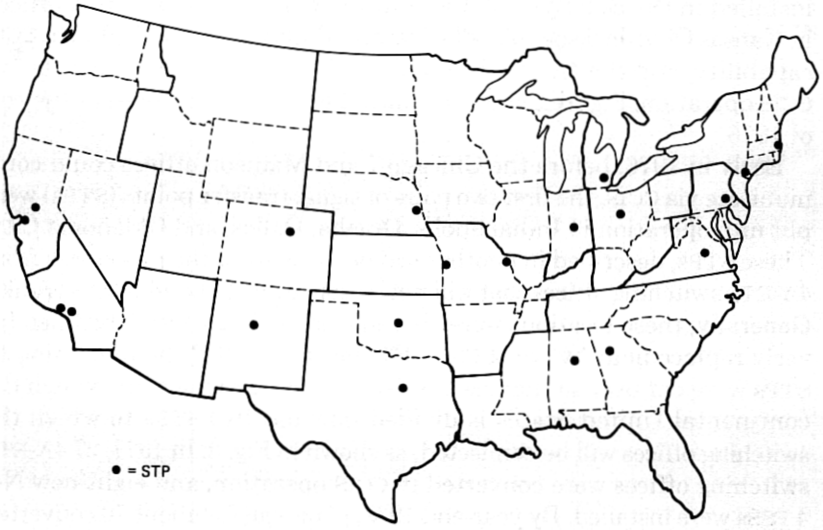

Fig. 3—Location of signal transfer points (STPs), showing a pair in each switching region.

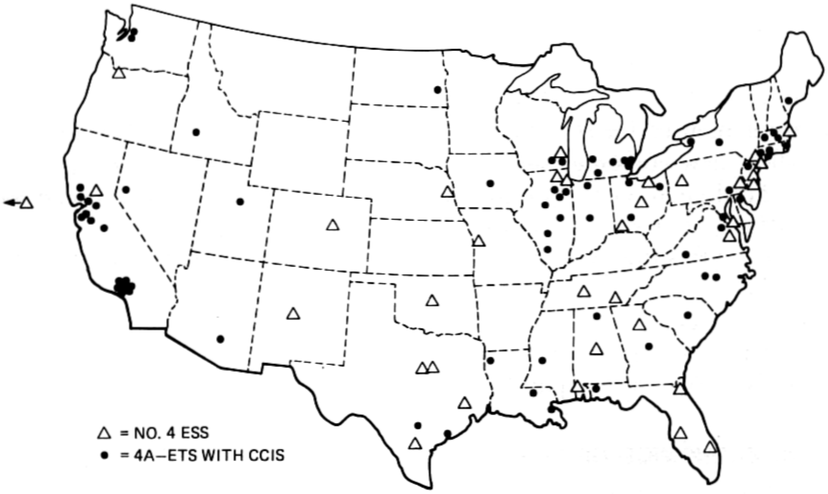

Fig. 4—Expected deployment of CCIS switching offices by year-end 1979.

group can signal in this new manner. There is thus a "squaring" effect in the number of CCIS trunks as a function of the number of offices. This is illustrated in Fig. 5.

V. LOCAL CCIS AND TRAFFIC SERVICE POSITION SYSTEMS

Most of the proposed customer services made possible by CCIS (such as certain forms of automation of collect calls and credit card calls) require some means of providing a direct interface between the telephone customer and the CCIS network. This interface will come about in two forms, by equipping TSPS with CCIS and by equipping local switching offices with CCIS. Studies are in progress on how to best equip local No.

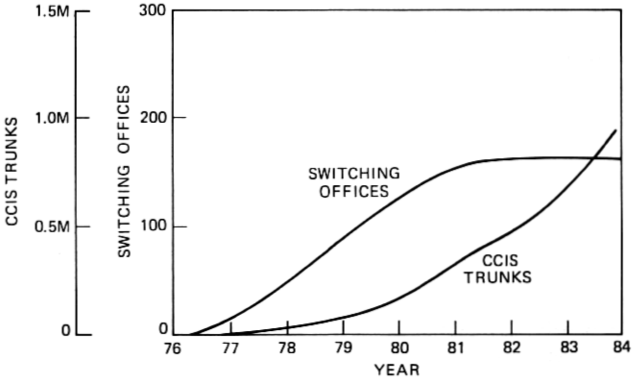

Fig. 5—Planned CCIS-equipped switching offices and trunks by year.

1 ESS and No. 1A ESS switching offices with CCIS. In addition, exploratory studies are being made to examine the feasibility of equipping No. 2 ESS, No. 3 ESS, and No. 5 crossbar-ETS offices with CCIS or a similar improved signaling method. An enhanced signaling system may also be implemented for *DIMENSION* PBXs and other PBXs. All of this would allow new customer services to be offered to most business and residential customers. For customers not served by CCIS-equipped local offices, access to the CCIS network can be made through the Traffic Service Position System (TSPS). This is the system that presently allows many customers to dial the called number for collect, credit card and other operator-assisted special billing calls after dialing 0. Almost 90 percent of Bell System customer lines will have access to TSPS by the early 1980s. CCIS capability is planned for TSPS about 1980.

VI. ECONOMICS OF THE BASIC CCIS SYSTEM

From the above discussion, we can see that the basic CCIS system will be well established by 1980, ready for the implementation of a wide variety of customer services, and cost-reducing network features. It is these services and features that will eventually bear the real economic fruits of CCIS, but at what cost was this flexible basic system established? In fact, the establishment of basic CCIS capability in the toll network results in overall system savings. Although there are significant costs associated with the conversion of each 4A-ETS switching office to CCIS operation, and with the construction of the signaling network itself, there are equipment savings in all toll offices due mainly to the elimination of the supervisory single-frequency detectors and transmitters that must be connected to each end of every analog carrier trunk using conventional (non-CCIS) signaling. By 1980, these and other CCIS equipment savings will begin to far outweigh the costs of establishing CCIS. In fact, in many cases, it has been shown to be economical to convert certain 4A-ETS switches to CCIS operation even though those machines are planned to be replaced by No. 4 ESS within 2 or 3 years from the conversion date. These robust economics have allowed plans to progress for CCIS despite national inflationary and recessionary trends and changing plans for the speed of deployment of No. 4 ESS (and consequent replacement of many 4A-ETS offices). Nevertheless, the big payoff is yet to come, in terms of economics as well as improved, more modern telephone service.

VII. CONCLUSION

CCIS is a major technical revolution in the telephone business, and the plans for implementation are ambitious. By 1980, the CCIS network will be in place ready to serve as a flexible medium for transfer of information among switching machines and other elements of the Bell System communication network. New services, defined by customer needs, will then be more easily implemented. And all of this will have been accomplished at a net capital savings for the Bell System.

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