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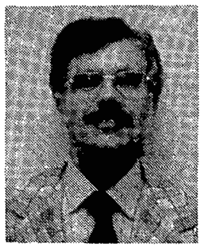

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Three Typical Blocking Aspects of Access Area Teletraffic

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Abstract—**In this paper, an effort is made to represent the military access area grade of service (i.e., probability of blocking) in a more realistic way than before. The circuit switching process is structured into three representative contention phases. The three phases are analytically tractable and are rather typical in existing military networks. All three phases apparently have service properties not accurately described by the conventional Engset, Erlang, and other classical models. Their blocking probabilities also differ from those predicted by the classical models.**

Given an access area network, the three blocking models may be applied individually or in a variety of combinations. The paper demonstrates several applications to typical access area telephony.

I. INTRODUCTION

MILITARY access area communication networks provide a broad range of communication services to a highly diverse user population. One service quality parameter that pertains to virtually all circuit switching situations is the so-called "grade of service." This paper develops a method for analyzing access area grade of service based on a three-phase blocking model. In the present context, grade of service is interpreted as a probability of being blocked by the system. Thus, busy called parties and malfunctioning message receivers are ignored.

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The access area concept is illustrated in Fig. 1. This figure stresses three interacting parts: the military access area (which is the primary focus of this paper), the Defense Communications System (DCS) backbone network, and the domestic common carriers. The access area proper usually comprises one or two military bases or building complexes. The access area bases share parts of a common telecommunications network. In addition to transmission facilities, the access area may contain central switching hubs (CSH, or switches, or hubs, for short), lesser switches (such as PABX's or PBX's), and various concentration elements. Both multiplexers (MUX) and intelligent or statistical concentrators (CONC) are found in cost effective designs of access area networks.

The access area traffic may be local, i.e., destined for the same or a geographically adjacent site, or it may be destined for some distant military region. In the latter case, the traffic is switched outward from or inward to the access area either

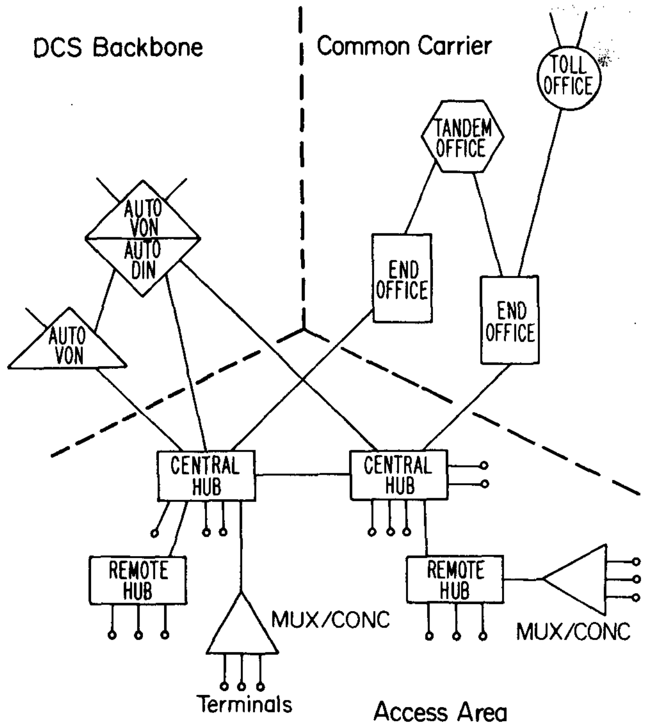

Fig. 1. Basic deployment concept of a military access area.

on the DCS backbone or via the common carriers. At the distant end, the terminating address can be either a military terminal or a civilian (government, commercial, household, or institutional) facility.

Communication circuits can take any one of several routes (or paths) through the cooperating networks. The route may pass through the DCS, but not more than once. It may pass through the toll or local facilities of a common carrier, but with high probability it will not do so more than once. And, to be complete, the route must traverse local access areas.

Given that individual military communications must take one of these paths, two traffic engineering questions arise immediately. First, is it possible to model the access area functions in such a way that accurate grade of service predictions can be made? And second, how does one do this in a simple useful way?

This paper addresses these two questions for a circuit switched access area network. To answer the first question in affirmative, a sequential circuit establishment description is developed. Specifically, starting with the next section, a set of three congestion or blocking phases is introduced. The intent is to represent the access area congestion as uniquely identifiable, separate, events of these blocking phases.

Thereafter, in later sections, probability of blocking results and curves are developed for the three phases (see Sections III, IV, and V). Section VI summarizes these grades of service tools by applying them to representative access area scenarios.

II. THREE PHASES OF BLOCKING IN THE ACCESS AREA

Assume that the DCS backbone and common carrier networks have sufficient capacity to be essentially nonblocking. Then blocking, if it occurs, must occur in the access area. But there, the route may encounter three kinds of nodal elements (Fig. 1): the concentrator (CONC), the remote hub (or the small customized switch, or PABX), and the larger central switch (or dial central office, DCO).

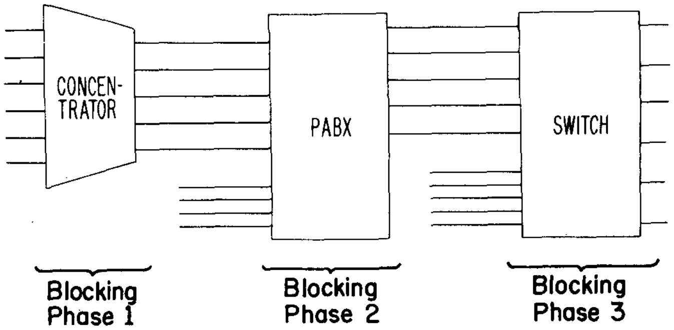

Fig. 2. Three phases of blocking.

In the originating access area, the route may pass through various combinations of CONC, PABX, and switches. The same is true at the destination access area, if a separate such area is involved. The details of different paths are listed in a later table, near the end of this paper. All total, at least some forty different route profiles may occur. And this excludes everything that happens in the DCS backbone or in the commercial common carriers. For simplicity, several local elements are also ignored, such as operator consoles (often blocking), multiplexers (nonblocking), and others of lesser significance.

The number of route profiles is considerable. Furthermore, for any offered load distribution among terminal groups, each of the forty circuit paths is apt to have different grade of service characteristics. The grade of service prediction is simplified if one can assign a unique probability of blocking to each of the three elements: CONC, PABX, and switch. In what follows, such a three-step approach is introduced.

Fig. 2 defines the three phases of circuit blocking within the access area network. The first phase of blocking occurs at a concentrator. Analytically, this happens to be the most unwieldy of the blocking phases. The problem setting of blocking Phase 1 and its approximate solution are presented in Section III.

The second phase of blocking in Fig. 2 is associated with a PABX. Looking from the user terminal side, the small PABX switch could be the first switching entity encountered by a station line. Lines can pass through concentrators or they can bypass the concentrators and be directly patched to the PABX. The probability of blocking for Phase 2 is treated in Section IV.

The third and last phase of blocking is shown (Fig. 2) to take place at a central switch. User terminals can be connected directly to the switch. Or they can be routed either through the concentrator, or the PABX, or both. The switch also has a long distance or toll side. For example, the right-hand side of the switch in Fig. 2 can be viewed as the collection of trunks to other DCS or common carrier switches. Section V discusses the Phase 3 blocking that occurs at such a switch.

III. BLOCKING PHASE 1

Assume the m-server facility of Fig. 3, where two types of user calls contend for the services of concentrator output

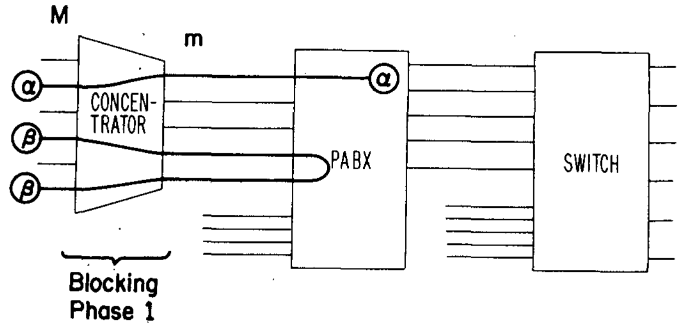

Fig. 3. Phase 1–blocking at a concentrator.

channels (servers). In a nutshell, the two types are distinguished by the number of servers (e.g., one or two) that they require per call.

The users, or sources, are the M terminals. Typically, M is greater than the number of servers m. To simplify matters, assume exponential distributions for both the interarrival and service (holding) times. Let blocked calls be lost or cleared without any aftereffect. Let the average service times be unity for both call categories, denoted as (α) and (β) in Fig. 3. In an informal way, one may refer to the (α) calls as "distant" and to (β) calls as "local."

Assume that the average arrival rates are different for distant and local calls. Let "a" be the arrival rate per idle terminal for distance or (α)-type calls, and let "b" be the corresponding rate for local or (β)-type calls. Assume that the concentrator and the PABX have full availability and that the PABX is effectively nonblocking.

The problem here is to derive the blocking probabilities for the two types of calls. The given parameters are M, m, a, and b. This is a queueing system or a birth-death problem of the $M/M/m/O/M$ kind [1]. Systems of this type have been studied before. All state probabilities, including blocking probabilities, are known to exist [1], [2]. While there may be considerable effort involved in deriving the formulas and in evaluating individual probability numbers, we skip the details here and proceed directly to the blocking probabilities of interest.

Let P_o stand for the blocking probability of the (α) category calls, and P_r for the (β) calls, respectively. One can envision "o" depicting the "out/in" nature of the (α) traffic, while r represents the "return" nature of the (β) calls.

Both exact (P_o, P_r) and approximate ($\tilde{P}_o$, $\tilde{P}_r$) expressions have been derived by the authors for appropriate ranges of parameters M, m, a, and b. Except for special cases, the expressions differ from conventional Engset, Erlang, and other classical formulas [1]-[5]. For brevity, the lengthy formulas are skipped here.[1]

Computations of blocking probability have been made for selected values of the parameters. Typical examples are shown in Figs. 4 and 5. These figures consist of four parts. The four parts show constant blocking probabilities, such as $\tilde{P}_o = 0.002$ or $\tilde{P}_o = 0.010$ for distant out/in calls, and $\tilde{P}_r = 0.010$ or $\tilde{P}_r =$ 0.050 for local return calls. The abscissa in all cases is m, the number of server channels. Notice that the m scale is different for the two figures, but it is consistently the same for the four parts of each figure. Similarly, a common ordinate $M(a + b)$ applies for every figure.

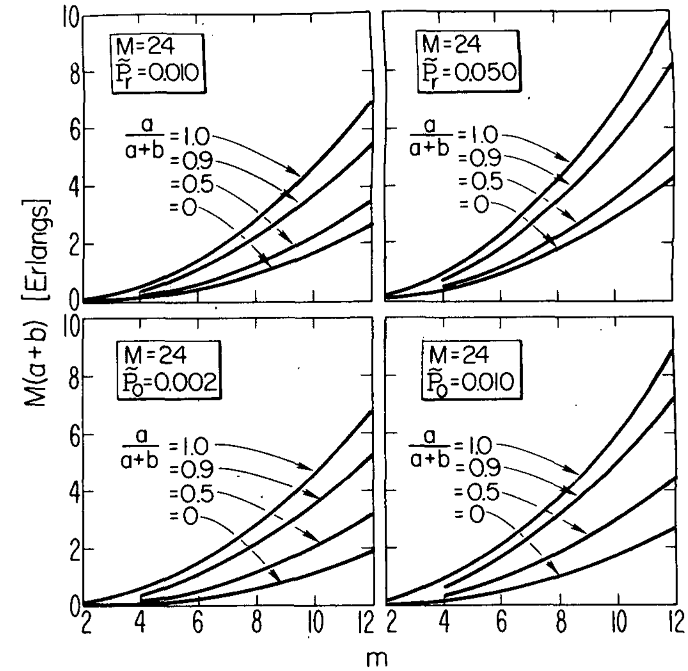

Fig. 4. Approximate Phase 1 blocking probabilities for M = 24 sources.

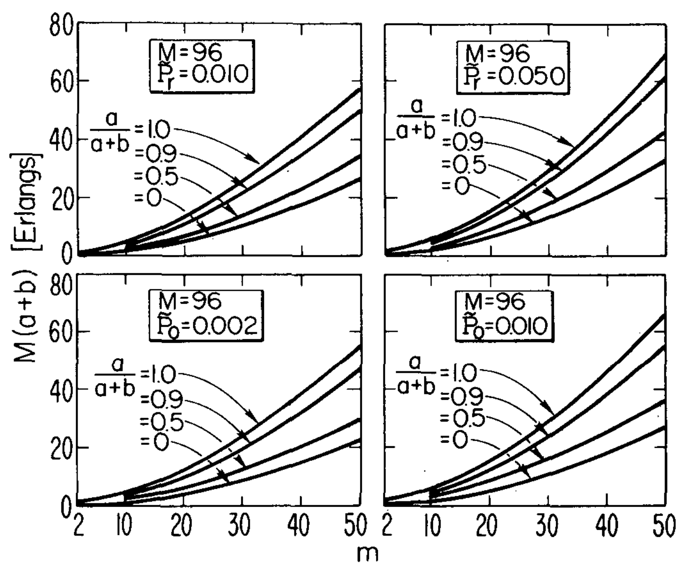

Fig. 5. Approximate Phase 1 blocking probabilities for M = 96 sources.

The ordinate $M(a + b)$ deserves a comment. It is called the "initial" offered load, as it is observed only when all the circuits through the concentrator are idle. To each initial load, there corresponds an effective offered load [3]-[5]. The effective offered load is always less than the initial load, but is slightly higher than the actual carried load. To compare the blocking probabilities with the effective load, one has to carry out additional calculation. That calculation has been omitted here.

[1] The detailed derivations and numerical results for Phase 1, as well as for Phases 2 and 3, are scheduled to appear in an NTIA Report (to be published).

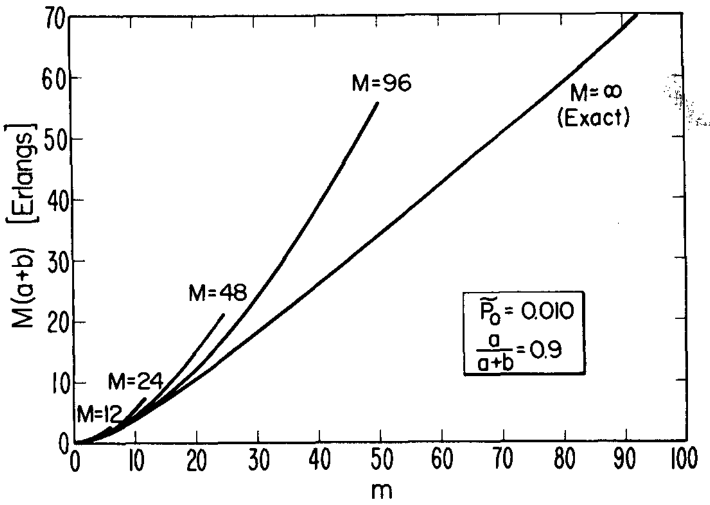

Fig. 6. The effect of the number of users M on 1 percent out/in call blocking.

Every quadrant part of each figure contains four curves. These curves are selected for constant values of parameter $a/(a + b)$. The latter is the average fraction of distant calls made through the service facility. One should comment on the adjective "approximate" in the captions of Figs. 4 and 5. It is valid only for $0 < a/(a + b) < 1$. When either $a = 0$ or $b = 0$, then the curves become exact. The exact cases are always useful as upper and lower grade of service bounds, respectively.

As the fraction of distant calls is increased, one finds that the same number of m servers can handle more traffic, given that the grade of service stays fixed. To emphasize the role of specific parameters, the curves can be variously redrawn. An example is shown in Fig. 6.

IV. BLOCKING PHASE 2

Assume the N-server facility of Fig. 7, which is depicted to be a PABX. Two groups of users, of arbitrary sizes m and n and with different traffic, contend for the N server channels shown.

Consider the two user classes. In accordance with the notation of Fig. 3, the upper class offers traffic of type (α). The m users here are concentrator or multiplex "loops." The lower class of n users supplies traffic of the type (γ). The latter may be loosely called "lines," although there is nothing to forbid these from being another class of concentrated loops.

Assume exponential distributions for both the interarrival and service (holding) times. Let the average arrival rate be λ_1 on every loop and let $1/\mu_1$ be its average service time. Caution: tandem systems can seldom preserve the Poisson nature of traffic throughout a network. However, the exponential assumptions appear to be consistent here. If $P_o \ll 1$ holds in Phase 1, then the total (α) traffic is passed nearly unperturbed to Phase 2. Not individual loop loads, but their total affects the PABX congestion. The latter, being almost the entire sum of exponential sources, appears Poisson for all practical purposes. Likewise, assume that λ_2 and μ_2 are the average arrival and service rates for the lines, respectively. Let $a_1 = \lambda_1/\mu_1$ and $a_2 = \lambda_2/\mu_2$. Finally, let the blocking probability at this PABX be P_x.

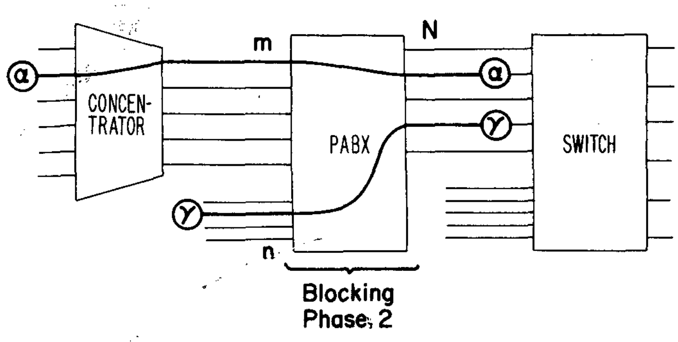

Fig. 7. Phase 2—blocking at a PABX.

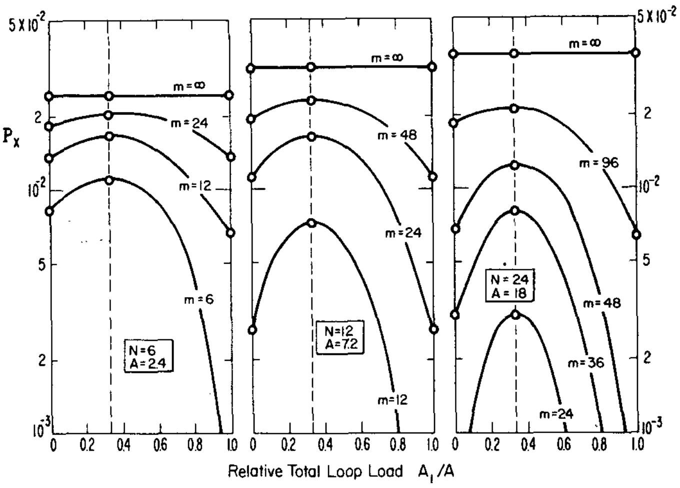

Fig. 8. Phase 2 blocking probabilities for loop-to-line ratio $m/n = 1/2$.

Formulas for P_x have been deduced by the authors.[1] One obtains the characteristics shown in Fig. 8. Probability P_x depends on five independent variables: m, n, N, a_1, and a_2. The initial loads offered by the two user classes are $A_1 = ma_1$ and $A_2 = na_2$, respectively. Their total load is $A = A_1 + A_2$. In Fig. 8, P_x is plotted versus the relative total loop load A_1/A. Note that the worst case maximum for P_x occurs at $A_1/A = m/(m + n)$.

V. BLOCKING PHASE 3

Consider the service facility labeled "switch" in Fig. 9. It is distinguished from other previously analyzed facilities by the fact that it provides two kinds of servers for three types of service requests (calls).

On the left side of the switch, there are a total of L channel ports, to be loosely called "lines." On the right side there are T "trunks." There are three types of calls through the switch. Note the distinction for paths (α), (δ), and (ϵ). For lack of better names, the (α)-type traffic at the switch will be referred to as "distant"; the (δ)-type as "local"; and the (ϵ)-type as "tandem." Assume the following.

1) The interarrival time distributions for the three kinds of service requests are approximately exponential, all possibly distinct. The service times are also exponentially distributed, but with a common mean of unity.

2) All service requests are generated by infinite user populations.

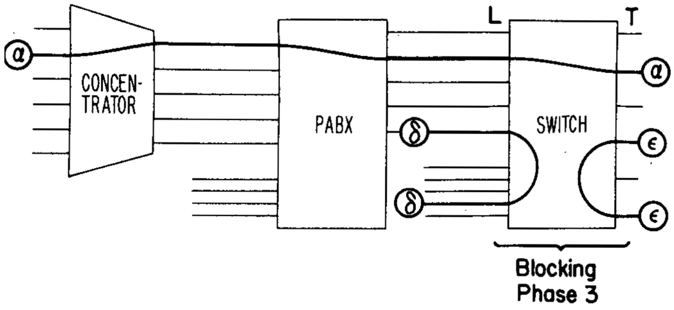

Fig. 9. Phase 3–blocking at a switch.

3) All blocked calls are lost without any aftereffect to the system.

4) The switching network is intrinsically nonblocking.

Finally, let P_d, P_l, and P_t denote the probabilities of blocking for the distant, local and tandem calls, respectively. The total offered loads for the three traffic types will be A, B, and C erlangs. To obtain service, a distant call requires that at least one line and one trunk is idle. Local calls need two lines and tandem calls need two trunks.

It turns out that closed form expressions are possible for the blocking probabilities. They have been derived by the authors.[1] When evaluated, the graphs similar to Fig. 10 materialize. All three probabilities of blocking are functions of five independent parameters: L, T, A, B, and C. Fig. 10 plots the probabilities versus the tandem load C for the assumed distant and local loads, A and B, respectively.

The tandem load C is seen to have a marked effect on the tandem call blocking probability P_t. As C tends to zero, P_t tends to its lowest value. As C increases, P_t grows monotonically. A somewhat lower rate of increase is encountered by P_d, the probability of blocking for distant calls. With respect to C, P_d also has a minimum at $C = 0$. Blocking probability for local calls P_l is nearly independent of C for the cases considered. A slight, perhaps surprising P_l maximum occurs at $C = 0$. It can be rationalized as follows. As C decreases, less distant calls are blocked due to shortage of trunks on the tandem side. On the local side, as a second-order effect, more lines are tied up by the distant traffic, leaving less capacity for local calls.

Fig. 10 is an initial step towards a full Phase 3 representation of a military access area switch. Extensions to larger sizes are desirable, but outside the scope of this paper.

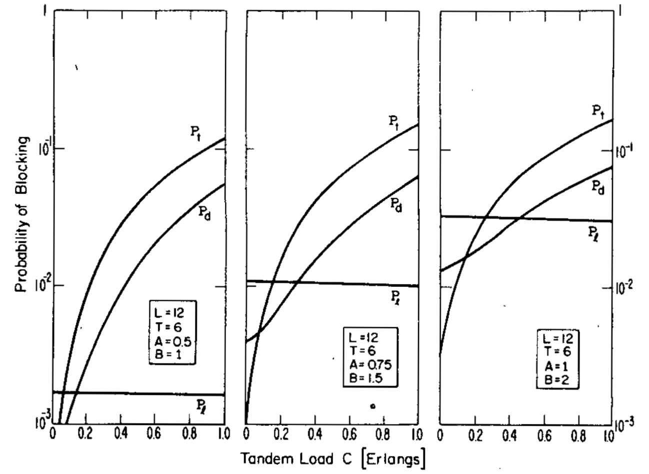

Fig. 10. The three blocking probabilities of Phase 3.

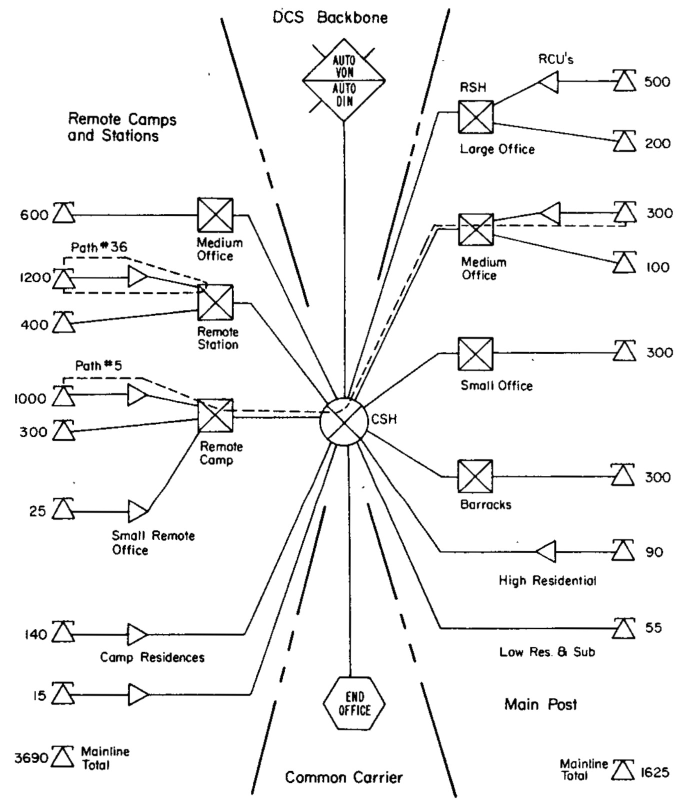

Fig. 11. Illustrative example of an access area communications network.

VI. APPLICATIONS OF THE THREE BLOCKING RESULTS

Six distinct blocking probabilities have been derived, computed and graphed (the lengthy formulas have been omitted here for reasons of brevity). Only the graphical results are given here. Sections III, IV, and V depict the blocking processes called Phases 1, 2, and 3.

The results apply to military access area grade of service. That is illustrated next for a typically sized access area (Fig. 11). The area deployment is assumed consistent with Fig. 1. After inclusion of the applicable terminal density profile, the main lines and the bridged telephone lines can be configured. A hierarchical access area network results as part of the interregional access configuration. The implementation concept includes digital concentration, multiplexing, switching, and transmission. Trunk circuits are assumed to be relatively standard PCM: 24 channels (T1), or 48 channels (T1C), or 96 channels (T2).

Given busy hour traffic intensities for typical user terminals, the access area end-to-end blocking probabilities can be assessed. In Fig. 11, let the lines with less than 0.10 Erlangs/line be homed to either concentrators or PABX's. Let the lines with higher intensity be directly patched to the central switching hub (CSH). It follows that blocking probabilities can be estimated for Phase I (Section III), Phase 2 (Section IV), and Phase 3 (Section V).

TABLE I
FORTY PATH PROFILES AND THEIR BLOCKING PROBABILITIES

Path #	Initial Area CONC	Initial Area PABX	Initial Area Switch	Additional Area Switch	Additional Area PABX	Additional Area CONC	Access Area Blocking Probability
1	X	X	X	X	X	X	.050 (max)
2	X	X	X	X	X		.045
3	X	X	X	X		X	.038
4	X	X	X	X			.033
5	X	X	X		X	X	.044
6	X	X	X		X		.039
7	X	X	X			X	.032
8	X	X	X				.027
9		X	X	X	X	X	.045
10		X	X	X	X		.040
11		X	X	X		X	.033
12		X	X	X			.028
13		X	X		X	X	.039
14		X	X		X		.034
15		X	X			X	.027
16		X	X				.022
17	X		X	X	X	X	.038
18	X		X	X	X		.033
19	X		X	X		X	.026
20	X		X	X			.021
21	X		X		X	X	.032
22	X		X		X		.027
23	X		X			X	.020
24	X		X				.015
25			X	X	X	X	.033
26			X	X	X		.028
27			X	X		X	.021
28			X	X			.016
29			X		X	X	.027
30			X		X		.022
31			X			X	.015
32			X				.010 (min)
33	X	X			X	X	.034
34	X	X			X		.029
35	X	X				X	.022
36	X	X					.010 (min)
37		X			X	X	.029
38		X			X		.024
39		X				X	.017
40		X					.012

Table I illustrates a calculation done for Fig. 11 with a standard modular implementation. As noted earlier, there are some forty discernible circuit paths. By and large, they all have their own unique end-to-end blocking probabilities. The latter, of course, are sums of the P_o, P_r, P_x, P_d, P_l, and P_t, that are parts of the three phases of blocking.

VII. CONCLUSION

Tools have been developed for analysis of military access area grade of service. The tools consist of structuring the network flow into three distinct congestion phases. These phases, discussed in Sections III, IV, and V, are individually quite distinct. From a teletraffic point of view, they represent new problems and new solutions. This paper has offered graphical solutions to all three phases.

Blocking probability curves have been computed for selected cases. These cases have turned out to be quite useful here to demonstrate the principles. Additional computations are needed for the extensive parameter ranges of interest in access areas and elsewhere.

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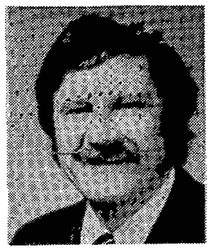

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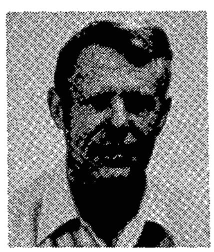
Dr. Nesenbergs has served the IEEE as the Chairman of the Boulder–Denver Chapter of ComSoc, as well as the Social Chairman of the initial International Communications Conference (ICC) in 1965, and as the Technical Program Chairman of the 1969 ICC. In 1973 and 1974 he was named to the ComSoc Advisory Council and performed the Editor's duties for the IEEE COMMUNICATIONS SOCIETY MAGAZINE.



Robert F. Linfield (SM'59) was born in Bozeman, MT, in 1925. He served on the U.S.S. Enterprise during World War II as an Aviation Radar Technician. He received the B.S. degree in engineering physics from the University of Colorado in 1956.

From 1948 to 1961 he was with the National Bureau of Standards in Washington, DC, Corona, CA, and Boulder, CO. In 1961 he joined a group which started the Boulder Laboratory for DECO Electronics, Inc. and was engaged in developing VLF survivable systems for the U.S. Navy. Westinghouse Electric Corporation acquired DECO in 1967 and this laboratory became the Westinghouse Georesearch Laboratory (WGL). He directed the Communications and Navigations Systems Section at WGL until 1974. Currently he is with the Advanced Network Division of the Institute for Telecommunication Sciences in Boulder. He is responsible for projects dealing with switched networks for various government agencies and is presently working on advanced military networks having strategic, tactical, and nontactical applications.