PERFORMANCE ANALYSIS OF A MODULAR VIDEOPHONE SWITCHING NETWORK

Wolfgang Fischer, Manfred N. Huber

Institute of Communications Switching and Data Technics,
University of Stuttgart, FRG

Karl J. Schrodi

Research Center of Standard Elektrik Lorenz AG,
Stuttgart, FRG

ABSTRACT

In the present ISDN only narrow-band services are offered, whereas in the future ISDN more powerful services (videophone, videoconferencing, TV programs etc.) requiring higher bandwidth will be included.

The videophone switching network considered in this paper has a one-sided three-stage architecture with separate access switches connected to several independent two-stage link-structured group switch planes. All stages are implemented by the same switching modules with 64 inlets and 64 outlets realized as a two-sided three-stage link structure with quadrupel links between the four 16x16 switching matrices (140 Mbps) of adjacent stages.

Performance evaluation of the switching module has been done by simulation whereas for the whole network an approximative algorithm has been developed taking into account all parameters of the network structure and the path hunting algorithm.

INTRODUCTION

While ISDN is still going to become reality a lot of effort is taken to enhance its capabilities by additional and more powerful services. These new services, as for example videophone, videoconferencing or switched distribution of television programs, usually require significantly higher transmission rates than today's ISDN services, thus upgrading the 64 kbps-ISDN to Broadband-ISDN (B-ISDN) (refs.1-3).

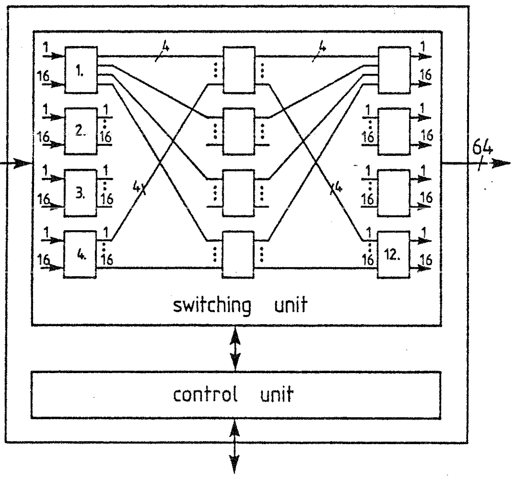

Figure 1: Broadband Switching Module

All functions of administration, signalling, call handling and maintenance for broadband services may be done in the same way and even by the same means as for general ISDN services; however, switching of broadband signals requires a dedicated circuitry. Configured to broadband switching networks this circuitry mainly determines the performance and quality of all broadband services in a B-ISDN.

The state of technology allows for the integration of broadband switching matrices with up to 16 or 32 inlets and outlets. At the Research Center of Standard Elektrik Lorenz AG (SEL) a 16x16 switching matrix circuit for 140 Mbps signals has been developed in a 2µm-CMOS-technology (ref.4). Based on this circuit an arrangement of a modular videophone switching network for up to 11264 lines is presented and analyzed in this paper.

STRUCTURE OF THE MODULAR NETWORK

Design Principles

Today's forecasts show a high grade of uncertainty concerning the acceptance of broadband services throughout the next decade. This situation calls for highly flexible and economical realizations of videophone switching networks, which are applicable to a wide range of subscriber lines and load with a minimum of advance investments for further extensions. A modular concept as described and analyzed in this paper satisfies

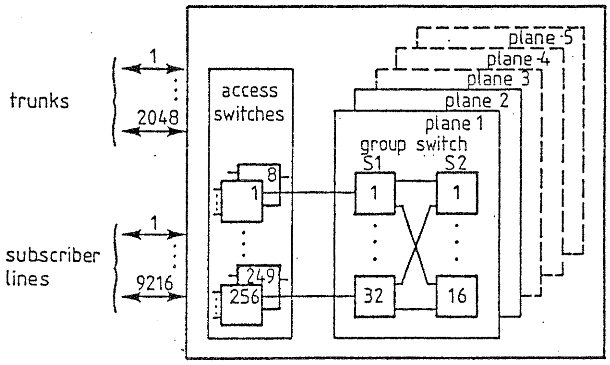

Figure 2: Videophone Switching Network Architecture

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these requirements in a nearly optimal way. Built up by identical switching units the videophone switching network grows with the number of connected subscribers and higher load by simply adding some more switching units.

All the switching units which are absolutely identical have their own dedicated control units. Each switching unit together with its control unit forms a universal switching module (figure 1) and a fully modular and economical videophone switching network concept is obtained, where this single module can take any position and any function without change.

Structure of the Videophone Switching Network

Switching Network Architecture The videophone switching network has a one-sided three-stage architecture with separate access switches (AS) connected to several independent two-stage link-structured group switch planes (figure 2). This architecture, which is well known from ITT's SYSTEM 12 narrowband digital switching network (ref.5), allows for a step-by-step growth of line numbers by adding ASs and an increase of carried load by installing further group switch planes. A maximum of 5 group switch planes is foreseen.

Connections are switched by the shortest paths possible, thus forming a heterogeneous switching arrangement, where higher switching network stages are relieved of unnecessary traffic loads. For local exchanges, which are suggested to be the main application of this videophone switching network, this feature is enhanced by a mixed wiring of subscriber lines and trunks to the ASs. Especially in highly hierarchic networks a good deal of outgoing external traffic may be led out into a trunk already by the AS. Incoming external traffic, however, will usually have to pass through the group switch stages since there is no relation between the ASs, which the incoming trunk and the addressed subscriber are wired to.

Broadband Switching Module Figure 1 shows the internal structure of the module's switching unit. It offers 64 inlets and 64 outlets and is realized as a two-sided three-stage link structure with quadrupel links between the four 16x16 switching matrices of adjacent stages. This straight switching arrangement has been recognized to form the best compromise between technological constraints and traffic requirements for a single Printed Board Assembly (PBA) realization of a 64x64 CMOS broadband switching module.

The switching module is operated in a one-way mode, i.e. each connection is set up from left to right (figure 1). To implement the one-sided switching arrangement as shown in figure 2 the outlet lines of these unidirectional switching modules are wired as forward links and backward links. Forward links lead to higher order switching network stages, backward links are connected to inlets of lower order stages, thus providing the way back to the outlets of the one-sided structure (figure 3).

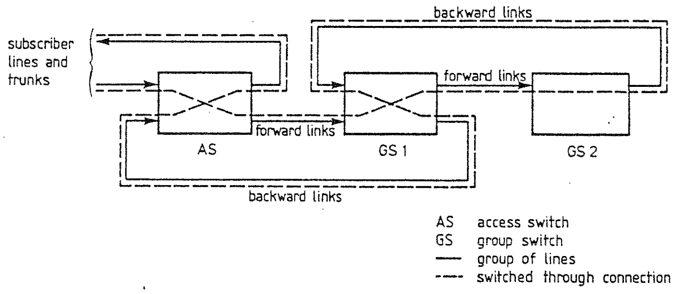


Figure 3: Linking of the Switching Network

36 subscriber lines and 8 trunks are provided by each AS. Note, that all groups of lines, which may carry different loads, e.g. subscriber or trunk access lines, are distributed equally to the 4 inlet (or outlet) switching matrices to obtain a balanced load inside the module.

Group Switch Planes Wiring of the modules in stage 1 and 2 of the group switch planes (GS1 and GS2) follows the same rules as for the access switch. There might be a full linkage between these stages in forward and backward direction, however, arranging the GS2 in groups with limited backward accessibility to GS1 leads to a higher grade of service, as this kind of grouping allows for larger groups of links back from GS2 to GS1. Figure 4 shows this principle in an unfolded representation of a switching network with 2 groups of GS2 modules (stages 2, 3 and 4 represent GS1, GS2 and again GS1 resp.).

Table 1 gives an overview of proposed numbers of GS1 and GS2 modules for each group switch plane, of the numbers of possible GS2 groups and the resulting forward and backward line numbers between the modules of these stages. In addition there are the numbers of ASs connectable to these group switch planes and the resulting numbers of subscriber lines and trunks of the whole switching network, if 8 ASs are connected to one GS1 module of all group switch planes as shown in figure 4. There are 4 lines forward and 4 lines backward between each GS1 module of any group switch plane installed and up to 8 ASs connected to them respectively.

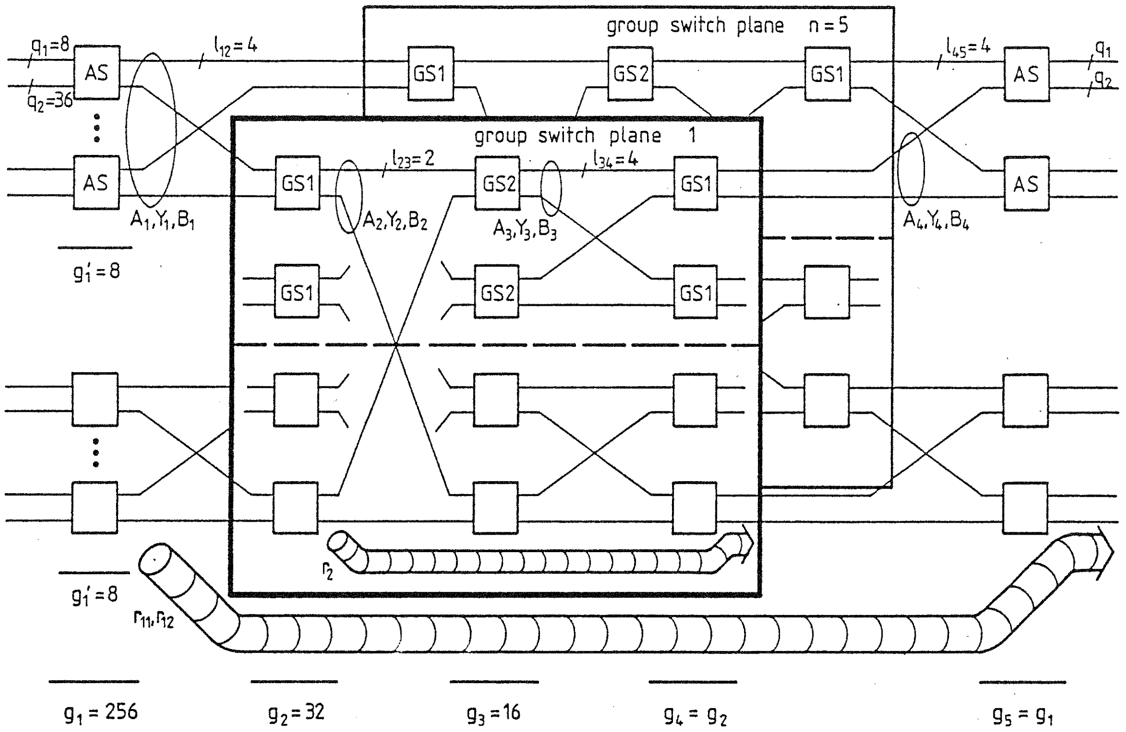
A grouping of group switch planes, e.g. with each AS connected to 4 group switch planes by 4 lines each in forward direction and to 2 of them by 8 lines each in backward direction is useful in principle, but it does not lead to lower blocking probabilities if retrials are used after a non-successful call-attempt.

PATH HUNTING

Path hunting in this modular videophone switching network employs a step-by-step algorithm, which is well known from ITT's SYSTEM 12 (ref.5). It operates in a "free search" mode (any of the

Table 1: Switching Network Configurations

g_2	g_3	GS2 groups	l_{23}	l_{34}	g_1	g_1 q_2	g_1 q_1
32	16	1 2 4	2 2 2	2 4 8	256	9216	2048
16	8	1 2	4 4	4 8	128	4608	1024
8	4	1	8	8	64	2304	512



igure 4: Unfolded Representation of the Switching Network Including Traffic Parameters

modules of the successor stage can be chosen if a link is available and if the destination line can be reached by this module) from the source line to a reflection point in any module of a predefined stage of the switching network and completes the path by a "directed search" back to the destination line.

Bidirectional connections are established by two independent simplex paths; blocking probability is reduced by up to 4 repeated path hunting trials for each simplex path connection when congestions have occured.

PERFORMANCE ANALYSIS

Simulative Investigation of the Module

Due to the lack of analytic approaches covering sophisticated hunting modes several path hunting algorithms have been simulated for investigating their influence on the blocking probability for the switching module of figure 1 in point-to-point selection mode:

1. sequential hunting, starting with the uppermost links
2. sequential hunting, starting with random links
3. choosing the pair of links with the smallest actual load

The results (figure 5) show that algorithm No.3 yields the best performance measures; it needs, however, slightly more path search time, but this is no performance problem.

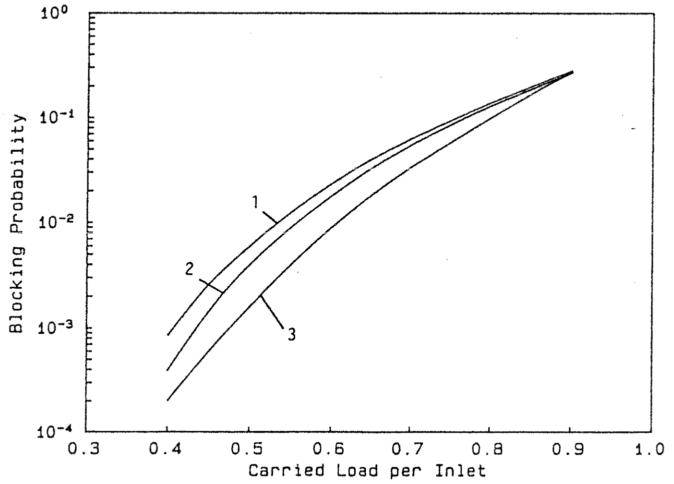


Figure 5: Blocking Probability vs. Carried Load per Inlet

Numerical Analysis of the Network

General Approach For the numerical analysis of the switching network an approximative algorithm has been developed taking into account

* the configuration (see table 1)
* the maximum number of trials R for a successful call-attempt
* the probability r of a call generated by a subscriber to leave the network and to seize a trunk.

For the description of the algorithm for the sake of simplicity the modules are considered to have no internal blocking. For the analysis program, however, this internal blocking has been included by means of a Lagrange interpolation of the simulation results at the appropriate places in the algorithm.

The offered load to each AS is generated by q_1 trunks carrying Erlang traffic and q_2 subscriber lines carrying Engset traffic. In the following all trunks are considered as belonging to a single trunk group. This leads to the effect that a call generated by a subscriber and entering the trunk group can in most cases return already in the AS and does not utilize any crosspoints in the group switch planes. This is indicated in figure 4 by the "tubes" taking away the Erlang traffic with probability r_{11} and the Engset traffic with r_{12} from the AS. r_2 is the probability for the traffic returning in GSI. These return probabilities are configuration and load-dependent. Their evaluation is shown below.

The analysis is based on the calculation of the probabilities of loss on the links between the modules from the carried load Y of each link which is derived from a load flow analysis.

The blocking effects on the links can be assumed to be independent of each other, thus, refering to figure 4 the probability of loss B_N across the network for a single trial (refs.6,8) is

$$B_N = 1 - \prod_{i=1}^{4} (1 - B_i) \tag{1}$$

where B_i: Probability of loss on the Link from Stage i to i+1.

For pure Erlang traffic B_i is calculated from the carried load Y_i by iteratively applying the Erlang loss formula. The load offered to the links immediately behind the ASs however is a superposition of Erlang- and Engset traffic. The performance measures for this compound process are evaluated by a two-dimensional birth-and-death process, where each dimension represents one traffic type. Let A be the offered load by the trunks connected to the AS and β the offered load per idle subscriber. Then the state probabilities $p(x_1,x_2)$ can be derived by local balance equations (ref.7) by applying a recursive algorithm.

For $q_1 \leq q_2 - l_1 + 1$ a closed form solution exists:

$$p(x_1,x_2) = \frac{\frac{A'^{x_1}}{x_1!} \cdot \binom{q_2'}{x_2} \cdot \beta'^{x_2}}{\sum\limits_{i=0}^{\min(l_1,q_1)} \sum\limits_{j=0}^{(l_1-i)} \frac{A'^{i}}{i!} \cdot \binom{q_2'}{j} \cdot \beta'^{j}} \tag{2}$$

where

x_1: number of occupations by Erlang traffic

x_2: number of occupations by Engset traffic

$l_1 = n \ l_{12}$

$x_1 + x_2 \leq l_1$

$q_2' = q_2 - (r_{12} \cdot Y_{1,Eng})$: Mean number of customers causing occupations by Engset traffic

$A' = A \cdot (1 - r_{11})$: reduced offered load for Erlang traffic

$\beta' = \beta \cdot (1 - r_{12})$: reduced offered load for Engset traffic

For $q_1 \geq q_2 - l_1 + 1$ $q_2' = q_2'(x_2)$ is state dependent, so for evaluation of the 2-dimensional state space only a recursive and iterative approach will be feasible. From the state probabilities the probabilities of loss can be calculated:

$$B_{1,Erl} = \sum_{x_1=0}^{\min(l_1,q_1-1)} p(x_1,l_1-x_1) \tag{3}$$

for Erlang traffic, and

$$B_{1,Eng} = \frac{1}{q_2' - \frac{Y_{1,Eng}}{1-r_{12}}} \sum_{x_2=0}^{\min(l_1,q_2-1)} [q_2'(x_2)-x_2] \, p(l_1-x_2,x_2) \tag{4}$$

for Engset traffic, where

$$Y_{1,Eng} = \sum_{x_1+x_2 \leq l_1} x_2 \, p(x_1,x_2) \tag{5}$$

the carried load of Engset traffic behind the AS.

Due to the superposition of calls generated by a large number of subscribers and trunks for all but the first links Erlang traffic can be assumed.

Multiple Trials In order to obtain small overall probability of loss in a step-by-step switching network, up to R reattempts are provided. The hunting algorithm for the outlets of the modules guarantees that in the average all group switch planes carry the same load, and that each trial uses a different plane if it is possible. The number of planes which can actually be reached depends on the pattern of occupations on the links behind the AS and can be smaller than R. Let x be the number of occupations, then the probability for the occurrence of these x occupations is

$$p_x = \sum_{x_1+x_2=x} p(x_1,x_2) \tag{6}$$

Assuming that all patterns for x occupations are equally distributed, the conditional probability $p_{n,x,k}$ is obtained that exactly k out of n planes cannot be reached if these x occupations exist.

$$p_{n,x,k} = \frac{\binom{n}{k} \cdot \binom{(n-k) \cdot l_{12}}{x-k \, l_{12}}}{N} - \binom{n}{k} \cdot \sum_{i=1}^{n-k} p_{n-k,x-k \cdot l_{12},i} \tag{7}$$

$N = \binom{l_1}{x}$ is the number of all possible patterns for $k \in [0,a]$ and $a > 0$; $p_{n,x,k} = 0$ for $k > a$; where a is the largest integer less than or equal $\left(\frac{l_{12}}{x}\right)$ defining the maximum number of non-reachable planes for the given x. The first fraction in (eq.7) yields the probability that at least k planes are not reachable. Its numerator gives the number of possible patterns which the occupations not involved in the blocked links $(x-k \cdot l_{12})$ can produce on the lines of these non-blocked links $((n-k) \cdot l_{12})$, multiplied with the number of combinations of k blocked links out of n. These occupations, however, could produce another blocking of links, thus in the second term of (eq.7) the probability is subtracted that any of the remaining n-k links is blocked.

Thus the total probability for reaching t planes for a given load from which the state probabilities are derived yields

$$p_t = \sum_{x=0}^{l_1} p_x \, p_{n,x,n-t} \tag{8}$$

We obtain the probability of loss for a call which cannot return before GS2 neglecting the fact that more than one trial can use the same plane. (This has not been neglected in the analysis. The probability that a certain number of trials enters the same plane can easily be calculated from the number of reachable planes and R.)

$$B = 1-\left(1- \sum_{t=1}^{n} p_t [1- \prod_{i=2}^{4} (1-B_i)]^{\min(t,R)}\right)\cdot(1-B_1) \tag{9}$$

For calls which are able to return before GS2, only the loss which they suffer from on their path has to be considered and weighted with their return probability to obtain the overall probability of loss.

For the derivation of the return probabilities it is assumed that a fraction r of the carried load created by the subscribers will leave the network into the group of $q_1 \cdot g_1$ trunks and that this happens with the lowest possible distance. This outgoing traffic is able to return already in the AS if the q_1 trunks connected to it are not blocked.

$$r_{12} = r \cdot (1 - B_T) \tag{10}$$

B_T is the blocking probability for the q_1 lines carrying a given load.

An incoming call arrives at an arbitrary trunk and proceeds to an arbitrary subscriber line.

$$r_{11} = 1/g_1 \tag{11}$$

Assuming that the incoming load from the trunks is equal to the outgoing load from the subscribers into the trunks we obtain the return robability r_2:

$$r_2 = \frac{Y_{Eng}\cdot[r\cdot B_T(1-B_T^*) + (1-r)\cdot 1/g_2] + Y_{Erl}\cdot 1/g_2}{Y_{Eng} + Y_{Erl}} \tag{12}$$

B_T^* is the blocking probability of the group of trunks which are connected to all ASs linked with one GS1 except the one AS whose trunks have been found to be blocked.

Duplex Connections Until now we have considered calls using only one direction. For duplex connections both paths are searched independently. This duplex connection is switched only if both directions can be switched successfully. So the probability of loss B_N is obtained by

$$B_N^* = 1 - (1 - B_N)^2 \tag{13}$$

Results The results are given for the parameters:

$n = 5$; $g_1 = 256$; $g_2 = 32$; $g_3 = 16$; $q_1 = 8$; $q_2 = 36$; $l_{12} = 4$; $l_{23} = 2$; $l_{34} = 8$; $l_{45} = 4$; $R = 4$;

Figure 6 shows results which have been obtained by simulation (included are the 95% confidence intervals) compared to the analytical results. (For the sake of economical use of computing time for the simulation no module blocking and no duplex calls have been considered).

Figures 7 and 8 present the probabilities of loss (with internal module blocking and duplex connections) for Erlang and Engset calls respectively using different return probabilities.

For the same set of parameters figures 9 and 10 present the mean number of trials for a succesful connection.

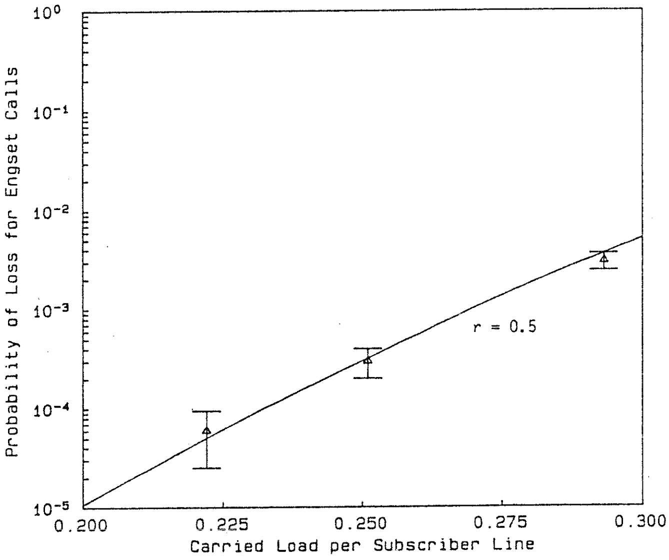


Figure 6: Probability of Loss for Engset-Calls

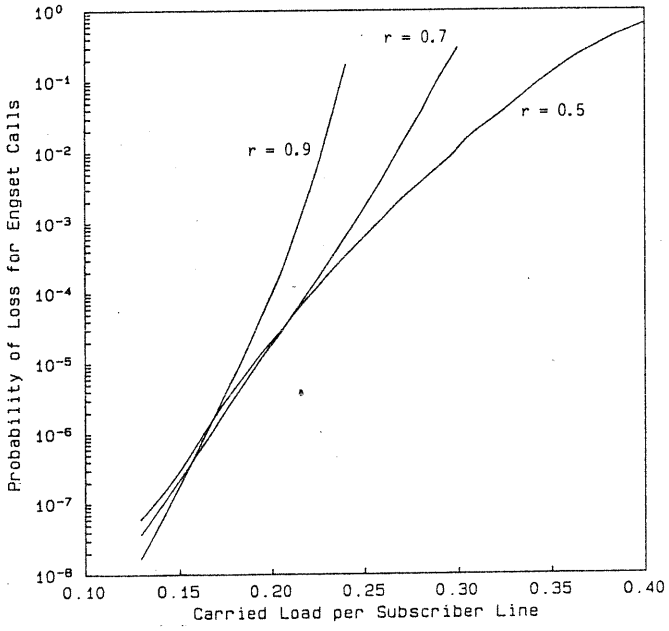


Figure 7: Probability of Loss for Engset-Calls

CONCLUSION

We have presented an approximative algorithm for the performance evaluation of a modular switching network which uses step-by-step path hunting. Compared with simulation results the approach has been shown to be very reliable in a wide range of parameters. A main goal has been to make obvious the different influences of operation mode, number of trials, probability of traffic to leave the network yielding load dependent return probabilities etc.

Results also showed that the network will perform very well under the assumptions presented.

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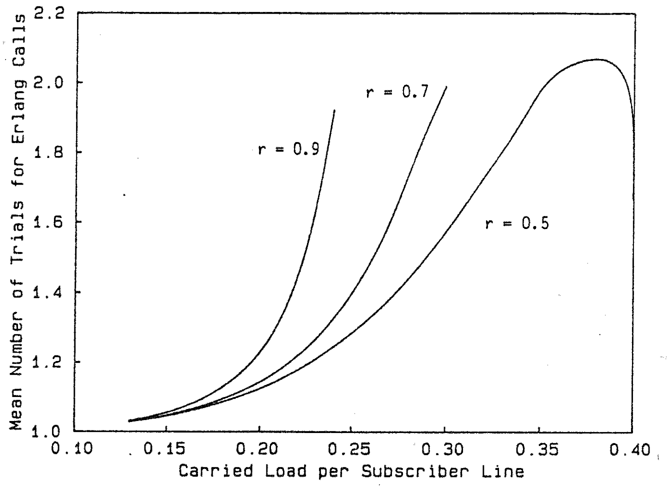

Figure 10: Mean Number of Trials for Erlang-Calls

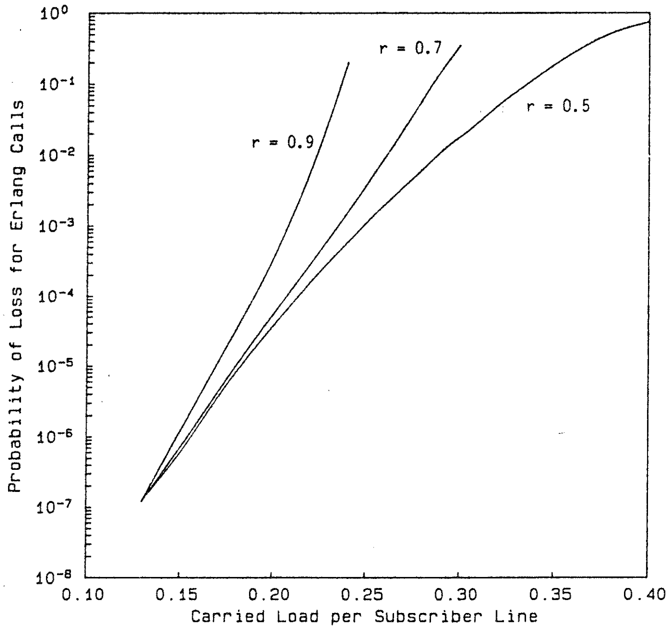

Figure 8: Probability of Loss for Erlang-Calls

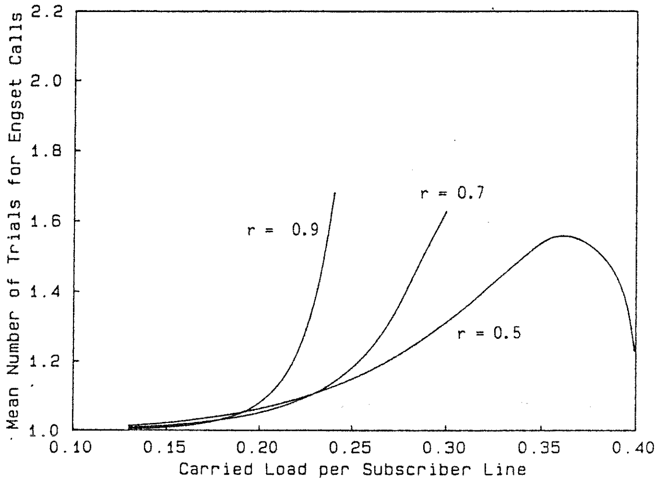

Figure 9: Mean Number of Trials for Engset-Calls

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