MESSAGE-SWITCHING NETWORKS WITH ALTERNATE ROUTING

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ABSTRACT

In modern data networks variable routing strategies allow to take into account the instantaneous traffic situation of the network.

Traffics offered to a direct "primary" route can be described realistically by means of Poisson traffic and therefore all characteristic traffic values can be determined by means of well known formulas. However, traffics overflowing from a primary to a secondary route possess quite other stochastic properties than Poisson traffic.

This paper shows, how to dimension store- and forward networks with alternate routing, taking into account the special properties of overflow traffic. Artificial traffic trials show the good accordance between simulated and calculated traffic values.

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1. PROBLEM

By reasons of economy, overload and cable-breakdown, networks with variable routing strategies are superior to networks without these facilities.
This paper deals with such networks operated by a store- and forward mode and alternate routing, i.e., traffic is offered at first to a primary channel: if this direct route is overloaded, traffic is diverted to a secondary route, perhaps to further routes.
Such partial traffics rejected by a route possess quite other stochastic properties than "direct traffic" offered to a primary channel (random traffic, pure chance traffic, Poisson traffic).

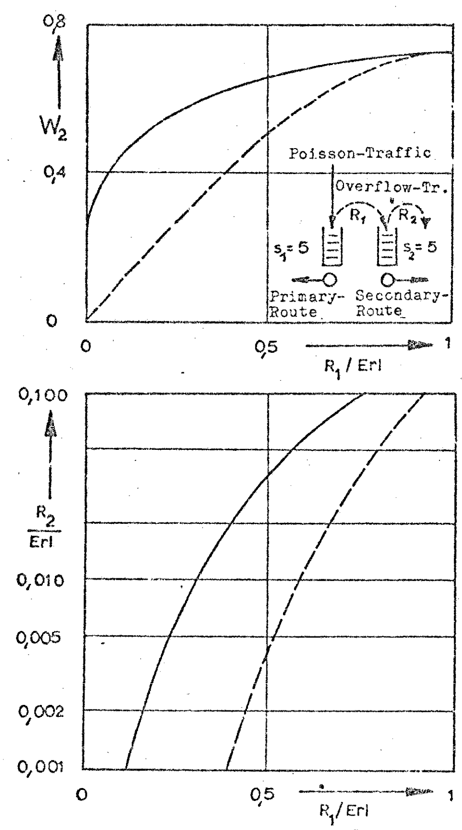


Fig 1: Probability of waiting W_2 and overflow traffic R_2 for a secondary system to which overflow traffic (mean value R_1) is offered. The secondary route is used only (in this example) if there are waiting already $s_1 = 5$ messages in the primary system. The dashed curves are obtained when assuming Poisson traffic with the same mean value.

As an example fig. 1 demonstrates the influence of these special properties on the traffic flow of the overflow system: the solid curves show values calculated exactly whereas the dashed curves are obtained when assuming random traffic instead of overflow traffic.

Therefore, neglecting the special stochastic behavior of overflow traffic, both the probability of waiting W_2 and the overflow traffic R_2 are underestimated considerably. This fact holds for all characteristic traffic values!

This typical property is well known for telephone networks (cf. Bretschneider /1/, Lotze/2/, Wilkinson /3/, etc.) and modern dimensioning methods - e.g. the design tables of the german PTT for local and toll networks - are taking into consideration the special stochastic properties of overflow traffic.
Now, these special stochastic properties have to be taken into account for data networks, too.

Various routing strategies for data networks have been proposed in the past (cf. Boehm and Mobley /4/, Fultz and Kleinrock /5/, Silk /6/, Prosser /7/, see also Butrimenko /8/, Brandt and Chrétien /9/, Beeforth, Grimsdale, Halsall and Woollons /10/, Davies /11/, Frank and Chou /12/, Kahn and Chrowther /13/, Lotze /14/, Petersen and Fu /15/, etc.).
In many papers comparisons have been done by means of simulation. For the first time, comparisons between different routing strategies by means of analytical methods have been made by Herzog and Kühn /16/. Among others there has been presented the basic idea for the dimensioning of data networks with alternate routing.

This method is now extended, i.e.

- the traffic flow within an individual data switching center is investigated by means of a more detailed model of the structur and
- total flowtimes of messages in networks with several nodes are determined.

Besides characteristic mean values and typical probability values, now also results for the waiting time distribution functions are presented.

2. MODELLING

2.1. Structure and Operating mode of Data Switching Centers.

Fig. 2. shows a simplified model for a modern data switching center. Messages arrive from other nodes of the network or from the terminal area of the considered node. These messages are stored either in different input-queues or in a common input-queue, resp.

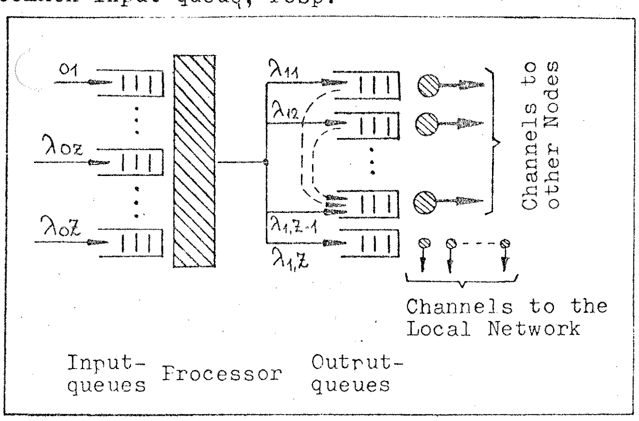


Fig.2.: Model of a data switching center. The dashed arrows indicate overflow traffic (cf. also section 2).

Operating of the input-queues will be done (e.g. in a cyclic mode) by the central processor. The processor interprets the header-information and determines the route to be chosen: if the direct route is overloaded, i.e. if there is waiting a distinct (but arbitrarily selected) number of messages, traffic is diverted to a secondary route (overflow traffics are indicated by dashed arrows in fig. 2).

According to this routing strategy, messages are put into an output-queue waiting for transmission to the next node.
All input-queues are assumed to be unlimited, i.e. no messages are rejected by the data switching center. Within one distinct queue messages are handled in the order of their arrivals (FIFO).

2.2. Traffic.

Messages arriving from the different directions are assumed to be distributed according to a Poisson-process, i.e. the distribution function of the interarrival times is given by

$$A_{oz}(\le t) = 1 - e^{-\frac{t}{a_{oz}}} = 1 - e^{-\lambda_{oz} t}$$

with the mean interarrival time a_{oz} or the mean arrival rate λ_{oz}, respectively for each direction z ($z = 1,2,\dots Z$).
This assumption approximates very close the actual interarrival times of messages, generated by the terminals. In addition, simulation results show clearly, that - assuming also negativ exponentially distributed message lengths - this holds true also for messages received from the neighbour nodes.

Processing times in the central processor are assumed to be negative exponentially distributed and uniform for each direction:

$$B_{oz}(\le t) = 1 - e^{-\frac{t}{b_o}}$$

with the mean processing time b_o.
If η_{zj} indicates the probability, that an incoming message of direction z should be transmitted in the outgoing direction j (primary route!), the total arrival rate for "direct" traffic is

$$\lambda_{1j} = \sum_{z=1}^{Z} \lambda_{oz} \cdot \eta_{zj}$$

The transmission speed may be arbitrarily chosen for each outgoing channel. Hence for messages with negative exponentially distributed holding times, the distribution function of the transmission times (for channel j) is:

$$B_{1j}(\le t) = 1 - e^{-\frac{t}{b_{1j}}}$$

with the mean transmission time b_{1j} per message in direction no. j.
The combination of both negative exponentially distributed interarrival and holding times (processing or transmission) is designated commonly as Poisson traffic, random traffic or pure chance traffic.

3. PRINCIPLE OF SOLUTION

3.1. General remarks.

In principle, an exact investigation of the traffic flow in data networks is possible: multi-dimensional state-probabilities are introduced, the Chapman-Kolmogoroff equations have to be determined and the evaluation has to be done with the aid of a relaxation method (cf. Schehrer /13/). However, for network structures of practical interest, these systems of equations are so large that their evaluation is not possible, even on the largest digital computers.
In this paper an approximate method is suggested, which allows to determine the traffic flow even in large networks. Firstly, the traffic flow through an individual data switching center is investigated and secondly, networks with several nodes are considered.

3.2. Traffic flow through a single data switching center.

When investigating the traffic flow the following four subsystems of a data switching center may be distinguished (cf. fig. 2):

- the input-system with the input-queues and the central processor,
- the primary-systems; each primary-system consists of one output-queue and one transmission channel to which direct Poisson traffic is offered only,
- the secondary-systems; each secondary-system consists of one output-queue and one transmission channel to which both offered overflow and direct traffic or overflow traffic only is directed and
- the terminal-system, connecting the data switching center with the local network and the terminals.

3.2.1. The input system.

The input-system corresponds to a single-server queuing system with a common or several parallel inputqueues, respectively, Poisson arrivals and negative exponentially distributed holding times (M/M/1). Such systems have been investigated and mathematically treated in numerous publications. Hence, formulas for all characteristic traffic values are available.
Burke /18/ proved with his famous theorem, that the output process of such an input-system is Poissonian, i.e. the interarrival times of messages offered to the transmission area of the data switching center (primary-, secondary-, terminal-systems) are also negative exponentially distributed.

3.2.2. The primary systems.

Only direct Poissonian traffic is offered to the primary systems - (M/M/1) with limited waiting room -. Therefore, formulas for many characteristic traffic values are available, such as mean waiting times, probability of waiting, waiting time distribution function etc. Traffics rejected by a primary system and offered to a secondary system (overflow traffics) are characterized in this paper not only by the first moment (mean value R_{1i}) but also by the second moment (variance σ_{1i}^2 or variance coefficient $D_{1i} = \sigma_{1i}^2 - R_{1i}$). By doing so the special stochastic character of overflow traffic can be taken into account in close approximation.

3.2.3. The secondary systems.

In the most general case, both

- direct traffics (mean $A_{1j} = \lambda_{1j} \cdot b_{1j}$, variance $\sigma_{1j}^2 = A_{1j}$ and therefore the variance coefficient $D_{1j} = 0$) and
- overflow traffics (mean R_{1i}, variance $\sigma_{1i}^2 > R_{1i}$, variance coefficient $D_{1i} > 0$)

are offered to a secondary system. Therefore, the total traffic offered to the secondary system no. j is described now not only by the sum of all mean values but also by the sum of all variance coefficients:

$$\overline{R}_{1j} = A_{1j} + \sum_i R_{1i}$$
$$\overline{D}_{1j} = \sum_i D_{1i}$$

In order to calculate the characteristic traffic values of the secondary system, a "substitute primary arrangement" and a "generating traffic" A* are determined such that an overflow traffic is generated with the mean value $\overline{R}_{1j}$ and the variance coefficient $\overline{D}_{1j}$ (cf. fig. 3). In other words: all actual traffics offered to the considered secondary system are prescribed approximately by one substitute overflow traffic with the exact mean value $\overline{R}_{1j}$ and the exact variance coefficient $\overline{D}_{1j}$ (and of course the exact variance $\overline{\sigma}_{1j}^2$). Moments of higher order are neglected.

Then this total arrangement - one substitute primary system offering overflow traffic ($\overline{R}_{1j}$, $\overline{D}_{1j}$) to the actual secondary system - is treated exactly by means of mathematical methods. Having determined the probabilities of state for this total arrangement all characteristic traffic values of the actual secondary system are calculated, too.

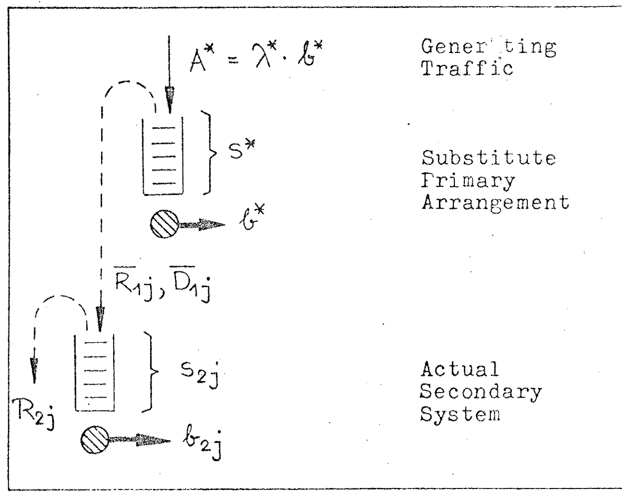


Fig.3.: Total arrangement for the calculation of the characteristic traffic values of secondary systems (cf. section 3.2.3.).

3.2.4. The terminal-system.

The terminal-system connects the data switching center with the local network and the terminals. Different types of local networks are available, such as individual subscriber lines, common bus-lines, concentrators, loop-networks etc. The main characteristic of all structures and operating modes is, that in general, there exists only one fixed route between an individual subscriber and the data switching center, i.e. there is no variable routing. Therefore, all traffics can be assumed to be Poissonian and there is no overflow traffic with special stochastic properties. Detailed studies on the traffic flow in local networks have been published (a summary of many publications is given by Herzog in /19/).

3.3. Traffic flow in a network with several nodes.

By means of the method, outlined in the preceding sections it is possible to investigate the traffic flow in each data switching center for given traffics. In data networks with several nodes the traffics are interdependent because of overflow. Therefore, the traffics offered actually to a specific route have to be determined often by iteration.
Having determined all characteristic traffic values for each connection between two nodes the total flow times for messages (sum of all waiting-, processing-, and transmission times) can be determined. The total flow times from the "originating" node to the destination are composed of the sum of flow times through the individual nodes, weighted with the probability, that a specific route has been chosen.

Fig. 4 shows as an example a small network with four nodes only. Messages from node I to the destination node II are send either on the primary route (I→II) or on the secondary route (I→III→II).

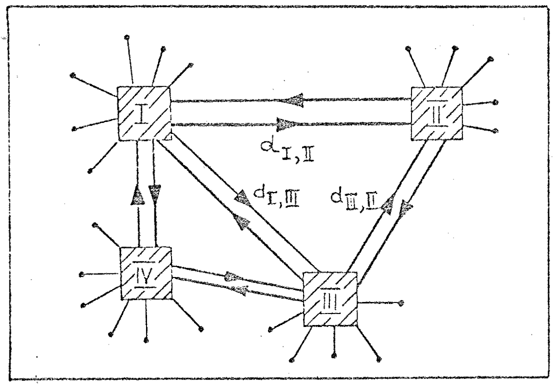


Fig.4.: Example of a small network demonstrating the calculation of total flow times (cf. section 3.3.).

At first we define by

$d_{k,l}$ the mean flow time for all messages transmitted on the channel from node k to node l and

$p_{k,l}(u,z)$ the probability, that when a message - from originating node u to the destination z - has reached the transit node k, it is transmitted via node l.

Then, the total mean flow time d(I,II) for all messages from node I to node II is given in our example by

$$d(I,II) = p_{I,II}(I,II).d_{I,II} + p_{I,III}(I,II)\{d_{I,III} + p_{III,II}(I,II).d_{III,II}\}$$

(where here $p_{III,II}(I,II) = 1$). Analogously, the corresponding equations can be found for all other traffics.

4. CALCULATION OF THE CHARACTERISTIC TRAFFIC VALUES OF A SINGLE DATA SWITCHING CENTER

This section shows in brief some well known formulas for systems with offered Poissonian traffic as well as new results for systems to which overflow traffic is offered.

4.1. The input-system.

The input-system corresponds to a single-server queuing system to which traffic is offered with markovian character (M/M/1). Therefore, formulas for all characteristic traffic values are available. E.g. for the most simple case - one common queue and arbitrary arrival rates $\lambda_{oz}(z = 1....Z)$ or Z cyclically processed queues with unique arrival rates - the mean waiting time of all messages is given by

$$w_o = \frac{1}{\lambda_o} \cdot \frac{A_o^2}{1 - A_o}$$

where

$$\lambda_o = \sum_{z=1}^{Z} \lambda_{oz}$$

$$A_o = \lambda_o \cdot b_o$$

Various queuing desciplines also for different arrival rates and parallel queues have been studied in detail by Kühn /20/.

4.2. The primary systems.

Primary systems are also pure markovian systems - (M/M/1) with $s_{1i} \leq \infty$ waiting places. Therefore, formulas which characterize the waiting process of such a system are well known from literature. In particular, the mean waiting time for all messages carried by a primary system is given by:

$$w_{Yi} = \begin{cases} b_{1i} \cdot A_{1i} \cdot \dfrac{1 - A_{1i}^{s_{1i}}[s_{1i}+1 - s_{1i} \cdot A_{1i}]}{1 - A_{1i}} \cdot \dfrac{1 - A_{1i}^{s_{1i}+2}}{(1 - A_{1i}^{s_{1i}+1})^2} ; & A_{1i} \gtrless 1 \\ b_{1i} \cdot \dfrac{s_{1i}+2}{2} ; & A_{1i} = 1 \end{cases}$$

If there is a limited waiting room in front of a channel ($s_{1i} < \infty$ waiting places) some messages are rejected. This overflow traffic (which is offered to a secondary system, cf. section 3) is characterized by the first two moments, the mean value R_{1i} and the variance coefficient $D_{1i} = \sigma_{1i}^2 - R_{1i}$. Arbitrary moments of overflow traffic have been studied formerly /16/ by means of a two dimensional markovian process. The most interesting results for us, mean value and variance coefficient are given by (cf. fig. 5.):

$$R_1 = \frac{A_1^{s_1+2}}{1 + A_1 \cdot \dfrac{1 - A_1^{s_1+1}}{1 - A_1}}$$

$$D_1 = R_1^2 \cdot \left\{ \frac{c_1 \cdot A_1}{c_2 \cdot R_1} - 1 \right\}$$

where

$$c_1 = \frac{1}{2k_2} \cdot \left\{ [1 + A_1 - (k_1 - k_2)] \cdot (k_1 + k_2)^{s_1+1} - [1 + A_1 - (k_1 + k_2)] \cdot (k_1 - k_2)^{s_1+1} \right\}$$

$$c_2 = 1 + \frac{1}{2k_2} \left\{ [1 + A_1 - (k_1 - k_2)] \sum_{\nu=0}^{s_1} (k_1 + k_2)^{\nu+1} - [1 + A_1 - (k_1 + k_2)] \sum_{\nu=0}^{s_1} (k_1 - k_2)^{\nu+1} \right\}$$

$$k_1 = 1 + \frac{A_1}{2}$$

$$k_2 = \sqrt{1 - \left(\frac{A_1}{2}\right)^2}$$

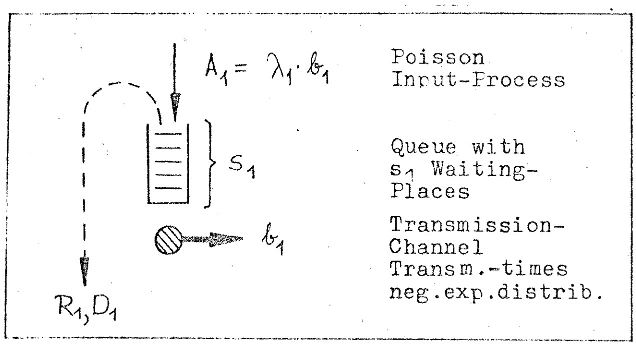


Fig.5.: Primary system with offered Poisson traffic.

4.3. The secondary systems.

As shown before, overflow traffic has quite other statistical properties than Poissonian traffic. However, when assuming a two dimensional Markovian process, it is possible to determine all characteristic traffic values, including the waiting time distribution. The exact mathematical treatment is outlined for "substitute arrangements" to which all actual systems can be traced back: one primary and one secondary system (cf. section 3.2.3. and fig. 3.).

4.3.1. Probabilities of state.

At first we define by $\{u_1, u_2\}$ the state that there are u_1 messages in the primary system and u_2 in the secondary system simultaneously (waiting or being served). Then, the two-dimensional Chapman-Kolmogoroff equations for the probabilities $p(u_1, u_2)$ of $\{u_1, u_2\}$ can be found. When introducing the Z-transform and systematic replacement of unknown probability-values by the "basic" states $p(o,u_2)$ it is possible to express all probabilities of state $p(u_1,u_2)$ by the marginal values $p(o,u_2)$, $p(o,u_2+1)$, ... , $p(o,s_2+1)$ (s_2: number of waiting places in the secondary system). In other words: the two dimensional state relations can be reduced to a one dimensional system ($u_1=o$). The solution of such a one dimensional system can be easily found. It is given by (cf. also /16,19/):

$$p(u_1,u_2) = \frac{A_1^{u_1}}{1 + A_1 \frac{1-A_1^{s_1+1}}{1-A_1}} \cdot \frac{\sum_{\varrho=u_2}^{1+s_2} c_{u_1,u_2,\varrho} \cdot b_\varrho}{\sum_{\gamma=0}^{1+s_2}\sum_{\varrho=\gamma}^{1+s_2} c_{u_1,\gamma,\varrho} \cdot b_\varrho}$$

where

$$c_{u_1,u_2,\varrho} = -\sum_{\xi=0}^{u_1-1} c_{\xi,u_2+1,\varrho} \cdot \beta_{u_1-\xi} \quad ; u_2 \neq \varrho ; u_2 \neq 0, \varrho > u_2$$

$$c_{u_1,0,\varrho} = -\sum_{\xi=0}^{u_1-1} c_{\xi,1,\varrho} \cdot \beta'_{u_1-\xi} \quad ; u_2 \neq \varrho ; u_2 = 0$$

$$c_{u_1,u_2,\varrho} = (f + A_1)\beta_{u_1} - A_1 \cdot \beta_{u_1-1} \quad ; u_2 = \varrho ; u_2 \neq 0$$

$$c_{u_1,u_2,\varrho} = A_1 \cdot \beta'_{u_1} - A_1 \cdot \beta'_{u_1-1} \quad ; u_2 = \varrho ; u_2 = 0$$

$$c_{u_1,u_2,\varrho} = 0 \quad ; u_2 > \varrho$$

$$b_{u_2} = \sum_{z_1=u_2+1}^{1+s_2} a_{u_2,z_1} \cdot \sum_{z_2=z_1+1}^{1+s_2} a_{z_1,z_2} \sum_{z_3=z_2+1}^{1+s_2} a_{z_2,z_3} \cdot \ldots \sum_{z_W=z_{W-1}+1}^{1+s_2} a_{z_{W-1},z_W} \quad ; W = 1+s_2-u_2$$

$$a_{u_2,\varrho} = \frac{-A_1 \cdot c_{1+s_1,u_2,\varrho} + (1+f+v \cdot A_1) c_{1+s_1,u_2+1,\varrho} - v \cdot c_{1+s_1,u_2+1,\varrho} - A_1 \cdot c_{s_1,u_2+1,\varrho}}{A_1 \cdot c_{1+s_1,u_2,u_2}}$$

$$v = \begin{cases} 1 & \text{when } 0 \leq u_2 < s_2 \\ 0 & \text{otherwise} \end{cases}$$

$$\beta_{u_1} = \frac{\alpha_1^{u_1} - \alpha_2^{u_1}}{\alpha_1 - \alpha_2} \; ; \; \beta'_{u_1} = \frac{(\alpha'_1)^{u_1} - (\alpha'_2)^{u_1}}{\alpha'_1 - \alpha'_2} \; ; \; f = \frac{\varepsilon_2}{\varepsilon_1} \; ; \; A_1 = \frac{\lambda_1}{\varepsilon_1}$$

$$\alpha_1,\alpha_2 = \frac{(1+f+A_1) \pm \sqrt{(1+f+A_1)^2 - 4A_1}}{2} \; ; \; \alpha'_1,\alpha'_2 = \frac{(f+A_1) \pm \sqrt{(f+A_1)^2 - 4A_1}}{2}$$

4.3.2. Characteristic mean values for secondary-systems.

All state probabilities $p(u_1,u_2)$ have been determined in the previous section. Therefore, it is easy to find the characteristic mean values for the secondary system, as there are:

Carried traffic

$$Y_2 = \sum_{u_1=0}^{1+s_1}\sum_{u_2=1}^{1+s_2} p(u_1,u_2) = \frac{\lambda_1}{\varepsilon_2} \left[p(u_1=s_1+1) - p(s_1+1,s_2+1)\right]$$

Lost traffic

$$R_2 = \frac{\lambda_1}{\varepsilon_2} \cdot p(1+s_1, 1+s_2)$$

Mean number of messages waiting for service

$$\Omega_2 = \sum_{u_1=0}^{1+s_1}\sum_{u_2=1}^{1+s_2} (u_2-1) \cdot p(u_1,u_2)$$

Mean waiting time for all messages, not rejected by the system

$$w_{Y2} = \frac{\Omega_2}{\lambda_1 [p(u_1=s_1+1) - p(s_1+1,s_2+1)]} = \frac{\Omega_2}{Y_2 \cdot \varepsilon_2}$$

Mean waiting time for all messages, which have to wait in the system

$$t_{W_2} = \frac{\Omega_2}{\lambda_1 \cdot \sum_{u_2=1}^{s_2} p(1+s_1,u_2)}$$

4.3.3. Probability of waiting for secondary-systems.

The probability that an incoming message has to wait under the condition, that it is offered to the secondary system is given by

$$W_2 = \frac{\sum_{u_2=1}^{s_2} p(1+s_1,u_2)}{\sum_{u_2=0}^{s_2+1} p(1+s_1,u_2)}$$

4.3.4. The waiting time distribution function (w.d.f.) for secondary systems.

The w.d.f. $F_2(\leq t)$ is the probability that an arbitrary message has to wait at most the time t under the condition that the considered message was offered to the secondary system. When determining the w.d.f., a test-call is considered. This test-call is offered to the secondary system, if there are u_2 messages in the secondary system ($u_2=o,1, .. s_2+1$).

The probability that the considered test-call has to wait at most the time interval t is defined as $F_{u_2}(\leq t)$.
Therefore, the total w.d.f. is given by

$$F_2(\leq t) = \frac{\sum_{u_2=0}^{s_2+1} \lambda_1 \cdot dt \cdot p(s_1+1,u_2) \cdot F_{u_2}(\leq t)}{\sum_{u_2=0}^{s_2+1} \lambda_1 dt \cdot p(s_1+1,u_2)}$$

$$F_2(\leq t) = \frac{1}{p(u_1=s_1+1)} \cdot \sum_{u_2=0}^{s_2+1} p(s_1+1,u_2) \cdot F_{u_2}(\leq t)$$

The complementary w.d.f. (complement of the waiting time distribution function) is $F_{u_2}(>t)$, i.e. the probability, that the considered test-call has to wait longer than the time t. When calculating this probability, the following three cases have to be distinguished:

$u_2 = o$:

the test-call will be transmitted immediately, i.e.

$$F_o(>t) = 0$$

$o > u_2 \geq s_2$:

the test-call has to wait. This waiting time is longer than the time t, if in this time interval no, one, etc. or at most (u_2-1) messages, waiting before the test-call can be transmitted. In the latter case, the test-call is "sitting" at the first waiting place, i.e. transmission can start not before the instant (t+dt):

$$F_{u_2}(>t) = \sum_{\gamma=0}^{u_2-1} \frac{(\varepsilon_2 \cdot t)^\gamma}{\gamma!} \cdot e^{-\varepsilon_2 \cdot t}$$

(The probability, that exactly γ messages can be transmitted in a fixed time interval is given by the well known Poisson-distribution).

$u_2 = s_2+1$:

the test-call is offered to the secondary system. However, because there is no free waiting place, it is rejected. In other words: the test-call is not allowed to wait

$$F_{s_2+1}(>t) = 0$$

The waiting-time distribution function $F_{u_2}(\leq t)$ is given in each case by the complement of the probability $F_{u_2}(>t)$.
Substituting this quantities into the fundamental equation the w.d.f. for an arbitrarily chosen message is given by

$$F_2(\leq t) = 1 - \frac{e^{-\varepsilon_2 t}}{p(u_1 = s_1+1)} \sum_{u_2=1}^{s_2} p(s_1+1, u_2) \sum_{\nu=0}^{u_2-1} \frac{(\varepsilon_2 t)^{\nu}}{\nu!}$$

5. NUMERICAL RESULTS, COMPARISON WITH SIMULATION RESULTS

As shown before, all characteristic traffic values for the input-system and also for primary systems can be determined exactly.
All characteristic traffic values referring to secondary systems are approximations because the actually offered overflow traffics are substituded by a ficticious traffic generating exactly only the most important moments of the actual traffics.
Therefore, a large number of simulation runs have been performed by means of two simulation programs. Comparison of both simulated and calculated values shows the accuracy of the new method (cf. fig. 6 to 11).

6. CONCLUDING REMARKS AND FUTURE PLANS

By reasons of economy and reliability networks with flexible routing strategies are superior to networks without this capability. Then however, overflow traffics occur with special stochastic properties.
In order to avoid wrong estimates of traffic capacity and flow times this special stochastic behaviour has to be taken into consideration when planning such networks.
Today, the exact mathematical treatment of complex networks is not possible even on the largest digital computers. Therefore a handy approximate method has been proposed which allows to determine important traffic characteristics for individual data switching centers as well as for complex store- and forward networks with alternate routing. Comparisons show the good accordance between calculated values and simulation results.

The above presented investigations dealt with

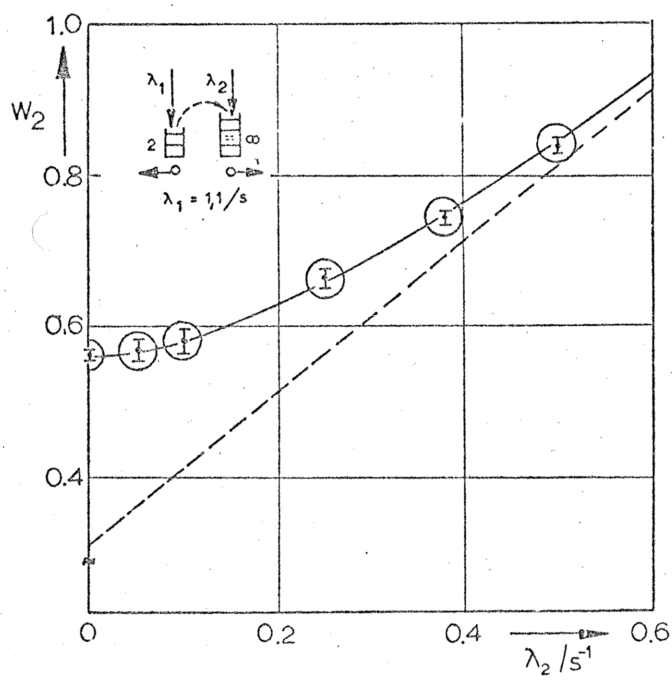


Fig.6.: Probability of waiting W_2 for a secondary system, to which overflow traffic and direct traffic (with call rate λ_2) is offered. The mean transmission time per message is 1 second for both primary and secondary channel. Comparison between calculation (——) and simulation (I; 95 % - confidence intervals). Neglecting the special character of the overflow traffic, the dashed line is obtained.

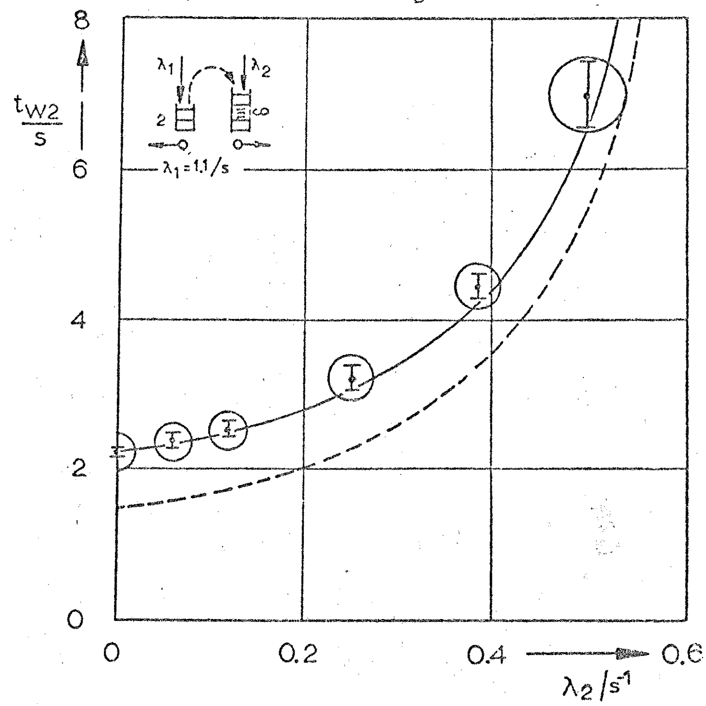


Fig.7.: Mean waiting time t_{W2} for messages which have to wait in the secondary system. Comparison between calculation and simulation (cf. fig.6.).

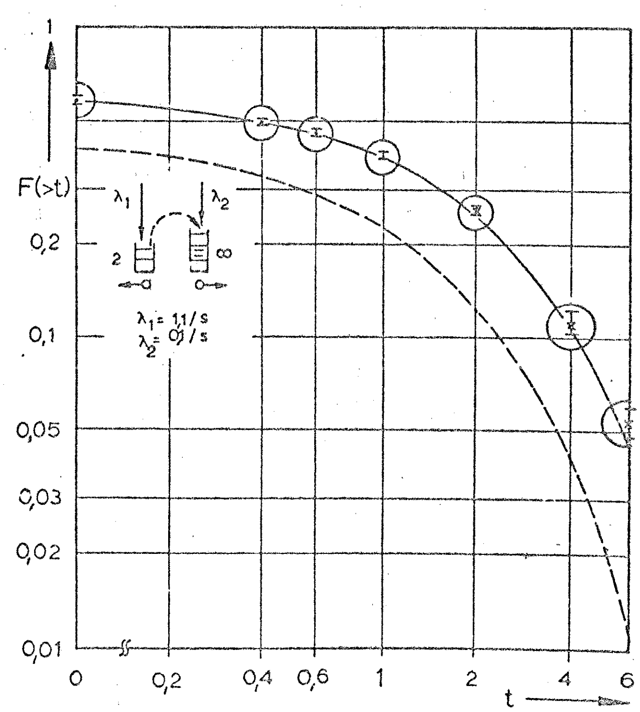


Fig.8.: Complementary w.d.f. for all messages offered to the secondary system. Comparison between calculation and simulation (cf.fig.6.).

networks with at most a single overflow for each direction. It could be advantageous for some networks to have more than one overflow possibility or to allow mutual overflow. Investigations are planned to include such possibilities in the new method.

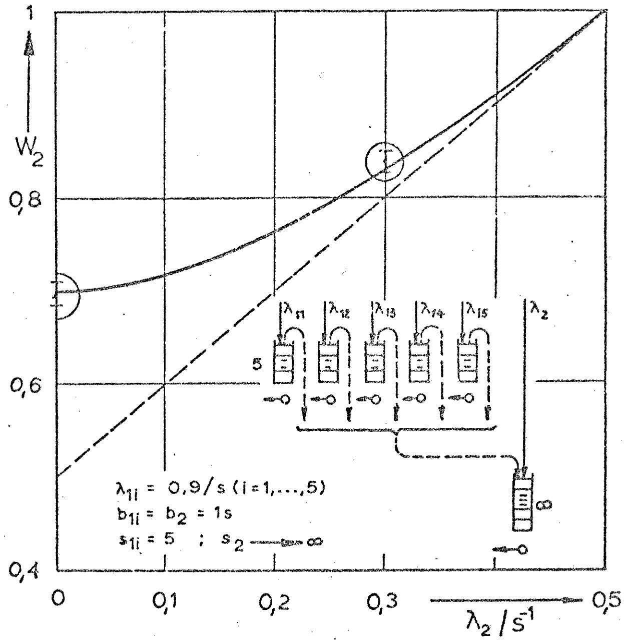


Fig.9.: Probability of waiting W_2 for a secondary system, to which five overflow traffics and direct traffic are offered. Comparison between calculation (——) and simulation (I; 95 %-confidence intervals). Neclecting the special character of overflow traffic, the dashed line is obtained.

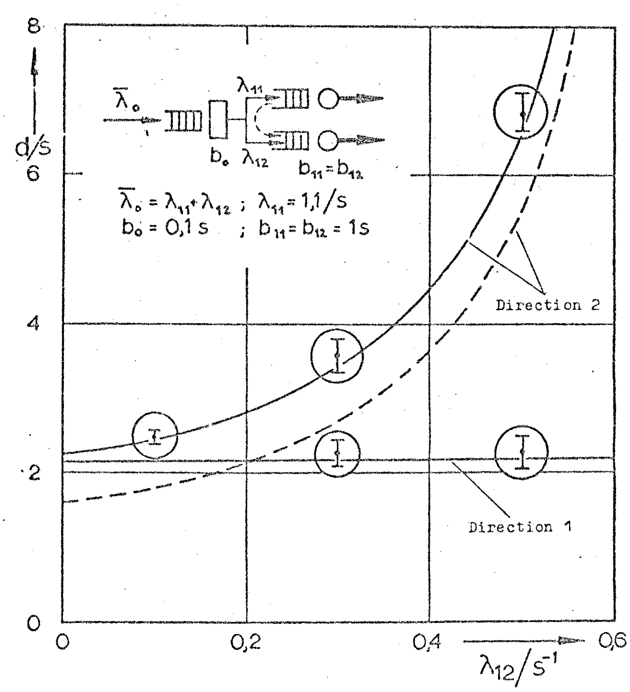
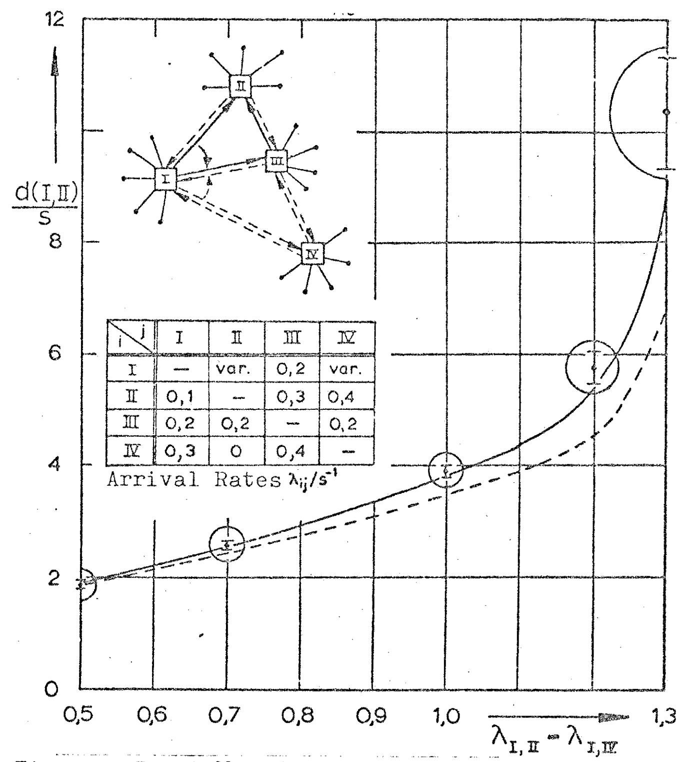


Fig.10.: Flow time through a data switching center for messages transmitted via direction 1 or 2 respectively. Comparison between calculation (——) and simulation (I; 95%-confidence intervals). Neglecting the special character of overflow traffic the dashed curve is obtained.



i \ j	I	II	III	IV
I	—	var.	0,2	var.
II	0,1	—	0,3	0,4
III	0,2	0,2	—	0,2
IV	0,3	0	0,4	—

Fig.11.: Total flow time for all messages from "originating" node I to the destination II. Example of a network with four nodes. Comparison between calculation (——) and simulation (I; 95%-confidence intervals). Neglecting the special character of overflow traffic the dashed curve is obtained.

In the last few years store- and forward networks with packet-switching became more important. For such networks, with constant transmission time for each packet an analogous solution seems to be possible.

The above investigated routing strategy is only one flexible routing strategy which can be realized most easily and without great expenditure. Numerous other strategies have been proposed and can be investigated only by means of simulation programs. If one could find for such strategies also good approximate calculation methods, it would be possible to compare different routing strategies analytically to a great extend.

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