EFFICIENT PRIORITY STRATEGIES FOR SWITCHING CENTERS IN COMMUNICATION NETWORKS

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Abstract : Various priority strategies for real-time computer systems are discussed, uniformly described and mathematically treated, as well. Numerical examples illustrate the importance of so called preemption-distance priorities.

1. PROBLEM

The most important demand to switching centers in communication networks is their fast reaction to urgent signals. Typical examples are the processing of

- alarms indicating the breakdown of transmission channels, of other switching centers or of system components in the considered switching center itself,
- routing informations concerning the instantaneous traffic load in the network,
- urgent messages (or telephone calls) between different terminals (or telephone subscribers) in the network.

Such demands might be fulfilled by means of pure preemptive priorities for all priority classes. However, each interruption needs some additional amount of overhead:

- the interrupt must be analyzed,
- the contents of registers have to be saved,
- the queues have to be reorganized,

etc. In order to keep this additional system load as small as possible modern real-time systems use reasonable combinations of preemptive and non-preemptive (head-of-the-line) priorities.

Two examples may illustrate the manifold of strategies to be considered and to be analyzed:

EWS 1 (cf. [1])

In the new electronic telephone switching system of the Federal German Post Office the following strategy is used:

All signals are classified into some few priority groups which interrupt each other (preemptive priorities). Within one group several non-preemptive (head-of the-line) classes are to be distinguished (e.g. alarms of different importance, various switching demands, etc.). Figure 1 shows a small

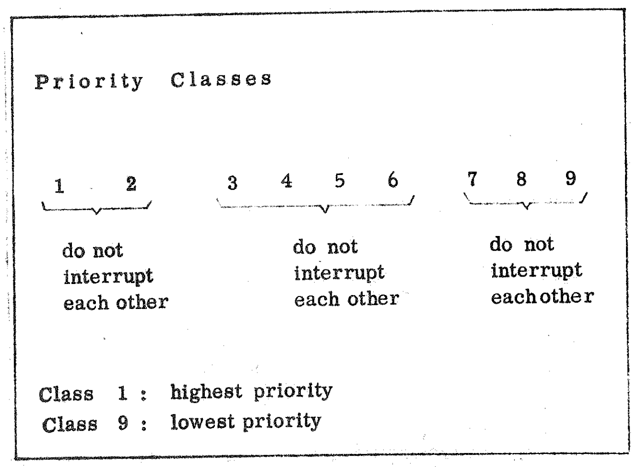

Fig. 1: First example for a combination of both, preemptive and non-preemptive (head-of-the-line) priorities (EWS 1, cf. text).

New arriving demand of class	does not interrupt service of class	interrupts service of class	Preemption Distance
1	1,2	3,4,5,6,7,8,9	2
2	1,2	3,4,5,6,7,8,9	1
3	1,2,3,4,5,6	7,8,9	4
4	1,2,3,4,5,6	7,8,9	3
5	1,2,3,4,5,6	7,8,9	2
6	1,2,3,4,5,6	7,8,9	1
7	1,2,3,4,5,6,7,8,9	-	-
8	1,2,3,4,5,6,7,8,9	-	-
9	1,2,3,4,5,6,7,8,9	-	-

Fig. 2: Service mechanism and Preemption-Distance corresponding to the priority strategy of figure 1.

but typical example for these types of priority strategies. Dependent on the importance of a demand, the distance to the next class of priorities to be interrupted - the so called Preemption-Distance - varies (cf. also fig. 2).

EDS (cf. [2])

EDS is the new electronic data switching system of the German Post Office and Western Union, as well. For the I/O-Control of the storage unit the following remarkable strategy is used: The priorities can be controlled such

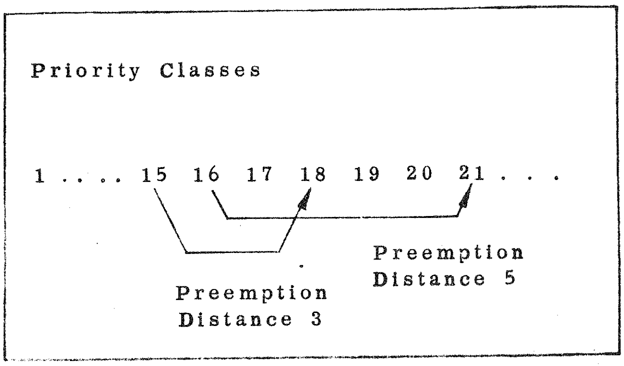

Fig. 3: Second example (EDS) for a combination of preemptive and non-preemptive priorities (cf. text).

that, e.g., priority class 15 interrupts demands of class 18, 19, etc., however not the intermediate classes 16 and 17 whereas class 16 interrupts only class 21, 22, etc. The strategy is illustrated in fig. 3 and allows generally interpreted a sliding passage from preemptive to non-preemptive priorities.

These are just two important examples, numerous other reasonable combinations of preemptive and non-preemptive priorities are possible and implemented.

In the following section it is shown how this variety of combinations can be uniformly described by means of the Preemption-Distance ξ. Therefore, it seems to be reasonable to introduce the unifying term "Preemption -Distance Priorities".

Results presented in [3] for Preemption-Distance priorities are generalized by introducing a General Erlangian distribution. Moreover, additional characteristic performance values are presented. Numerical examples demonstrate the advantages of Preemption-Distance priorities.

2. DESCRIPTION OF PREEMPTION-DISTANCE PRIORITIES.

2. 1. Uniform Preemption-Distance for all Classes, Preemptive priorities, Non-Preemptive Priorities.

Already in the first section the preemption-distance was introduced: The distance between an arbitrary but distinct priority class and the next priority class being interrupted.

Fig. 4 illustrates this definition: Demands of class p ($p \in 1,2,\dots P$; class 1 most urgent) interrupt only demands of class ($p+\xi$) to P, however not the intermediate classes ($p+1$) to ($p+\xi-1$). On the other hand demands of

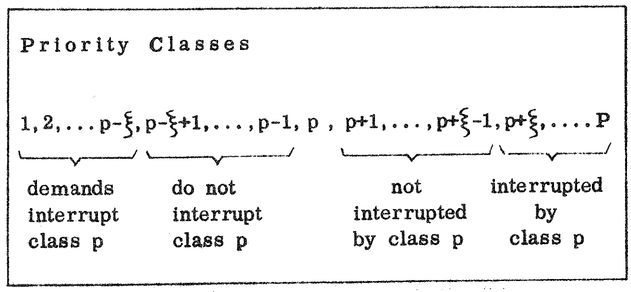

Fig. 4: Introduction of the Preemption-Distance . The special cases, preemptive priorities ($\xi=1$) and non-preemptive priorities ($\xi= P$), are included.

the considered class p can be interrupted by class 1 to ($p-\xi$), however not by classes ($p-\xi+1$) to ($p-1$).

It is seen easily that two wellknown special cases of Preemption-Distance priorities are included:

$\xi = 1$: Preemptive priorities

$\xi = P$: Non-preemptive (head of the line) priorities.

2. 2. Arbitrary, Non-Uniform Preemption-Distance for each Priority Class.

Introducing for each class p ($p \in 1,2,\dots,P$) the preemption-distance $\xi(p)$ with a definition analogeous to section 2.1. arbitrary combinations of pure preemptive and non-preemptive priorities are possible. Although the uniform representation and analysis is possible, this way of solution is rather complex.

A much more elegant solution is possible using a uniform preemption-distance and introducing "empty" priority classes: ficticious priority classes (with the arrival rate null) are interleaved between the actual ones.

This trick allows us to generate all strategies of practical interest easily (the only two special cases known from literature [4, 5] are included). Furthermore, it facilitates the investigation of their influence on the waiting process.

As an example fig. 5 shows how the priority strategies of the EWS-type (cf. fig. 1 and section 1) can be obtained.

Uniformly prescribed Preemption-Distance	actual and "empty" priority classes	mean arrival rate	actual priority classes	actual Preemption-Distance
4	1	λ_1	1	2
4	2	λ_2	2	1
4	3	-	-	-
4	4	-	-	-
4	5	λ_5	5	4
4	6	λ_6	6	3
4	7	λ_7	7	2
4	8	λ_8	8	1
4	9	-	-	-
4	10	-	-	-
4	11	-	-	-
4	12	-	-	-
4	13	λ_{13}	13	-
4	14	λ_{14}	14	-
4	15	λ_{15}	15	-

Fig. 5: Example for the generation of a non-uniform Preemption-Distance by means of "empty" classes (cf. fig. 1, 2 and text).

3. ANALYSIS

3.1 Structur and Operating Mode of the Investigated System.

Fig. 6 shows schematically the system to be investigated: Arriving demands are classified into P parallel queues according to their priority. All queues are assumed to be

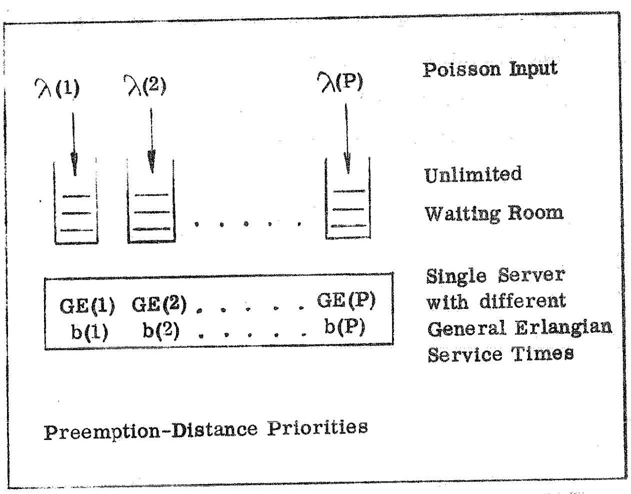

Fig. 6: The investigated system (details cf. text).

unlimited, i.e. every arriving demand will be stored and processed. This assumption is almost always fulfilled, especially in systems with dynamic core allocation.

All demands are served according to an arbitrary Preemption-Distance strategy, treated in the previous sections. FIFO is assumed within each priority class.

3.2. Traffic Parameters.

Demands of each priority class p($p \in 1, 2, \ldots, P$) are distributed according to a Poisson process with the mean arrival rate $\lambda(p)$:

$$A_p(\le t) = 1 - e^{-\frac{t}{a(p)}} = 1 - e^{-\lambda(p)\cdot t}$$

Service times follow -individually for each priority class- a General Erlangian (GE) distribution:

$$B_p(\le t) = \sum_{\nu=1}^{l(p)} q_\nu(p)\left(1 - e^{-\frac{t}{b_\nu(p)/k_\nu(p)}} \sum_{\eta=0}^{k_\nu(p)-1} \frac{\left(\frac{t}{b_\nu(p)/k_\nu(p)}\right)^\eta}{\eta!}\right)$$

with the mean value

$$b(p) = \sum_{\nu=1}^{l(p)} q_\nu(p)\cdot b_\nu(p)$$

and the variance

$$\sigma^2(p) = \sum_{\nu=1}^{l(p)} \frac{k_\nu(p)+1}{k_\nu(p)} \cdot b_\nu(p)^2 \cdot q_\nu(p) - b(p)^2$$

where

l : number of (ficticious) parallel "chains" of exponential "stages"

q_ν: probability that chain no ν ($\nu \in 1, 2, \ldots, l$) is passed

k_ν: number of stages for chain no ν

b_ν: mean service time for one stage of chain no ν

It is worthwhile to notice that this distribution allows to approximate any type of distribution function of service times with any required accuracy. Obviously, it includes the hyperexponential ($k_\nu(p)=1$) as well as the Erlangian distribution ($l(p)=1$) both most important for many applications.

Neglected is the time to handle interrupts. This assumption is also allowed because of large real-time computers have duplexed register sets and hardware for interrupt handling (for small systems without these facilities, cf. section 5).

3.3. Analysis.

3.3.1. General remarks.

The most famous methods to investigate the stochastic behavior of such non-Markovian queuing systems are

- the method of imbedded markov chains [6]
- the phase method [7]
- the integral method [8]
- the method of substitut variables [9]

When investigating arbitrary kinds of Preemption-Distance priorities, all methods failed because of the complex interdependencies between different priority classes. However, a general solution was possible by means of the method of moments: The fate of an individual demand of priority class p is persued from its arrival up to the point where it leaves the system. All possibilities of interruptions, processing, pushing back in the queue, etc. are considered. Finally, when introducing expectation values the presented solution can be obtained.

3.3.2. Characteristic Performance Values.

The expected response time (time spend in the system, waiting and being processed) d(p) for a demand of priority class p ($p \in 1, 2, \ldots, P$) is composed of the following five terms:

1) The expectation $b_R(p+\xi-1)$ of the remaining rest-service time for demands of the priority classes 1 to $(p+\xi-1)$ present at its time of arrival in the server and not being interrupted by the considered p-demand.

2) The expected time $w_I(p)$ necessary to serve demands of the priority classes 1 to p waiting in the system at its time of arrival.

3) Its expected time in service b(p).

4) The expected time $w_{II}(p)$ necessary to serve demands of preemptive priority classes 1 to $(p-\xi)$ which enter the system, while the considered p-demand is still in the system.

5) The expected time $w_{III}(p)$ necessary to serve demands of the non-preemptive priority classes $(p-\xi+1)$ to $(p-1)$ which enter the system, while the considered p-demand is still in the system, however before its last interruption.

A detailed study of these five terms presented in [10] leads to the following recursive solution for the expected response time for priority class p ($p \in 1, 2, \ldots, P$):

(5)
$$d(p) = \left\{ \sum_{i=1}^{p-1} A(i) \cdot d(i) + b(p) + b_R(\leq p+\xi-1) - \sum_{i=1}^{p} A(i) \cdot b(i) - \sum_{i=1}^{p} \Omega_u(i) \left\{ b(i) - b_g(i) \right\} - b_n(p) \sum_{i=p-\xi+1}^{p-1} A(i) \right\} \cdot \left\{ 1 - \sum_{i=1}^{p} A(i) \right\}^{-1}$$

Where
$$b_R(\leq p+\xi-1) = \sum_{v=1}^{p} \frac{A(v)}{2\,b(v)} \sum_{\nu=1}^{\ell(v)} \frac{k_\nu(v)+1}{k_\nu(v)} \cdot b_\nu(v)^2 \cdot q_\nu(v) + \sum_{v=p+1}^{p+\xi-1} \frac{A(v)}{\lambda_u(v)^2 \cdot b(v)} \cdot \left\{ \lambda_u(v) \cdot b(v) - 1 + \sum_{\nu=1}^{\ell(v)} \frac{q_\nu(v)}{(\lambda_u(v) \cdot b_\nu(v)/k_\nu(v)+1)^{k_\nu(v)}} \right\}$$

is the expected time a demand of class p has to wait until demands of lower priority which can not be interrupted leave the server.

$$\Omega_\mu(i) = \lambda(i) \cdot \frac{b(i) \sum_{j=1}^{i-1} A(j) - b_n(i) \sum_{j=i-\xi+1}^{i-1} A(j)}{1 - \sum_{j=1}^{i-1} A(j)}$$

is the mean number of demands of class i waiting however being interrupted at least once.

$$b_n(p) = \frac{1}{\lambda_u(p)} \left\{ 1 - \sum_{\nu=1}^{\ell(p)} \frac{q_\nu(p)}{(\lambda_u(p) \cdot b_\nu(p)/k_\nu(p)+1)^{k_\nu(p)}} \right\}$$

is the remaining rest-service time of a demand of class p after its last interruption.

$$b_g(v) = \frac{1}{2 \cdot b(v)} \sum_{\nu=1}^{\ell(v)} \frac{k_\nu(v)+1}{k_\nu(v)} \cdot b_\nu(v)^2 \cdot q_\nu(v).$$

is the remaining service time for a demand of class i.

Additionally,

$$A(p) = \lambda(p) \cdot b(p)$$

$$\lambda_\mu(p) = \sum_{i=1}^{p-\xi} \lambda(i)$$

Remark: It should be mentioned that an explicit solution has also been found. However, from the computational viewpoint the presented recursive solution is more practical.

Besides the expected response time and waiting time w(p) = d(p) - b(p) the following characteristic performance measures have been derived:

Probability that a demand of class p is interrupted at least once:

(6)
$$P_u(p) = 1 - \sum_{\nu=1}^{\ell(p)} \frac{q_\nu(p)}{(\lambda_\mu(p) \cdot b_\nu(p)/k_\nu(p)+1)^{k_\nu(p)}}$$

Mean number of interrupts per demand of priority class p:

(7)
$$u(p) = \lambda_u(p) \cdot b(p)$$

Probability of waiting for demands of priority class p:

(8)
$$W(p) = \sum_{i=1}^{p+\xi-1} A(i) + \left\{ 1 - \sum_{i=1}^{p+\xi-1} A(i) \right\} \cdot P_u(p)$$

4. NUMERICAL RESULTS

Three examples may show the various kinds of operating strategies and service times to be prescribed and analyzed now uniformly.

The examples also show how advantageous Preemption-

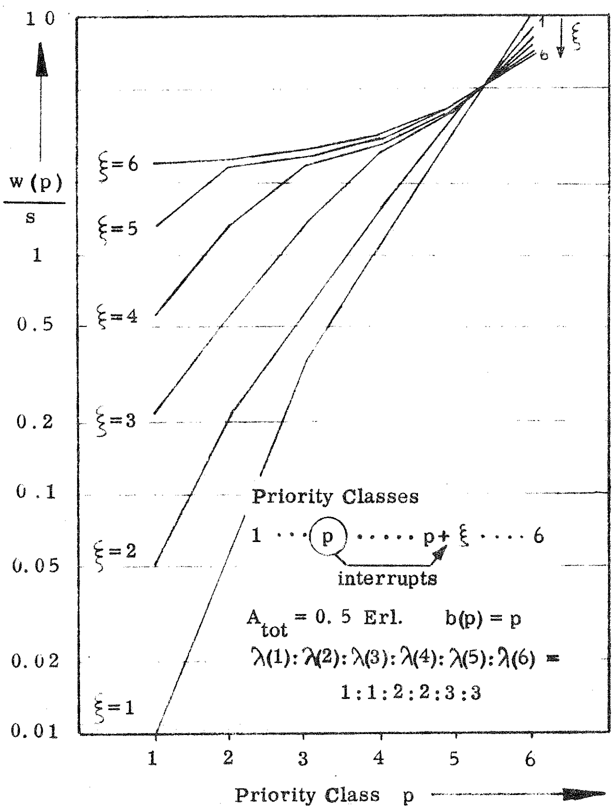

Fig. 7 : Mean waiting time w(p). For this example all service-times are assumed to be exponentially distributed, however with different mean values per class.

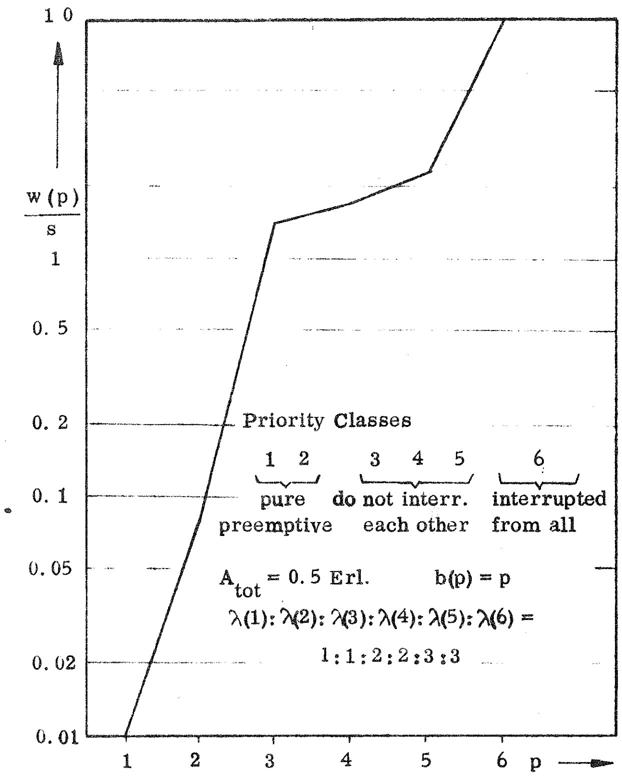

Fig. 9 : Typical example for an efficient combination of pre-emptive and non-preemptive priorities (compare it with the priority strategies of figure 7 !).

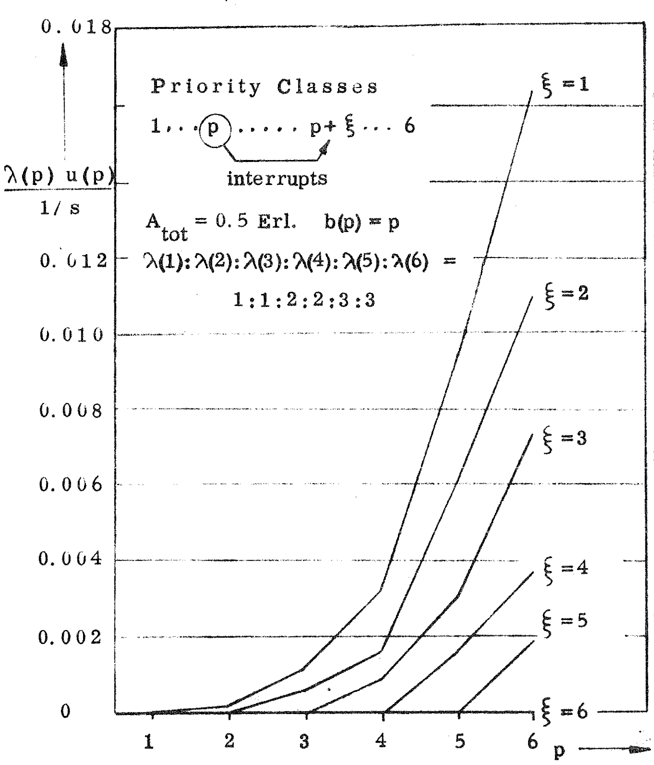

Fig. 8 : Mean number of interrupts per second for uniform Pre-emption-Distance (cf. fig. 7).

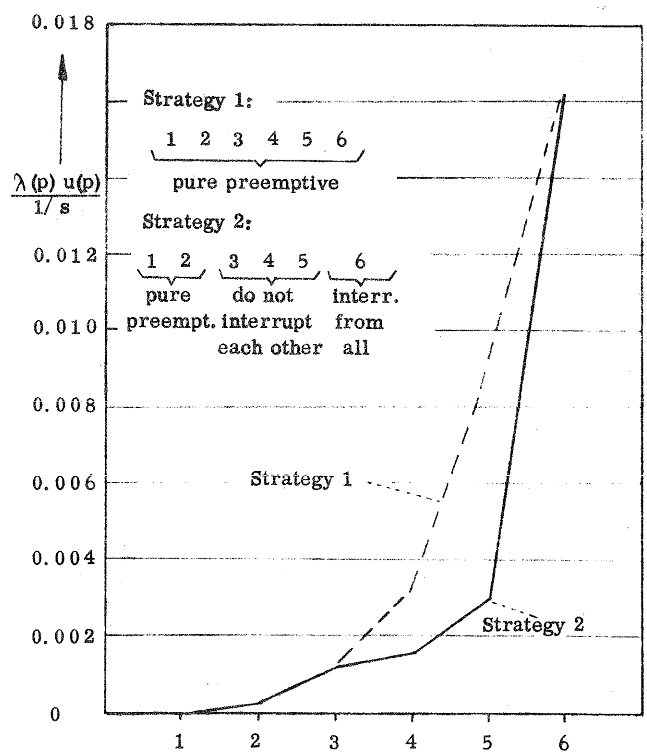

Fig. 10 : Mean number of interrupts per second for non-uniform Preemption-Distance (cf. fig. 9).

Distance priorities are compared to pure preemptive or pure non-preemptive (head-of-the-line) priorities.

4.1. Uniform Preemption-Distance.

Fig. 7 shows the influence of the Preemption-Distance on the mean waiting time. Traffic intensity and traffic character are constant.

The response time is 250 times smaller for $\xi = 1$ than for $\xi = 6$ (head-of-the-line). However, the price to be paid is shown in fig. 8: an immense amount of interruptions occur.

4.2. Non-Uniform Preemption-Distance.

Fig. 9 shows a reasonable and often used "mixed" strategy between the two extremes leading for the urgent demands exactly to the same fast response time as preemptive priorities, however saving a remarkable amount of interrupts (cf. fig. 10).

4.3. Extreme Distribution Functions for the Processing Times.

Fig. 11 demonstrates which extreme types of distribution functions are included in the solution presented above. Fig. 12 shows for this example some values for the probability of waiting.

5. CONCLUSION

Reasonable combinations of preemptive and head of the line priorities are of major interest when operating switching centers in communication networks. They guarantee fast reaction to urgent signals avoiding large overhead. All these strategies are uniformly described by introducing the Preemption-Distance. The only two special cases known from literature are included in the description and analysis, as well.

The modelling with service times according to a General Erlangian distribution allows the accurate description of any type of processing times.

Mean values (response time, waiting time,...) and characteristic probability values (probability of interruption,...) show the main feature of a destinct strategy. For many practical applications these results are sufficient. A more detailed analysis is possible by means of the distribution function and a first step in this direction is the variance being taken just into consideration.

Modern switching centers have duplexed register sets and hardware for interrupt handling. Therefore, the time for interrupt handling is very small compared to the processing times. However, it is proposed to analyze control-

Priority Class	Does Not Interrupt	Interrupts Class	Preemption Distance
1	1	2, 3	1
2	1, 2, 3	-	2
3	1, 2, 3	-	-

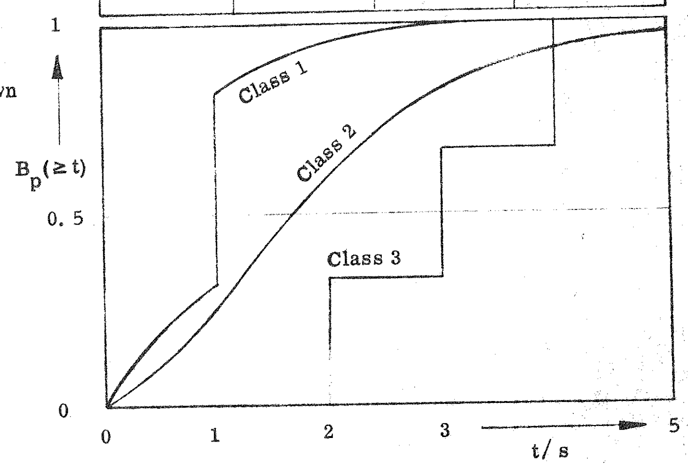

Fig. 11: Example for three different types of service time distribution functions included in the General Erlangian distribution. The mean values are assumed to be proportional to the class-number (b(1)=1sec, b(2) = 2 sec, b(3) = 3 sec), the Preemption-Distance is non-uniform.

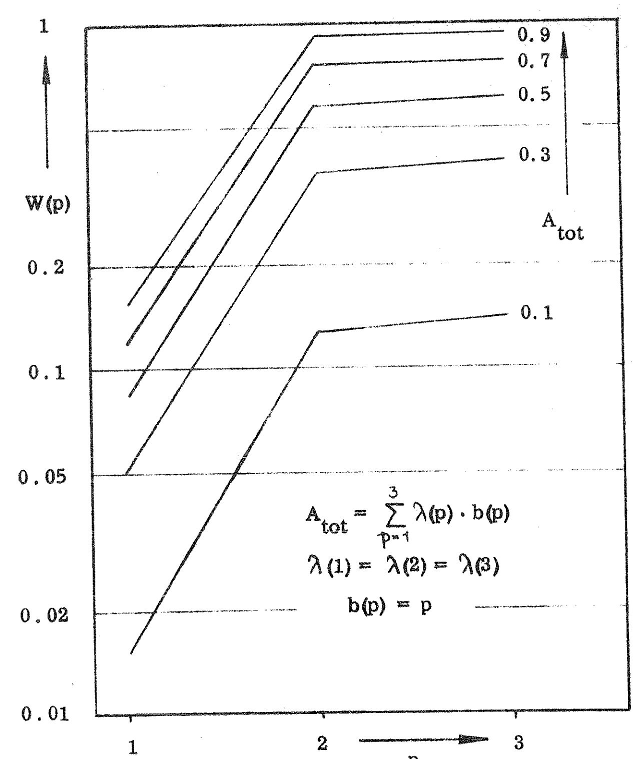

Fig. 12: Probability of waiting W(p) for all three priority classes. Priority strategy and service time distributions cf. figure 11.

computers also with the method presented above. And for small control-computers interrupt handling may be done by software adding a remarkable overhead. First results for these systems are already available and will be published at some future time.

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