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The Optimal Markov Strategy for Access in ISDNs with Reserves of Channels

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Abstract

In this paper, the use of the Markov Decision Process (MDP) to find the optimal strategy for access in ISDNs with reserves of channels is proposed. ISDN provides multiple channels for telecommunications access. The problem is formulated as a multi-resource queuing (MRQ) system where different types of customers require a random number of channels simultaneously. The algorithm that realizes the optimal strategy for access when heterogeneous customers demand service in ISDNs is developed.

Keywords: Optimal Markov strategy, Markov Decision Process (MDP), access in ISDNs, reserves of channels.

1. Introduction

Integrated Services Digital Networks (ISDNs) and other multi-channel telecommunication systems present a multi-resource facility where, access to and management of the bandwidth resource becomes important for quality of service and utilization. The general scenario for ISDN access includes a heterogeneous collection of customers which demand a random number of servers (channels) from the resource manager at the access point to the network.

The modelling of access to the ISDN bandwidth resource at the access point has been the topic of research using different approaches. The narrowband ISDN can be viewed as a time division multiplex (TDM) facility, where each time slot in the TDM frame is termed a Basic Bandwidth Unit (BBU) and can be accessed separately. When larger bandwidth links are required, multiple slots are accessed. Multi-slot channels are also termed superchannels (Deniz, 1994). A mixture of traffic comprising K types of customers is assumed to share this facility. In its simplest form, three different broad classes of traffic may be assumed. Pure circuit (circuit switched - CS), pure packet (packet switched - PS) and hybrid circuit and packet (CS and PS) traffic classes may be modelled for accessing the ISDN. Pure circuit switched

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systems can be analysed as "blocked calls lost systems" where the blocking probabilities become important measures of performance of the system. Pure packet switched systems can be analysed as queuing systems, where blocked calls are queued and delayed. Heterogeneous users (data, voice and video) will have differing service requirements. In the hybrid switching system approach, a mixture of these traffic classes is assumed to exist. Different performance criteria can be chosen in this case.

Another issue in the multi-channel system access is the way the bandwidth resource is partitioned. In some studies, the BBUs are divided into two groups: CS and PS areas. In others, there is a CS, a PS and a common pre-emptable reserve channel group, that can be used if and when needed by the higher priority traffic type. In some cases a movable boundary is assumed between the user areas (Kummerle, 1974) and (Zafiropulo, 1974). Hybrid switching in TDM systems has been studied by (Maglaris and Schwartz, 1979, 1982; Li and Mark, 1984).

Queuing systems for ISDN access have generally been modelled as multi-resource (multi-server) queuing systems with F identical, parallel servers, and where customers upon arrival demand a variable (random) number of servers (BBUs) for the duration of their service times. The most important property of this class of queues is that a given customer can enter service only when all the requested servers are available. The traffic assumptions can be as described above. A special case of the model for the traffic is when the traffic types are categorised into two classes: wide-band (WB) and narrow-band (NB) traffic types where one or both may be assumed blockable or queueable.

Channel assignment techniques in hybrid switching are analysed by (Schwartz and Karimeche, 1982). The performance of blockable WB and queueable NB traffic types is studied by (Kraimeche and Schwartz, 1985b) as a mixed blocked/queued traffic. The case of blocked calls cleared for NB and WB traffic with trunk reservation is studied by (Liao et al., 1989). A multi-server queuing system with blockable NB and queueable WB customers under a wide-band restricted access strategy is studied by (Serres and Mason, 1988). The case of *K* heterogeneous CS traffic types in the "blocked calls cleared" model is studied by (Kraimeche and Schwartz, 1984).

The optimal strategy for access to ISDN facility is a new approach to the old problem. The study by (Melikov and Ponomarenko, 1992) solved the problem of finding the optimal strategy of access in ISDNs without reserves of channels by means of controllable priorities. (Melikov and Ponomarenko, 1992b) has developed solutions for the analogous problem for ISDN with finite number of users in which a user generating a customer is assumed to be blocked. A survey of methods for calculation and optimisation of models of multi-resource queuing (MRQ) is given in (Melikov, 1996).

This paper assumes that the bandwidth resource at the ISDN access point is divided into two parts. The first partition is available to all user requests and is labelled as the active channel group, while the second partition is labelled the reserve channel group and is available in a controlled manner to user requests. Formulation of the access problem, development of the mathematical model and the optimal strategy for access to be used are explained in the following sections.

2. Formulation of the Problem and the Mathematical Model

The bandwidth resource at the ISDN access presents a total of N Basic Bandwidth Units (BBUs) which can be divided into two groups; $N=A+R$, where $A>1$ is the number of active channels and $R>1$ is the number of reserve channels, where each channel is identical. The customer arrival process is a stationary Poisson process with mean rate L where, each new arriving customer requires b_i, $1 \le b_i \le A$, $i=1,\ldots,K$ channels simultaneously with probability s_i, where $0 < s_i < 1$, $i=1,\ldots,K$ and $s_1+..+ s_K = 1$. Then the streams of customers are assumed to form K independent Poisson processes with mean rates, $l_i := L s_i$, $i=1,\ldots,K$, where, customers from stream i (type i customers), require b_i channels whose service start and end times are simultaneous. The service time for type i customers has general distribution with means m_i^{-1}, $i=1,\ldots,K$.

The service mechanisms for customers of different types are defined as follows. An arriving customer requests N channels indicated by its bandwidth requirement as defined above. If at the arrival moment the number of free channels in the active region are sufficient to service this customer, these channels are allocated to the requesting customer, otherwise free channels in the reserve area may be used. However, if the total number of free channels (active and reserve) are insufficient to service the customer request, the arriving customer is lost (or blocked) with probability 1.

The mechanism of use of the reserve channels is described below. If at the moment of ending the service of any customer type i, the number of busy channels is more or equal to A, then all channels that end service become reserve; otherwise, any N channels are placed in the active region and the remaining in the reserve region.

The loss of any type i customer is estimated by penalty $c(i)$, $i=1,\ldots,K$, and the use (switch) of j reserve channels is estimated by penalty of $d(j)$, $j=1,..,R$. Then, the problem of finding the optimal strategy of access to the ISDN may be formulated as below. Find such a strategy of access that minimises the total penalty per unit time in steady state regime that includes penalties from loss of customers of different types and penalties from using reserve channels. Hence, the access strategy defines the sequence of decisions at the arrival moment of customers to the ISDN access point. At this point, two different decisions may be taken: (i) customers may be blocked (and lost) or (ii) reserve channels may be allocated to service their request.

3. Finding the Optimal Strategy for Access

Based on the assumptions described in the previous section, a K-dimensional Markov chain may be used to describe the state of the system; $\boldsymbol{n} = (n_1,\ldots,n_K)$ at equilibrium, where n_i is the number of type i customers in the system. Using the state space, E, this can be defined as:

$$E := \{\, \boldsymbol{n} :\ n_i = 0,1,\ldots[(A+R)/b_i\,],\quad i = 1,..,K \ \ and\ \ (\boldsymbol{n},\boldsymbol{b}) \le A+R \,\}$$

where, $\boldsymbol{b} = (b_1,\ldots\ldots,b_K\,)$, $[x]$ is the greatest integer less or equal to x and $(\,\boldsymbol{n},\boldsymbol{b}\,)$ is the dot product of vectors $\boldsymbol{n}$ and $\boldsymbol{b}$.

To describe the class of strategies in which to find the optimal strategy of access, consider the moments at which the customers arrive. Let us assume that at the arrival moment of type i customer, the state of the system is $\boldsymbol{n} \in E$. Let $q(\boldsymbol{n}) = A - (\boldsymbol{n}, \boldsymbol{b})$ represent the number of free active channels available at state $\boldsymbol{n}$ if $q(\boldsymbol{n}) \geq 0$. Then, if $b_i \leq q(\boldsymbol{n})$, the arriving customer gains access to the bandwidth in the system with probability 1; if at this moment, $q(\boldsymbol{n})$ satisfy the inequality $b_i > q(\boldsymbol{n}) + R$, then arriving type i customer is lost with probability 1. If at the arrival moment of type i customer the system state is $\boldsymbol{n} \in E$, where $q(\boldsymbol{n}) < b_i \leq q(\boldsymbol{n}) + R$, the following decisions are possible: (i) customer is lost or (ii) $b_i - q(\boldsymbol{n})$ reserve channels can be used to service this customer. Probabilities for decisions above are defined by $a_i^-(\boldsymbol{n})$ and $a_i^+(\boldsymbol{n})$, respectively. Then,

$$a_i^-(\boldsymbol{n}) + a_i^+(\boldsymbol{n}) = 1 \quad \text{for all } \boldsymbol{n} \in E_i. \tag{1}$$

where, $E_i := \{\boldsymbol{n} \in E : q(\boldsymbol{n}) < b_i \leq q(\boldsymbol{n}) + R\}, \quad i = 1,\ldots,K.$

Now, we consider the moments that customers leave the system. Let the state of the system to be $\boldsymbol{n} \in E$, where $n_i > 0$, before the departure epoch when type i customer leaves the system. Then, if after this moment $(\boldsymbol{n} - \boldsymbol{e}_i, \boldsymbol{b}) \geq A$, where $\boldsymbol{e}_i$ is the K-dimensional vector whose all the components are zero except i-th component, which is 1. All b_i channels that become free are reserves; otherwise any A channels are actives and the remaining channels become reserve.

The intensity of transfer from state $\boldsymbol{n}$ to $\boldsymbol{n}'$ is defined by Q ($\boldsymbol{n}, \boldsymbol{n}'$), where $\boldsymbol{n}, \boldsymbol{n}' \in E$. Then the calculation of the elements of the infinitesimal matrix of this Markov chain can be obtained through the following expression:

$$\Theta(\boldsymbol{n}, \boldsymbol{n}') = \begin{cases} l_i \left[\mathrm{I}(\boldsymbol{n} \notin E_i) + \mathrm{I}(\boldsymbol{n} \in E_i)\, a_i^+(\boldsymbol{n}) \right] & \text{if } \boldsymbol{n}' = \boldsymbol{n} + \boldsymbol{e}_i, \\ n_i m_i & \text{if } \boldsymbol{n}' = \boldsymbol{n} - \boldsymbol{e}_i, \quad i = 1,\ldots,K, \\ 0 & \textit{otherwise}, \end{cases} \tag{2}$$

where I(A) is the indicator function of event A.

The probabilities in (1) define the Markovian Controllable Parameters (*MCP*). The total value of the penalty in the system in per unit time depends on the value of the *MCP*, so their optimal value minimizes the total value of the penalty in the system. The optimal value of the *MCP* defines the optimal strategy of access to ISDN also.

Proposition 1: The total value of the penalty in the system in per unit time at equilibrium can be calculated from the following expression:

$$G(\mathrm{p}(\boldsymbol{n}), a_i^{\pm}(\boldsymbol{n})) := \sum_{\boldsymbol{n} \in E} \sum_{i=1}^{K} \Big\{ l_i \ \mathrm{p}(\boldsymbol{n}) \left[c(i) \Big(\mathrm{I}(b_i > q(\boldsymbol{n}) + R) + \mathrm{I}(\boldsymbol{n} \in E_i)\, a_i^-(\boldsymbol{n}) \Big) + d(b_i - q(\boldsymbol{n}))\ \mathrm{I}(n \in E_i)\, a_i^+(\boldsymbol{n}) \right] \Big\} \tag{3}$$

where $p(\boldsymbol{n})$ is the stationary probability of the state $\boldsymbol{n} \in E$. Thus, our goal is to solve the following problem:

$$G\left(\; p(\boldsymbol{n}), a_i^{\pm}(\boldsymbol{n}) \; \right) \quad \rightarrow \quad \text{min.} \tag{4}$$

Proof 1: This fact is based on the components already defined in big parenthesis in (3). Indeed, the first component describes the penalties that occur as a result of loss of type i customers in state $\boldsymbol{n} \in E$ which appear with probability 1 if $b_i > q(\boldsymbol{n}) + R$; the second component describes the penalties that occur with probability $a_i^-(\boldsymbol{n})$ in the state $\boldsymbol{n} \in E_i$ at the arrival epoch of type i customers; the third component describes the penalties for use of $b_i - q(\boldsymbol{n})$ reserve channels at the arrival epoch of type i customers in state $\boldsymbol{n} \in E_i$ that appears with probability $a_i^+(\boldsymbol{n})$.

Finally, the problem of finding the optimal strategy of access is formulated as a MDP and it is desired to obtain such a value of the MCP which minimizes the value of expression (3). The constraints of this problem are (1) and the global balance equations composed from expression (2). This has the following form:

$$
\begin{aligned}
&- \sum_{i=1}^{K} \left\{ l_i \left[\mathrm{I}(\boldsymbol{n} \notin E_i) + \mathrm{I}(\boldsymbol{n} \in E_i)\; a_i^+(\boldsymbol{n}) \right] + n_i\, m_i \right\} p(\boldsymbol{n}) \\
&+ \sum_{i=1}^{K} \left\{ (n_i + 1)\, m_i \;\; p(\boldsymbol{n} + \boldsymbol{e}_i)\;\; \mathrm{I}(\boldsymbol{n} + \boldsymbol{e}_i \in E) + l_i \;\; p(\boldsymbol{n} - \boldsymbol{e}_i)\;\; \mathrm{I}(n_i > 0) \right. \\
&\qquad \left. \left[\mathrm{I}(q(\boldsymbol{n}) \geq 0) + a_i^+(\boldsymbol{n} - \boldsymbol{e}_i)\, \mathrm{I}(q(\boldsymbol{n}) < 0) \right] \right\} = 0
\end{aligned} \tag{5}
$$

Further to this balance equation we have the normalizing condition:

$$\sum_{\boldsymbol{n} \in E} p(\boldsymbol{n}) = 1 \tag{6}$$

An approach based on the use of linear programming (LP) technique for the solution of similar problems was developed in (Melikov and Ponomarenko 1992a, 1992b). This problem can be reduced to the LP problem by substituting non-linear elements in (4) and (5) as shown:

$$b_i^+(\boldsymbol{n}) = p(\boldsymbol{n})\, a_i^+(\boldsymbol{n}) \qquad \text{and} \qquad b_i^-(\boldsymbol{n}) = p(\boldsymbol{n})\, a_i^-(\boldsymbol{n}) \tag{7}$$

where, $\boldsymbol{n} \in E_i$, $i=1,\ldots,K$.

Then, the problem formulated above is equivalent to the following LP problem:

$$L_1\,(\,\mathrm{p}(\boldsymbol{n}),\, b_i^{\pm}(\boldsymbol{n})\,) \quad \to \quad \text{min.}, \tag{8}$$

$$L_2\,(\,\mathrm{p}(\boldsymbol{n}),\, b_i^{\pm}(\boldsymbol{n})\,) \;=\; 0, \tag{9}$$

$$b_i^{-}(\boldsymbol{n}) + b_i^{+}(\boldsymbol{n}) = \mathrm{p}(\boldsymbol{n}) \qquad \text{for all } \boldsymbol{n} \in E_i, \quad i = 1,\dots,K \tag{10}$$

$$\sum_{\boldsymbol{n}\in E} \mathrm{p}\,(\boldsymbol{n}) = 1 \tag{11}$$

$$e \le \mathrm{p}(\boldsymbol{n}) \le 1 \qquad \text{for all} \qquad \boldsymbol{n} \in E_i, \quad e > 0 \tag{12}$$

$$0 \le b_i^{\pm}(\boldsymbol{n}) \le 1, \qquad 0 \le b_i^{-}(\boldsymbol{n}) \le 1 \qquad \text{for all} \qquad \boldsymbol{n} \in E_i, \quad i = 1,\dots,K \tag{13}$$

Now, let us comment on the last problem developed in equations (8) through (13). Conditions (8) and (9) are (4) and (5) respectively, rewritten on the basis of (7) giving L_1 and L_2 as linear functions based on the parameters p$(\boldsymbol{n})$ and $b_i^{\pm}(\boldsymbol{n})$. Constraints (10) and (13) are obtained from (7) by means of (1) and (12) is known from the theory of finite Markov chain (in practice e may be chosen to be of order of $\varepsilon \cong 10^{-9}$).

Using the results of (Melikov and Ponomarenko 1992a, 1992b), we may prove the following proposition.

Proposition 2: In the optimal solution of the problem (8) - (13), for each state $\boldsymbol{n} \hat{I}\; E_i$, $i=1,\dots,K$, only one *MCP* may be positive and others are respectively equal to zero.

This important fact provides us a means to develop the following *nonrandomized* algorithm for optimal access in ISDN at the arrival epoch of type *i* customer.

Begin

1. Identify the current state $\boldsymbol{n}$ (i.e. define the value of components of the vector $\boldsymbol{n}$).
2. If $b_i > q(\boldsymbol{n}) + R$ then type *i* customer is lost.
3. Else if $b_i \le q(\boldsymbol{n})$ then type *i* customer gains access to the system and is serviced by active channels.
4. Else if $a_i^{+}(\boldsymbol{n}) = 1$, then $b_i - q(\boldsymbol{n})$ number of reserve channels are used for servicing type *i* customer.
5. Else type *i* customer is lost.

End.

It is necessary to develop a special scheduler (program-dispatcher) for using this algorithm in practice. The main functions of this scheduler are: (i) to store the array of decision, (ii) to identify the current state of the system and type of the arriving customer at each arrival epoch, (iii) to define the optimal decision from the array of decisions.

4. Conclusion

The approach taken in this paper is to look at the problem of access to the ISDN in the most general case; since the optimal strategy is based on wide strategy assumptions. These include *K* different types of customers, general distribution for service times, and the optimal strategy is searched in a wide access strategy class. For example, in some approaches to solving the optimisation problem, the use of reserve channels is not permitted if all the active channels are busy. In other approaches, the reserve channels are not allowed to be used if already some requests have been allowed the use of reserve channels. In this study, a wider spectrum of possibilities are taken into account and both cases are considered in the formulation of the problem. Therefore, the solution to this optimisation problem forms a larger class of solutions while other cases form a special case of this approach.

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