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# Virtual Path Bandwidth Control Versus Dynamic Routing Control

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**Abstract**

Virtual Path Bandwidth (**VPB**) control and Virtual Circuit Routing (**VCR**) control are competitive control schemes for traffic management in ATM networks. The objective of both controls is to minimize the Call Blocking Probability (**CBP**) of the congested end-to-end links, under constraints posed by the transmission links capacity of the network. Firstly, we compare the performance of two VCR control schemes, the **DAR** and **DCR**, well-known in the environment of STM networks, considering several trunk reservation parameters and different control intervals. Secondly, we compare the performance of VPB control schemes with that of VCR control schemes, both under static and dynamic traffic conditions. Under static traffic conditions the efficiency of the two control schemes in minimizing the worst CBP of the network is examined, whereas under dynamic traffic conditions their response time is measured by means of simulation. In short, VPB control is more effective than VCR control when the traffic fluctuation is large while VCR control has a faster response time than VPB control.

**Keywords**

Virtual Path Bandwidth Control, Dynamic Routing Control, ATM networks.

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# 1 INTRODUCTION

In ATM networks, network/traffic management has a layered structure of two levels, the Call-level and the Cell-level, which correspond to the distinction of traffic in call and cell components, respectively. We concentrate on the Call-level traffic management and especially on controls which drastically influence the global performance of an ATM network under constraints posed by the bandwidth capacity of transmission links. Virtual Path Bandwidth (VPB) control and Virtual Circuit Routing (VCR) control are the main controls strongly related to the transmission links capacity. Their performance is evaluated by the Call Blocking Probability (CBP). Bandwidth and trunk reservation controls are also related to the transmission links capacity and closely cooperate either with VPB or VCR control.

In this paper, we compare the performance of VCR control schemes, also called Dynamic Routing (**DR**) (Mase, 1989), with the performance of VPB control schemes (Logothetis 1992, Shioda 1994), in the environment of ATM networks.

The VCR control objective is to provide an alternate route for each Virtual Circuit Connection (VCC) that fails to be established on the first choice (direct) Virtual Path Connection (VPC), exploiting the spare capacity of the network. The VPB control objective is to rearrange the installed bandwidth of the VPs according to the offered traffic fluctuation so as to minimize the worst (maximum) CBP of all end-to-end links.

Several DR control schemes have been proposed for use in the traditional telephone networks:

a) Dynamic Non-Hierarchical Routing (DNHR), a time-dependent routing scheme developed by AT & T (Ash, 1990),
b) Trunk Status Map Routing (TSMR) (an extension of DNHR) that modifies the routing patterns calculated by DNHR considering the trunk status (Ash, 1985),
c) Dynamic Alternative Routing (DAR), a decentralized state-dependent routing developed by British Telecom (Stacey 1987, Key 1990),
d) Dynamically Controlled Routing (DCR), a centralized version of the state-dependent dynamic routing (Rengier 1983, Cameron 1983),
e) State and Time-dependent Routing (STR), a hybrid routing scheme that combines the time-dependent control at the routing pattern definition and state-dependent control at the VC-level routing definition, proposed by NTT (Mase, 1990).

We have chosen two of the above DR control schemes to be considered as VCR control schemes in ATM networks: the decentralized control scheme DAR and the centralized control scheme DCR. Before comparing their performance with that of VPB control schemes, their performance in minimizing the worst CBP is comparatively examined, when they cooperate with several Trunk Reservation control schemes, or when different control intervals are considered.

The performance of the VCR and VPB control schemes is examined under static and dynamic traffic conditions on a test-bed ATM-network of 10 nodes, in a ring topology, accommodating two service-classes. Under static traffic conditions we examine the performance of VPB and VCR controls in minimizing the worst CBP of the whole network. The applied VPB control is optimal and is obtained analytically, through a global network optimization model. The results of the application of the VCR control schemes are obtained through simulation. Under dynamic traffic conditions, we examine the response time of the above control schemes. For the application of VPB control we consider the Medium-Term VPB control scheme, described in reference (Logothetis, Shioda, 1995), with a control interval long enough, because the required time for bandwidth rearrangement is considerably long, due to the existing call connections at that time-point. As far as the incorporated bandwidth and trunk reservation control schemes are concerned, the bandwidth reservation scheme which equalizes the CBP of the two service-classes is considered for the VPB control, while several trunk reservation schemes are considered for the VCR control schemes. Concerning the dynamic traffic condition, we consider that traffic fluctuates according to a step function (theoretical case), applied on one switching pair, in one traffic-flow direction only.

This paper is organized as follows: In Section 2 an ATM network architecture is described which is appropriate for the applicability of VPB and VCR control schemes. In Section 3, the objective and the VPB control schemes are presented. Section 4 includes three subsections. In subsection 4.1 and 4.2, the VCR control schemes, DAR and DCR, respectively, are described and the calculation of the involved CBP in the VPs of an ATM network is given. In subsection 4.3 the two VCR control schemes are comparatively examined. Firstly, they are compared in respect to the resultant average CBP of the network, under static traffic condition and in cooperation with several trunk reservation control schemes. Secondly, the same comparison is carried out when the best trunk reservation control scheme is considered for cooperation (obtained from the first comparison) and the control (update) interval of the DCR control scheme varies. In Section 5, the VPB and VCR control schemes are comparatively examined, under static (subsection 5.1) and dynamic (subsection 5.2) traffic conditions. As a conclusion, we summarize the results of this paper in section 6.

## 2 ATM NETWORK ARCHITECTURE

An ATM network architecture is considered in which each ATM switch (ATM-SW) is accompanied by an ATM Cross-Connect (ATM-XC) system. The ATM-XCs are interconnected by a ring transmission line and compose the backbone network (Figure 1a). This architecture has the advantage of simplicity and offers higher transmission line utilization (Sato, 1990). The transmission links are assumed bi-directional. A connection between two ATM-SWs is established via any available path that has been registered in a table, called Routing Table **(RT)**. Under the consideration of this paper the route of a path between two ATM-SWs passes through ATM-XCs only.

Other network topologies could be also considered. In the topology of the backbone network of Figure 1a, two parts can be distinguished to make our study easier: one composed of the ATM-XCs, called outer network and another composed of the interconnected ATM-XCs, called inner network.

Thanks to the Virtual Path (VP) concept, the traffic management by reallocating the established bandwidth of the paths (VPB management) according to the traffic variations becomes favorable in ATM networks. The concept of VP, whereby two ATM-SWs face only the direct logical (imaginary) link (VP) between them, makes the structure of the backbone network transparent to the ATM-SW pairs. This is due to flexibility of the ATM-XCs to provide the required bandwidth in the end-to-end links (VP connections) of the ATM-SWs. Therefore, from the VPB management point of view, the whole ATM network is equivalent to a meshed network in which only the direct links are used (Figure 1b). These links represent the

VPCs.

Since we assume the equivalent mesh network architecture, where the ATM-SWs are fully interconnected with VPCs, the first choice route for a VC to establish a VCC, is its direct VPC. When the VCC is blocked at the first choice route, an alternate route will be attempted (according to the applied VCR control scheme) which consists of two VPCs. This routing scheme meets the basic requirements for the application of the well-known DR control schemes of the STM networks (Yokoi, 1995).

The VCR controller can be either a decentralized controller, like the DAR, or a centralized one, like the DCR. In the case of a decentralized control scheme, in each ATM-SW there is one VCR controller who is informed about the traffic-flow condition in the VPCs of the network, by counting the number of VCC

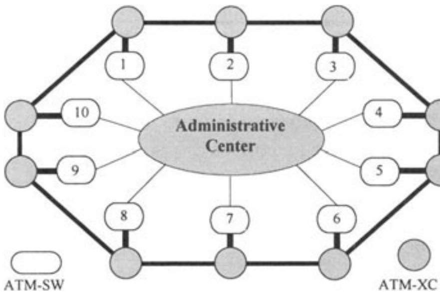


**Figure 1a** ATM network architecture.

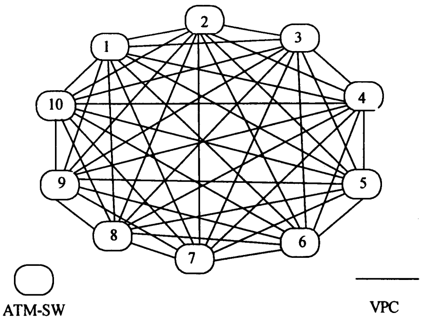


**Figure 1b** Equivalent meshed VPC network.

failures, in order to define the route for the next call arrival (next VCC). On the other hand, a centralized VCR controller is located at a network management centre and determines alternative VPCs to realize a VCC, for each ATM-SW pair of the network. This is done by receiving every few seconds the traffic conditions of the VPCs from each ATM-SW and exploiting the idle capacity of the VPCs.

The VPB controller is located at an administrative centre (centralized controller). It communicates with the ATM-SWs to collect the measurements of carried traffic and blocking during each control interval. Based on these measurements, it calculates the offered traffic. From the offered traffic, the installed bandwidth in the transmission links and the VPs listed in the RT, the VPB controller determines the allocation of the bandwidth to the VPs, by solving a large network optimization model. Then, it updates the data relevant to the VP bandwidth in the ATM-SWs. The realization of the produced VPB allocation is executed by the ATM-SWs simultaneously, after a delay due to the existing call-connections at the time point of bandwidth rearrangement. The ATM-SWs increase or decrease the number of cells which have a specific Virtual Path Identifier (Saito, 1991) when the bandwidth of this VP is increased or decreased, accordingly. It is worth mentioning that no communication between the VPB controller and the ATM-XCs is required.

## 3 VPB CONTROL

Telecommunication networks are designed to convey the traffic of all switching pairs so as to meet a pre-described QOS. Due to traffic variations from hour to hour the traffic load on some switching pairs is below the forecasted value and free bandwidth results. On the other hand, overloads occurring at the same time on other switching pairs cannot use the free bandwidth of the network, if it is not possible to transfer the surplus bandwidth towards the congested switching pairs. This is the work of VPB control. It reallocates the bandwidth of the VPs according to the offered traffic so as to improve the global performance of the network, under constraints posed by the transmission links capacities. The resultant distribution of the totally installed bandwidth to the VPs is the VPB allocation.

To rearrange the VP bandwidth dynamically, the following types of VPB control schemes have been proposed:

a) Very-Short-Term control schemes based on the information of the concurrent connections in the VPs (Ohta, 1988), with control interval less than 5 min.

b) Short-Term control schemes based on the blocking measurements taken during the control interval which ranges from several minutes to a few hours (Shioda. 1991).

c) Long-Term control schemes based on traffic prediction with control interval ranging from a few hours to a few days (Monteiro, 1990).

d) Medium-Term VPB control based on traffic measurements, with control interval ranging from several minutes to a few hours (Logothetis, Shioda,1995).

The Very-Short-Term and the Short-Term control must be distributed control schemes in order to respond quickly to sharp traffic fluctuations and absorb them. To achieve this, they need very simple computations. They can ignore the traffic characteristics of service-classes (Ohta, 1988), which is an important advantage in the B-ISDN environment. The Very-Short-Term control achieves an optimal network performance. The implementation, however, of this control scheme is very difficult and, therefore, it is only of theoretical value. A large number of control steps is needed, especially when the traffic volume is large. The Short-Term control schemes are readily implemented but they lack optimality.

On the other hand, the Long-Term control is a centralized control where the controller aims at an optimal network performance in the control interval by solving a large network optimization problem. However, the controller is based on the prediction of the offered traffic which is a time consuming task, though it is not possible to be accurate. Therefore, the importance of the achieved optimality is weakened. The main advantage of the Long-Term control schemes is that they can easily be implemented, because VP bandwidth is rearranged only a few times per day.

The Medium-Term VPB control scheme reconciles the advantages and disadvantages of the Short-Term and Long-Term control schemes. The controller must be a centralized one in order to optimize the network performance globally within its control interval. The control interval must be rather short in order to respond satisfactorily to medium-term traffic fluctuations. Short-term traffic fluctuations could be absorbed by the implementation of VCR control in a further stage. To achieve this Medium-Term VPB control, the controller formulates a global network optimization model which is driven from the offered traffic, determined from on-line measurements of the carried traffic and the CBP of each service-class of the network. The optimization criterion is to minimize the worst CBP of all VPCs (Logothetis 1993, Logothetis 1995).

## 4 VCR CONTROL

VCR control is an alternate dynamic routing method that updates the set of possible alternate VPCs for each ATM-SW pair based on the state of the network (state-dependent), or according to preplanned routing patterns calculated so as to meet the forecasted traffic demand for each time period of the day (time-dependent). Benefits of the dynamic alternate routing in comparison to the fixed alternate routing are: the higher utilization of network resources (and hence cost savings) and the tolerance against network failures and traffic fluctuations.

In this paper, two conventional dynamic routing control schemes, the Dynamic Alternative Routing and the Dynamically Controlled Routing, are examined in their applicability to ATM networks.

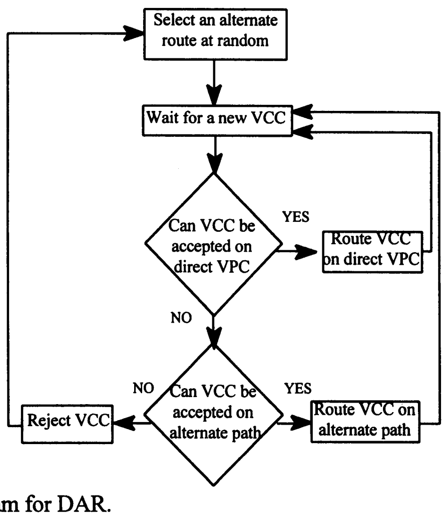


**Figure 2** Flow diagram for DAR.

### 4.1 Dynamic Alternative Routing (DAR)

DAR is an example of a decentralized routing control scheme. According to this algorithm, a VCC that fails on the first choice VPC (direct) is offered to the current-choice alternate route (composed by two VPCs) and if it is blocked, a new current-choice is selected at random from all possible alternate routes, to be used for the next VCC attempt (Figure 2).

*Performance evaluation of an ATM network controlled by DAR*

To evaluate the performance of an ATM network controlled by DAR, we determine the CBP of the VPCs. For the long-run stationary behavior of the network, we extend the methodology found in references (Gibbens 1989, Key 1989, Mitra 1991) to the ATM environment, considering that each VP is commonly shared by two service-classes ($c_k$) with $b_{ck}$ (k=1,2) required bandwidth per call.

The following notations are used:

$V_s$: Bandwidth assigned to the VPC s.
r(1): First-choice VPC used by the switching pair r.
r(2): Alternate route of two VPCs used by the switching pair r.
$R_r$: Set of all possible alternate routes for the switching pair r.
$R_s$: Set of switching pairs that use the VPC s as a first or as a second VPC of their alternate routes ( $r \in R_s$, $r{:}s \in r(2)$ ).
$a_r^l$: Probability that the alternate route l is selected for the switching pair r.
l(s): Alternate route that contains the VPC s.
$l_1(s)$: First VPC of the alternate route l(s).
$l_2(s)$: Second VPC of the alternate route l(s).
$\rho_{1,s}^{c_k}$: First-choice (direct), Poisson traffic offered to the VPC s, by the service-class $c_k$.
$\rho_{2,s}^{c_k}$: Alternate traffic (assumed as Poisson traffic) offered to the VPC s, by the service-class $c_k$
$B_{1,s}^{c_k}$: CBP for the first-choice traffic offered to the VPC s, by the service-class $c_k$.
$B_{2,s}^{c_k}$: CBP for the alternate traffic offered to the VPC s, by the service-class $c_k$.

The alternate traffic of each service-class $c_k$ offered to the VPC s, is determined as:

$$r_{2,s}^{c_k} = \sum_{r:s \in r(2)} r_{1,r(1)}^{c_k} B_{1,r(1)}^{c_k} a_r^{l(s)} (1 - B_{2,s'}^{c_k}), \quad s' \in r(2) - s, \ k = 1,2 \qquad (1)$$

After a long-run time, since the selection of alternate routes is uniform and the blocking rates over the two VPCs of an alternate route are equalized, the Selection Probability, $a_r^{l(s)}$, of an alternate route results to be inverse proportional to the blocking of the alternate route:

$$a_r^{l(s)} \propto \frac{1}{(1-(1-B_{2,l(s)})(1-B_{2,l_2(s)}))} \quad \text{and} \quad \sum_k a_r^k = 1, \ k \in R_r \qquad (2)$$

For the determination of the CBPs of each VPC of the network, we consider only the Call-level characteristics of the service-classes. We propose the recursive formula found in references (Kaufman 1981, Roberts 1982) to be used for the determination of CBPs, taking into account the bandwidth reservation control between the service-classes. As it has been observed (Logothetis, 1992), this formula has a high accuracy especially when the service-classes have the same mean service-time. To apply this formula to the DAR, we have to consider that four traffic streams, $t_k$ (k=1,2,3,4), are offered to each VPC. The traffic streams $t_1$ and $t_3$ are due to the first and the alternate offered traffic of the first service-class, respectively, whereas the $t_2$ and $t_4$ are due to the first and the alternate offered traffic of the second service-class, respectively.

The CBPs of the VPCs are determined as:

$$B_{t_k} = \frac{1}{G} \sum_{n=1}^{b_{t_k}+R(t_k)-1} G(V_s - n) \quad (3)$$

where

$$G = \sum_{i=1}^{V_s} G(i) \quad (4)$$

$$G(i) = \frac{1}{i} \sum_{k=1}^{4} r_{t_k} D_{t_k}(i - b_{t_k}) G(i - b_{t_k}) \quad \text{for } i = 1,..,V_s \quad (5)$$

$$D_{t_k}(i - b_{t_k}) = \begin{cases} b_{t_k} & \text{for } i \le V_s - R(t_k) \\ 0 & \text{for } i > V_s - R(t_k) \end{cases} \quad (6)$$

$R(t_k)$ is the bandwidth reserved for each traffic stream due to the Bandwidth and the Trunk Reservation Control (Figure 3).

In this way, we have formulated in the ATM environment a system of equations (1-6) which is solved by an iterative method in the computer. This system is equivalent to the fixed-point system of equations which is valid for the STM environment.

## 4.2 DYMAMICALLY CONTROLLED ROUTING

DCR is an example of a centralized routing control scheme. It uses a central processor to find an alternate route (composed by two VPCs) for each switching pair of the network, based on the free capacity of the VPCs of the whole network. The central processor:

- gathers, during its control interval, all the appropriate information (VPC trunk status, traffic,etc.), from each ATM-SW,
- calculates, for each switching pair, the alternate route selection probability which is proportional to the measured idle capacity of the alternate route set,
- selects the alternate route based on the selection probability,
- sends the alternate route information to the ATM-SWs.

The control (update) interval of DCR is in the order of a few seconds, whereas the theoretical case of a zero control interval can be considered as well.

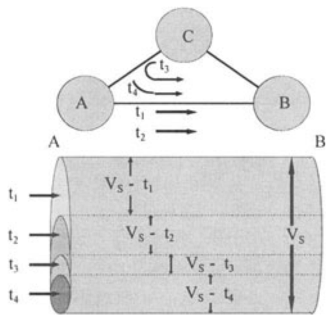


**Figure 3** Bandwidth and Trunk Reservation in a VPC.

## *Determination of Call Blocking Probability*

For the determination of CBP in an ATM network controlled by the DCR, the same notations with the DAR system are used. In addition to them the following notations are used:

$L_s$: Residual capacity of the VPC s.
$C_s$: Occupied bandwidth of the VPC s.
$T_s$: Trunk Reservation number of the VPC s.
$L_{l1}$: First VPC of the alternate route $l \in R_r$.
$L_{l2}$: Second VPC of the alternate route $l \in R_r$.

The DCR control solves the same system of equations, as the DAR controller, under stationary traffic conditions (Girard, 1990). However, in the DCR, the Selection Probabilities of the alternate routes are computed, for zero update interval, as follows:

Firstly, the residual capacity $L_s$ of VPC s, is computed as:

$$L_s = V_s - C_s - T_s \tag{7}$$

The $C_s$ is calculated as the total traffic carried on the VPC s:

$$C_s = \sum_{k=1}^{2} (r_{1,s}^{c_k}\ (1 - B_{1,s}^{c_k}) + r_{2,s}^{c_k}\ (1 - B_{2,s}^{c_k}))\ b_{c_k} \tag{8}$$

The residual capacity of the alternate route of two VPCs is computed as:

$$\bar{L}_l = \min(L_{l1}, L_{l2}) \tag{9}$$

and the Selection Probability of the alternate route is given as:

$$a_r^{l(s)} = \frac{\bar{L}_{l(s)}}{\sum_{k \in R_r} \bar{L}_k} \tag{10}$$

## 4.3 Comparison of the VCR control schemes

Two reservation parameters, the Bandwidth and Trunk Reservation numbers, must be considered for a VCR control scheme in order to improve the performance of multi-service networks, such as ATM networks. Bandwidth Reservation aims at guaranteeing the QOS of each service-class multiplexed in a VP, by reserving some fraction of the VP bandwidth for the service-classes which require larger bandwidth. So, calls of service-class $c_k$ are refused to be connected when less than $t(c_k)$ bandwidth is available in the VP. By a proper selection of the Bandwidth Reservation number the resultant CBP of the two service-classes, in each VP, can be equalized. On the other hand, Trunk Reservation aims at guaranteeing the network stability when an alternate routing scheme is applied. It protects the first offered traffic to a VP against alternate routed traffic which makes use of this VP. It depends on VP bandwidth and traffic load offered to the VPs.

**Table 1**

| Trunk Reservation Number | Maximum Traffic Fluctuation (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| 0 | 1.91 | 2.59 | 3.50 | 3.47 | 4.49 | 5.23 | 5.77 | 6.14 |
| | 1.72 | 1.62 | 2.46 | 3.31 | 4.22 | 4.85 | 5.27 | 5.99 |
| 24 | 1.07 | 1.12 | 1.43 | 1.64 | 1.98 | 2.39 | 2.86 | 3.31 |
| | 0.72 | 0.90 | 1.17 | 1.74 | 1.95 | 2.48 | 2.85 | 3.39 |
| 48 | 1.00 | 1.10 | 1.31 | 1.62 | 2.03 | 2.31 | 2.87 | 3.20 |
| | 0.86 | 0.97 | 1.34 | 1.44 | 1.81 | 2.17 | 2.59 | 3.13 |
| 72 | 1.22 | 1.44 | 1.56 | 1.87 | 2.20 | 2.65 | 3.09 | 3.36 |
| | 0.96 | 1.07 | 1.34 | 1.65 | 2.11 | 2.45 | 2.88 | 3.12 |

In Table I, the average CBP of an ATM network (described below) which operates with DAR (first number in Table I) or DCR (second number in Table I) VCR control schemes, versus Trunk Reservation numbers is given. The same Trunk Reservation number is considered for each VP-link. The Bandwidth Reservation number is such that the CBPs of the two service-classes are equalized. Table I shows that in case of small traffic fluctuation the CBP of the network increases as the Trunk Reservation number increases. In case of large traffic fluctuation a larger Trunk Reservation number is needed.

The performance of the two VCR control schemes described above, is examined in the ATM network of 10 ATM-SWs (see below). The Trunk Reservation number is taken from Table I and corresponds to the best one for each traffic fluctuation. Five versions of the DCR are presented. The DCR-0 with zero update interval and the DCR-5, DCR-10, DCR 15, DCR-20 of update interval 5, 10, 15, 20 sec, respectively. Figure 4, shows the average CBP of the whole network operating with the DAR control or the DCR-0, DCR-5, DCR-10, DCR-15, and DCR-20 control schemes versus traffic fluctuations. The results show that the DCR-0 has the best performance, while the performance of DAR is better than the DCR-5, DCR-10, DCR-15 and

DCR-20. In practice, however, the DCR-0 cannot be applied; since this control is a centralized one, a control interval of the order of a few seconds is required, at least. Figure 5 shows the average CBP of the whole network operating with DAR and DCR versus control interval. When the control interval is small the performance of the DCR is better than that of the DAR.

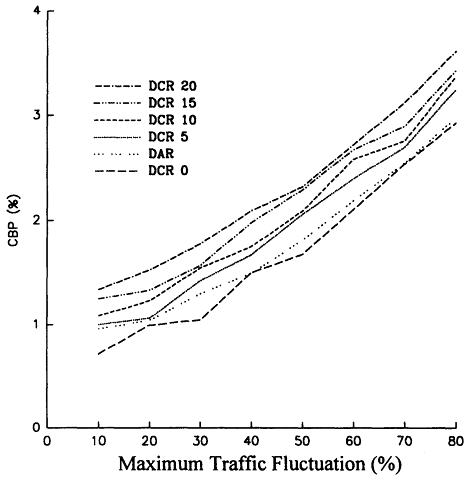


**Figure 4** Average CBP versus maximum traffic fluctuation for DAR and DCR.

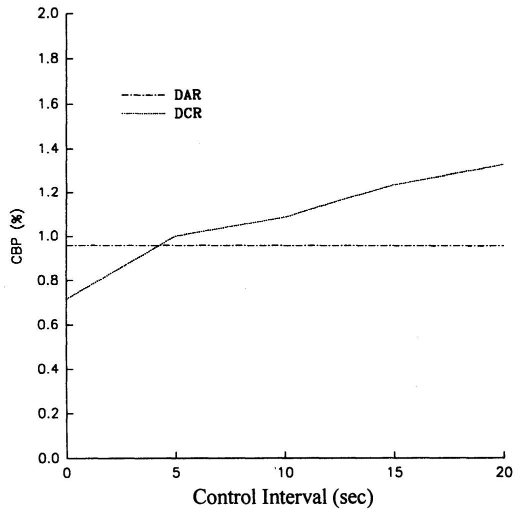


**Figure 5** Average CBP versus control interval for DAR and DCR.

# 5 COMPARISON OF VPB CONTROL WITH VCR CONTROL

The performance of the VPB control and the VCR control are compared under static and dynamic traffic conditions on a 10 ATM-SWs ring ATM network. Under static traffic conditions the average and the worst CBP of the network are presented. Under dynamic traffic conditions, the response time of the two traffic controls is examined.

Two service-classes are accommodated in the network. The required bandwidth per VCC for the first service-class is 64 kbps (considered as bandwidth unit or one trunk capacity), and for the second service-class is 1.536 Mbps (i.e. 24 bandwidth units). Because of the Bandwidth Reservation Control, 1.472 Mbps (23 bandwidth units) are reserved to benefit the second service-class, in each VP. The Trunk Reservation number is taken from Table I and corresponds to the best one for each traffic fluctuation. Both service-classes have exponentially distributed holding times with mean value of 100 sec.

The VPs of the network are dimensioned so as to satisfy the grade-of-service of 3% (CBP). The traffic offered to each ATM-SW are 260 Erl and 12 Erl for the first and the second service-class, respectively. The VP bandwidth is 43.008 Mbps (672 bandwidth units), for each VP. The bandwidth of a transmission link (between two ATM-SWs) is calculated as the sum of the VPs that use this transmission link.

## 5.1 Static Traffic Conditions

The average and the worst CBP of the whole network are examined when the offered traffic fluctuates randomly according to the uniform distribution by a maximum of 10% of the design traffic-load, reaching to 80% in steps of 10%.

In Figure 6, the worst CBP of the network is shown versus the maximum traffic fluctuation, when VPB control, VCR control and No-Control are applied to the network. Figure 6a shows the results of No-Control, DAR and VPB control comparatively, whereas Figure 6b shows the results of No-Control, DCR and VPB control. The resultant worst CBP of DAR and DCR is obtained through simulation (Logothetis, Kokkinakis, 1995), while the results of VPB control are obtained analytically and are optimal (Logothetis 1993, Logothetis 1995). As we can observe, the VPB control is more effective when the maximum traffic fluctuation is large, while when the traffic fluctuation is small the VCR controls perform better than VPB control.

In Figure 7, the average CBP of the whole network is shown versus the traffic fluctuations. Figure 7a presents the results of No-Control, DCR and VPB control comparatively, whereas Figure 7b presents the results of No-Control, DAR and VPB control. When a VCR control is applied, the network performance in respect to the average CBP is better for all traffic fluctuations. It is worth mentioning that the objective of VPB control is to minimize the maximum CBP of the network; therefore, when this criterion is satisfied, no action is taken in order for the average CBP of the network to be improved.

Figure 8a and 8b comparatively show the worst CBP and the average CBP of the network versus the maximum traffic fluctuation, respectively. The DAR and DCR curves of Figure 6a and 6b are portrayed together in Figure 8a. Likewise, the DCR and DAR curves of Figure 7a and 7b are portrayed together in Figure 8b.

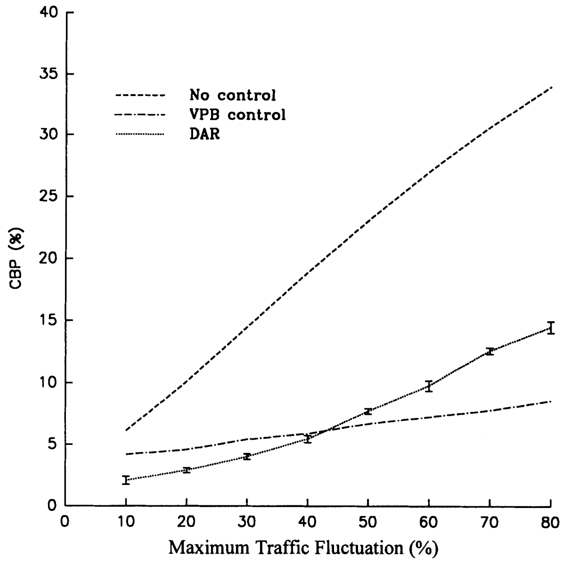


**Figure 6a** Worst CBP versus maximum traffic fluctuation for the VBP and DAR controls.

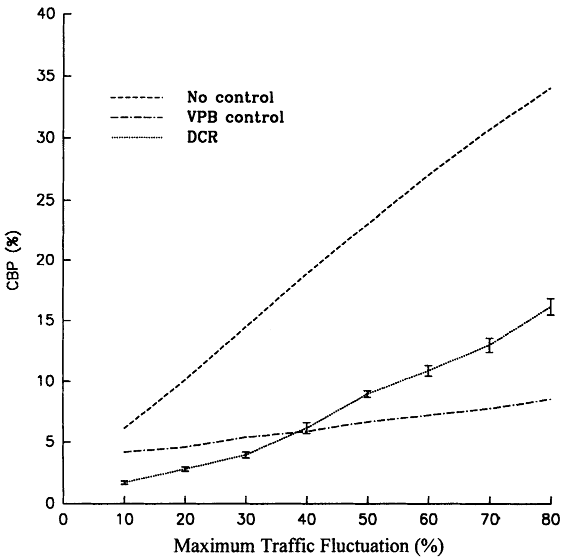


**Figure 6b** Worst CBP versus maximum traffic fluctuation for the VBP and DAR controls.

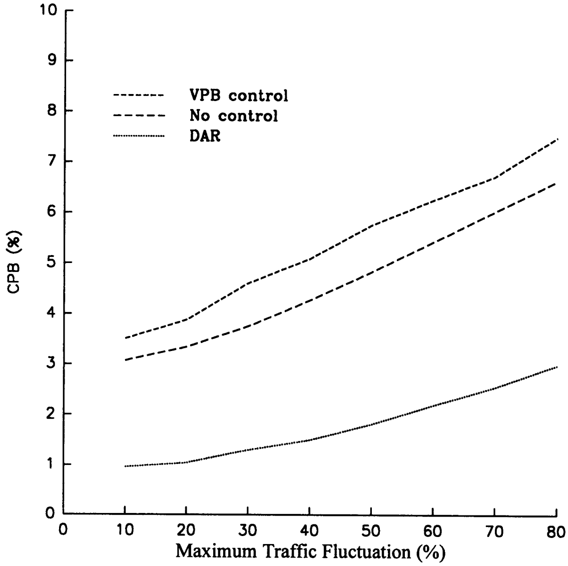


**Figure 7a** Average CBP versus maximum traffic fluctuation for the VBP and DAR controls.

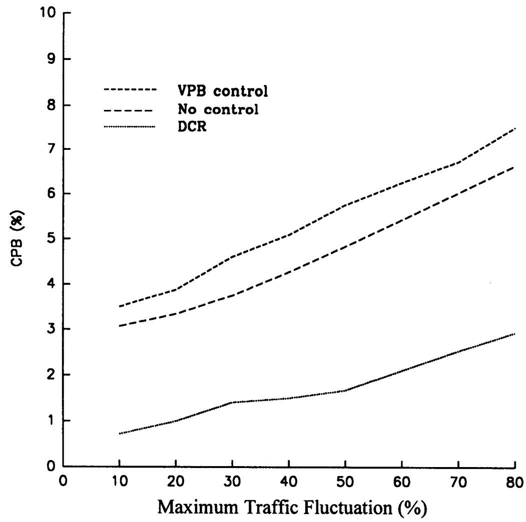


**Figure 7b** Average CBP versus maximum traffic fluctuation for the VBP and DCR controls.

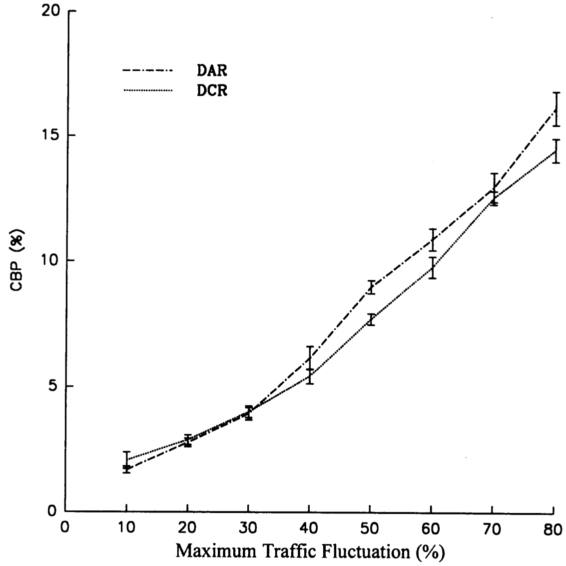


**Figure 8a** Worst CBP versus maximum traffic fluctuation for the DAR and DCR controls.

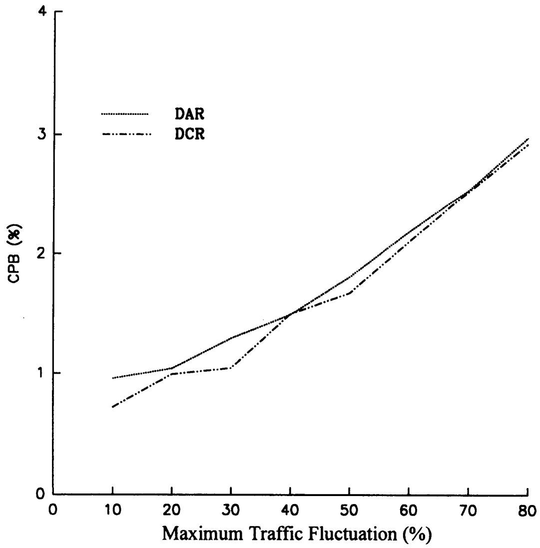


**Figure 8b** Average CBP versus maximum traffic fluctuation for the DAR and DCR controls.

## 5.2 Dynamic Traffic Conditions

Under dynamic traffic conditions, we examine the response time of the VPB and VCR controls. The response time of the controls is examined for the theoretical case of a step function, applied to one ATM-SW pair (in one traffic-flow direction). That is, the traffic offered to one ATM-SW pair increases as a step function by 100% in both service-classes.

First, a medium-term VPB control scheme is applied (Logothetis, Shioda, 1995), with a control interval of 30 min. That is, the VPB rearrangement procedure starts every 30 minutes. We assume that the traffic fluctuation occurs at the end of the second control interval (i.e. after 60 min). Bandwidth reservation of 23 bandwidth units is applied to the first service-class. Second, the DAR control is applied which is a decentralized control scheme governing each call arrival. Third, the DCR control is applied with a zero control interval (DCR 0) and, fourth, the DCR control is applied again with 10 sec control interval (DCR 10). Trunk reservation of 48 bandwidth units is applied to benefit the first choice path for all VCR controls. The CBP of each ATM-SW pair is measured every 15 min.

Figure 9 shows the worst CBP of the network versus time. The response time of the VPB control is 75 (135-60) min. VCR controls respond faster than VPB control to absorb the traffic variation because of their very short control interval. The VPB control needs a considerably larger control interval because of the required time for bandwidth rearrangement due to the existing call-connections at the time point of bandwidth rearrangement.

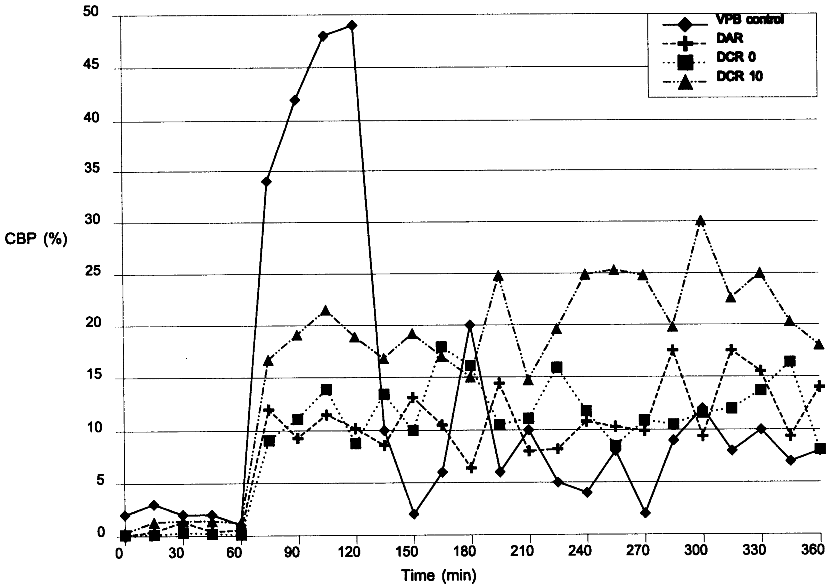


**Figure 9** Response time for the VPB and VCR controls.

## 6 CONCLUSION

Two traffic controls, the VPB control and the VCR control, are presented for ATM networks and the following comparisons are examined:

a) The performance of two VCR control schemes, the DAR and DCR, is examined, considering several trunk reservation parameters. A larger trunk reservation number is needed when the traffic variation among the ATM-SW pairs of the network increases.

b) The same comparison is carried out, considering various control intervals for the DCR control (centralized control). A very small control interval is needed for the DCR control to achieve a better performance than the DAR.

c) Under static traffic conditions, the VPB control is compared with the VCR (DAR and DCR) controls in respect to their effectiveness in minimizing the worst CBP of the network. The worst CBP of the network without any control is shown. The VPB control is more effective than VCR control when the traffic fluctuation is large.

d) Under dynamic traffic conditions, the response time of each traffic control scheme is measured by means of simulation. The VCR control has a faster response time than the VPB control. This is due to the considerably larger control interval required for VPB control. Nevertheless, the response time of VPB control is satisfactory if we consider the network resiliency within two control intervals.

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