

## A Comparison between Different Approaches for VPC Bandwidth Management

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**Abstract-** By reserving transmission capacity on a series of links from one node to another, making a virtual path connection (VPC) between these nodes, several benefits are obtained. VPCs will enable segregation of traffics with different QoS, simplify routing at transit nodes, and simplify connection admission control. As telecommunications traffics experience variations in the number of calls per time unit, due to office hours, inaccurate forecasting, quick changes in traffic loads, and changes in the types of traffic (as in introduction of new services), there is a need to cope for this by adaptive capacity reallocation between different VPCs. The focus of this paper is to introduce a distributed approach for VPC management and compare it to a local and a centralised one. Our results show pros and cons of the different approaches.

### 1. Introduction

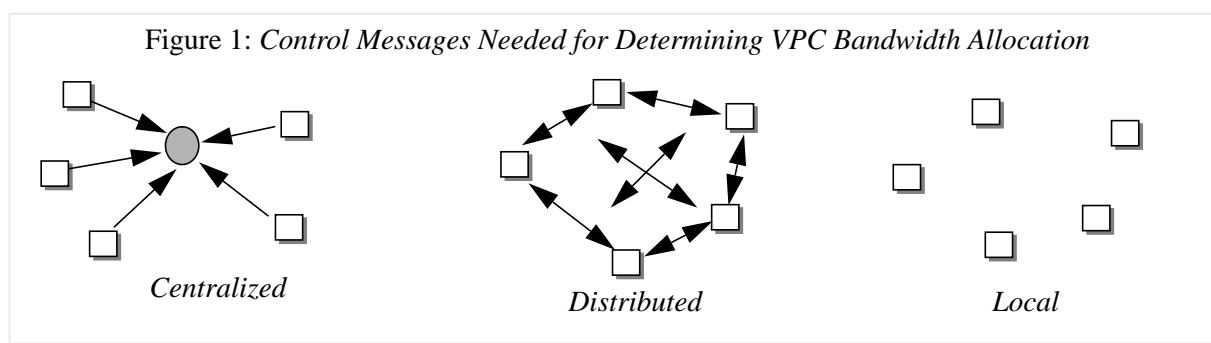
To accept a new call a check must be made to ensure that there is enough capacity left to establish the call through a series of links between the end nodes. When a route is found the required amount of capacity is reserved for the call. The established call uses this logical connection which is called a virtual channel connection (VCC). A virtual path connection (VPC) groups VCCs together to be handled as an entity. The VPCs can be seen as reserved capacity between two nodes. By using VPCs the acceptance of a new call is simplified because the routing and reservation of capacity has already been done.

A VPC network constitutes a higher layer which is logically independent of an underlying physical network. Having several VPC networks each supporting one type of traffic simplifies statistical multiplexing and quality-of-service (QoS).

There are always variations in telecommunications traffics. Traditional telephone networks have been di-

mentioned for the so called busy hour to cope with the maximum traffics. This means that much of the capacity will stay unused for most of the time. By using VPCs the capacity allocation can be altered dynamically. This allows us to meet the traffic variations by reshaping the VPCs in order to match the current demands. This means savings on the amount of capacity required in a network if we can utilize non-coincidental busy hours to reallocate the capacity. The concept of VPCs and VCCs is supported in the asynchronous transfer mode (ATM) and in the synchronous digital hierarchy (SDH/SONET).

The management of the VPCs can be centralised, distributed or local, see fig 1. The central approach has the ability to make VPC capacity reallocation based on global information. The idea of local and distributed approaches is to increase the robustness and improve performance compared to a central approach [6], which is depending on a central computer [2,3,9]. By assigning costs for rejected calls and overhead



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such as control messages, the performance of the different approaches can be compared.

Sections 2-4 describe the different approaches for VPC bandwidth management where the distributed approach is explained in more detail. Then in section 5 we evaluate the distributed approach. Section 6 gives the results from comparisons between the strategies. Finally, we conclude the paper in section 7 and discuss further work in section 8.

## 2. The Distributed Approach

Several VPCs between each node pair can be used in this method [1]. The VPC with the shortest physical length is preferred and is labelled PVPC, while the others are referred to as optional VPCs and labelled OVPCs.

The VPC bandwidth management is done with help of control messages. The following sections will describe the functions of four types of messages:

- Path finding (PATH) + Answer
- VPC Establishment
- Traffic bid (BID)
- Available Capacity (ACAP) + Answer

### 2.1 Path Finding Message (PATH)

PATH is used for path identification by broadcasting it from all nodes to all other nodes. The broadcasting can be done from time to time or at command to recover from faulty links [10,11]. In our evaluation we have only used it once to initiate the management system.

When a PATH is received, the node checks that the message has not already been received or traversed more than a maximal number of links, if so, the PATH is dropped, otherwise the node adds its own node number into the message's data field and forwards it to all links except the link on which it came. When a PATH arrives at the destination, an answer message will be sent back to the originating node, the same way the actual PATH has travelled. This message contains a route to the destination.

### 2.2 VPC Establishment Message

The node of origin selects some routes received as answers to PATH which are put in a table. We have evaluated three different selection criteria, viz. shortest, link disjoint, and node disjoint paths. The selected paths are ordered by the number of links and the total physical distances. When a limited set of VPCs has been selected the VPCs are established by send-

ing source routed messages along the paths enabling the intermediate nodes to set up their routing tables.

### 2.3 Traffic Bid Message (BID)

The BIDs convey originating traffic intensities to destination nodes along the different paths. We have named this traffic bidding. The traffic information sent can be viewed as bids for capacity. This will inform the intermediate nodes about the traffic demands for particular VPCs.

When new information has been received for all VPCs on a link, the link capacity is divided in units between the VPCs in a way that maximizes its utilization. (In our study the capacity unit can accommodate ten connections.) This is done by calculating the marginal utilization (MU) based on the ErlangB formula. The MU is the number of extra calls the VPC is expected to carry if allocated an extra capacity unit. BIDs are always followed by a determination of available capacity by means of ACAPs.

### 2.4 Available Capacity Message (ACAP)

ACAP messages are sent on each VPC to find out the capacity allowed for the whole path. This means that VPCs get the minimum allowed capacity on the series of links. The amount of available capacity is stored in the ACAP on successive links. When it reaches the end node, indicating the available capacity, an answer message is sent back to the originating node. When a VPC can not use the allowed link capacity on all of the traversed links, the surplus is made available to those VPCs which has marked the links as their bottlenecks. (Answer messages contain information to mark the links that are bottlenecks.)

### 2.5 The Distributed Method

The VPC capacity reallocation is done periodically. The period is chosen to minimize costs. (Updating more often than the traffics change is not economical.) The offered traffics are estimated by arrival counting [2,3]. Each reallocation is divided into three parts: first traffic bid, subsequent bids, and a capacity allocation part.

The **first traffic bid** is trigged by one of the nodes making all nodes transmitting BIDs. The measured offered traffics are sent on the PVPCs. The OVPCs are tested for available capacity by transmitting BIDs which are fractions (10%) of the offered traffics. Other strategies for the first bid have been evaluated in [1].

When the available capacities are received by the

ACAP answer messages, after the first traffic bids, the OVPCs are ordered by their available capacity. The **subsequent bids** are based on the available capacities. If the estimated offered traffic is  $T$ , the needed capacity  $C$  can be calculated with the Erlang's B-formula giving a specified blocking probability  $p$ . The available capacity  $C_i$  can handle a certain amount of traffic  $t_i$  calculated from (1). The index  $i$  specifies the path (for PVPCs the index  $i$  is equal to 1), and in our study  $p$  is set to 1%.

$$t_i : E_{C_i}(t_i) = p \quad (1)$$

If the total amount of allowed capacity is greater or equal to  $C$ ,

$$\sum_{i=1}^k C_i \geq C$$

where  $k$  is the number of VPCs needed, the traffic bids on the first  $k$  VPCs that sum up to  $C$  are set to  $t_i$  in (1).

For the last used VPC  $C_k$  is modified to:

$$\left( \sum_{n=1}^k C_n \right) - C$$

and the bid is recalculated from (1). VPCs with an index greater than  $k$  will get a zero bid. On the other hand if the allowed capacity is not enough the traffic bids are set proportionally to the  $t_i$ s and summing over all VPCs that has been given any capacity.

$$t'_i = T \cdot \frac{t_i}{\sum_n t_n}$$

After each new bid cycle the network gradually tunes into a better state of capacity allocation. Different number of bids per VPC have been studied.

When all bid cycles are done the process of **capacity allocation** is carried out. The purpose is to make any unused capacity available for allocation on successive rounds of ACAPs. This can be repeated a few times to enable more unused capacity to be distributed to VPCs that can use it [12]. The last cycle will allocate unused capacity to one hop VPCs (which always will be able to use it at least to some extent).

### 3. The Local Approach

The selected approach for local VPC bandwidth management is the one developed by Mocci et al. [5]. This method allocates just enough VPC capacity to meet the blocking constraints. This calls for the cal-

ulation of the average blocking probability over a finite time interval of a system in a transient state. The calculation can be simplified by the method of Virtamo and Aalto [15].

At regular intervals (with length =  $T_u$ ) the needed VPC capacity is determined. From a precalculated table or a function the needed capacity for the next interval is given by the current number of active calls. Allocation is done in such a way that the expected time average of the blocking probability in the interval will be less than a predefined limit (1% in our study).

The idea of this approach is to handle traffic variations in a short time scale that is larger than the mean interarrival time but smaller than the average call holding time. The needed amount of capacity can be calculated for all possible traffics and occupation states. However, to get a relevant measure of the offered traffic, a measure over several updating intervals is needed. We have used a calculation which does not depend on the actual offered traffic [16]. In our implementation we have used:

$$N(k) = k + 1.26 \cdot k^{0.39}$$

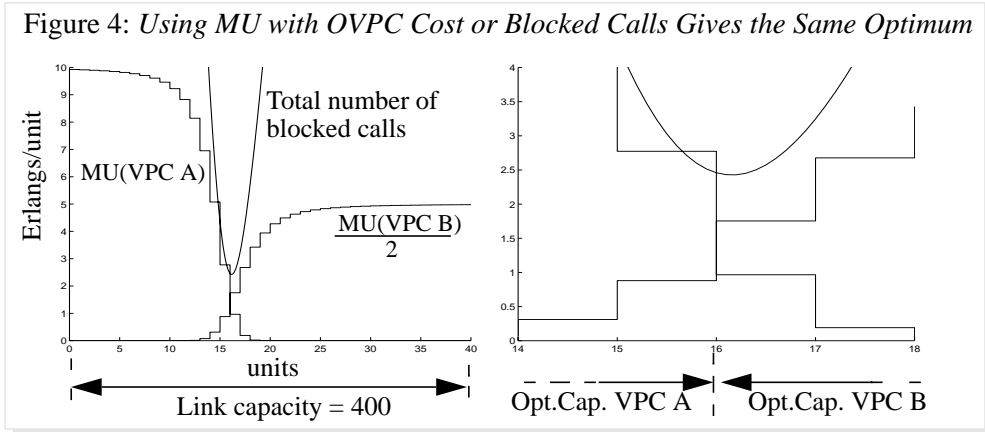
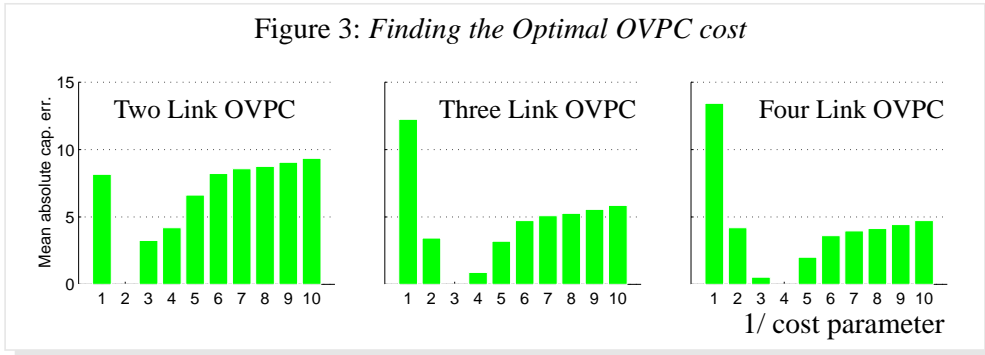
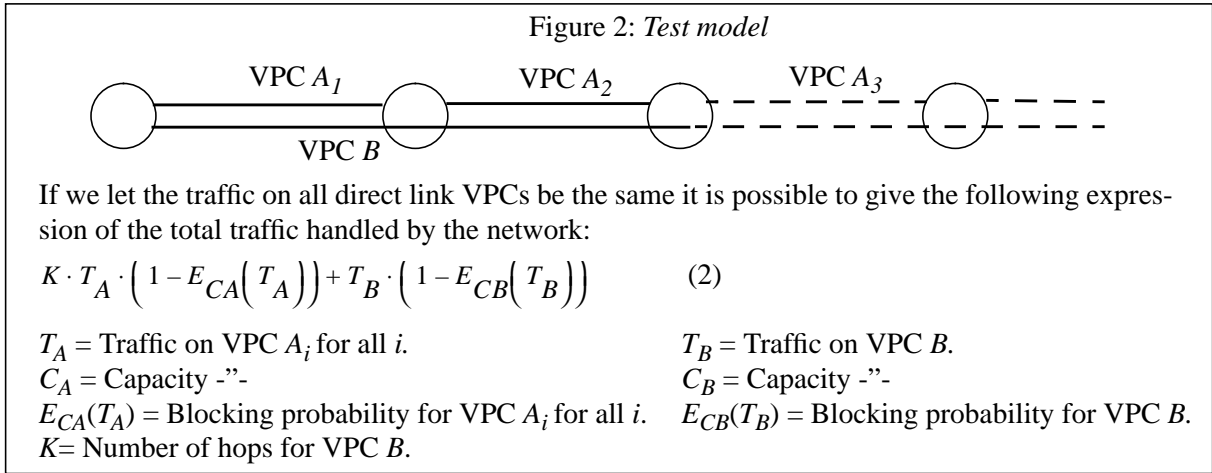
to get the needed capacity, where  $k$  is equal to the number of currently active calls. This function is optimized for 1% blocking probability and an updating interval of 0.1 time units. (better functions exist for other updating intervals and blocking probabilities.)

When more capacity is needed a capacity request signal is sent on the PVPC. If the request cannot be satisfied, the OVPCs are tried in the order they have been put in the routing table by the selection process. When less bandwidth is needed will capacity on OVPCs be released first and in the reverse search order. When trying to get capacity on the links a reservation must be made. This makes interference from other requests impossible. To avoid deadlocks the following procedure is followed. If a request message reaches a node where the next link is already reserved a message will be sent back to the node of origin releasing its current reservations. The node of origin tries again after a short random delay.

The updating interval has a lower bound determined by the time to handle the control signals and perform VPC bandwidth allocation in the nodes.

### 4. The Central Approach

We have used a method described in [3]. In this method all nodes monitor the offered traffics and report their results to a network management center periodically with the same frequency as for the



distributed approach (6 time units). The center computes an updated VP network bandwidth allocation and returns the results to the nodes for implementation.

### 5. Evaluation of the Distributed Approach

We have used ten non-hierarchical networks (in the VC sense) each having ten nodes (which can be seen as core ATM networks). The evaluation has been done with homogenous traffics with the same QoS demands and Poissonian traffic arrivals. Multiplexing in the burst scale (e.g. for VBR services) is hidden in the use of equivalent bandwidth [7,8]. For each origin-destination pair an offered traffic was

assigned to give 1% expected loss for the given transmission capacity (basic traffics). These traffics can also be seen as busy hour traffics. To simulate a difference between actual traffics and the basic traffics ten different traffic patterns were generated for each network by randomly selecting a busy center. Nodes inside the center increase their traffics. This will be referred to as the imbalance. In this paper values within brackets show results when having a greater imbalance. Details are described in appendix A.

#### 5.1 Finding the OVPCs

When selecting the paths it seems to be better to choose link disjoint or node disjoint ones than just

the shortest ones. Disjoint paths increase the probability to avoid a busy center. The results from different selection criteria, three OVPCs, three BIDs, no ACAP iterations, and no alternative routing are as follows (the fixed VP bandwidth management is optimized for the basic traffics and has no OVPCs):

Criterion	Mean bl.[%]	Max bl.[%]
Fixed	1.810 (17.0)	5.320 (51.0)
Shortest paths	1.038 (5.30)	3.112 (25.8)
Link disjoint	1.024 (5.22)	3.096 (25.1)
Node disjoint	1.022 (5.23)	3.090 (25.4)

## 5.2 Cost of OVPCs

We try to optimize the total amount of handled traffic in the network. When distributing the capacity of one link the effects on the other links should be taken into account. The benefit, in terms of total handled traffic, of having one two-hop VPC is less than two one-hop VPCs. This means that longer VPCs (in terms of hops) must have less priority in the distribution process than shorter ones. This has been implemented by dividing the MU by a cost parameter.

To better understand the problem and to get the value of the cost parameter, we have done an analytical study of a path with direct link VPCs and one multi-link VPC traversing all links as in fig. 2. The optimal capacity distribution can easily be found by changing the capacity on VPC  $A_i$  until the optimum of (2) is found (see fig. 2).

Fig. 3 shows the absolute value of the difference between the optimal capacity and the allowed capacity from our approach with different cost parameters. The results shown are averages over a set of traffic mixes for VPC  $A$  and  $B$ .

It is seen that the cost parameter appears to be the inverted value of the number of traversed links and we have seen that the optimal OVPC cost does not depend on the traffic variations nor on the link capacity.

Fig. 4 shows an example of using the number of hops to divide the MU. (The curve for VPC  $B$  starts from

the right side of the diagram). The number of hops is 2,  $TA_1=TA_2=140$ , and  $TB=220$  Erlangs. Another curve shows the total number of blocked calls derived from (2):

$$2 \cdot E_{CA}(TA) \cdot TA + E_{CB}(TB) \cdot TB \quad (3)$$

The right part shows an enlarged fig. of the cross-point area. One can see that the same solution is found by maximizing the penalized MU as when minimizing (3). We have also evaluated more complex networks than the one in fig. 2, and seen that the choice of cost parameter remains the same.

## 5.3 Fairness

To give the same possibilities for all node pairs to get capacity the PVPCs are not penalized. To equalize the treatment between OVPCs and PVPCs we have subtracted the number of hops of the PVPC from the number of hops for the OVPC. We have seen that the VPs are treated more equally this way and the total profit will increase.

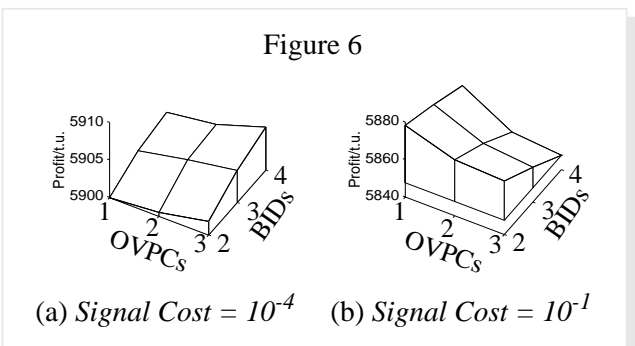
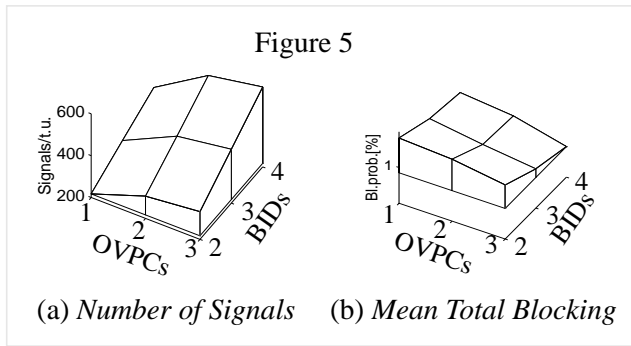
The iterations of ACAP are used to allow multi-hop paths to get extra capacity. (VPCs traversing more links are more likely to get the allowed capacity restricted.) When using node disjoint paths and ACAP iterations the results are:

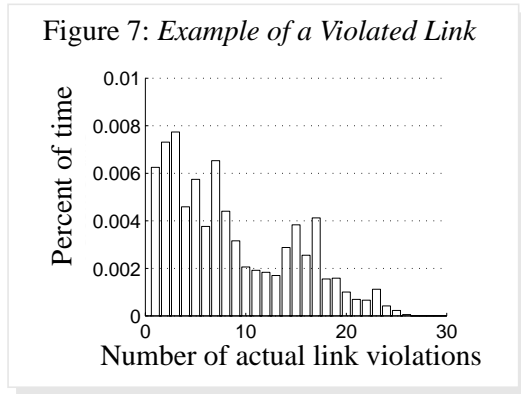
Iterations	Mean bl.[%]	Max bl.[%]
1 iteration	1.016 (5.36)	3.090 (25.3)
3 iterations	1.012 (5.25)	3.090 (25.2)
5 iterations	1.005 (5.20)	3.087 (25.3)

The results show that the decrease in blocking probability is rather limited.

## 5.4 Profit

The cost for control messages (by means of RM-cells using some of the bandwidth) affects the total profit. Fig. 5 shows how the total mean network blocking decreases as the number of control messages increases. Fig. 6 shows two different costs for control mes-





sages and their impact on the total profit. The profit of handling one call is set to one unit. If a control message is seen as an RM cell, the cost can be related to a phone call. Suppose that a phone call uses 167 cells/second, then the RM cell could be given a cost of  $1/(167 \cdot \text{seconds per mean holding time})$  which is  $\sim 10^{-4}$ . This cost might be too optimistic because there are also costs other than the ones related to bandwidth. These are difficult to estimate. By using a signal cost of 0.1, the signals can be seen as having a lot of overhead. As seen in fig. 5 and 6 the number of OVPCs and BIDs to use depends on the actual signal cost.

### 5.5 Link Violations

Another interesting aspect is the occasionally occurring link violations. These are caused by excess calls on links which have been granted less capacity and that are not disconnected in time before new calls arrives on VPCs which have been granted more capacity after a reallocation. There are three ways to deal with this. One way is to move ongoing connections to a path that can accommodate them. Another way is to wait for the connections to finish until capacity is released. The third way is to use “guard bands” which will not be allocated to any particular VPC. By this one hopes that there will be enough bandwidth to deal with over allocations. We have used guard bands of one extra capacity unit on each link. (A better dimensioning is possible.) The amount of link violations depends not only on the guard band but also on the actual network and traffics.

Fig. 7 shows the link violations on the most overloaded link for one of our test networks using the distributed approach with guard band, medium traffic imbalance and a 50% increase of the basic traffic load. The link’s capacity is 1010 i.e. 20 is 2% of the total capacity. The time a call could be affected by link violations (in this example) is in average less than 0.08% of the call holding time.

## 6. Comparisons

In this evaluation we have used dynamic alternative routing [14] on the call scale, i.e. if the direct VPC does not have room for an arriving call, a two-VPC rerouting is tried. If this does not succeed the call is rejected and a new transit node is selected (at random) for the next time a call needs to be rerouted. Two control messages are used to determine the transit nodes’ status (question + answer). The central approach use a special algorithm for global optimization of trunk reservation. This algorithm can not be used by the local and distributed ones, since they do not have access to global information. Instead they reserve one capacity unit to direct traffic. Our comparison is based on the mean total network blocking probability, a measure of the maximal VP blocking, the link violations divided by the total simulation time, and the fraction of profitability reached, e.g. if all calls are handled without any costs, the reached profitability is 100%.

The local approach tries to maximize the network’s unused capacity without violating the predefined blocking probability while the others utilize all of the capacity. The fixed approach only uses the PVPCs and the capacity allocation remains constant.

The distributed approach is evaluated in two cases labelled distributed 1 and 2 with the following settings:

Case	OVPCs	BIDs	ACAPs	Sig.Cost
Distributed 1	0	1	1	0.1
Distributed 2	2	4	4	$10^{-4}$

The local approach is evaluated for two different updating intervals ( $T_u$ ):

Case	OVPCs	$T_u$	Sig.Cost
Local 1	2	0.1	0.1
Local 2	2	0.01	$10^{-4}$

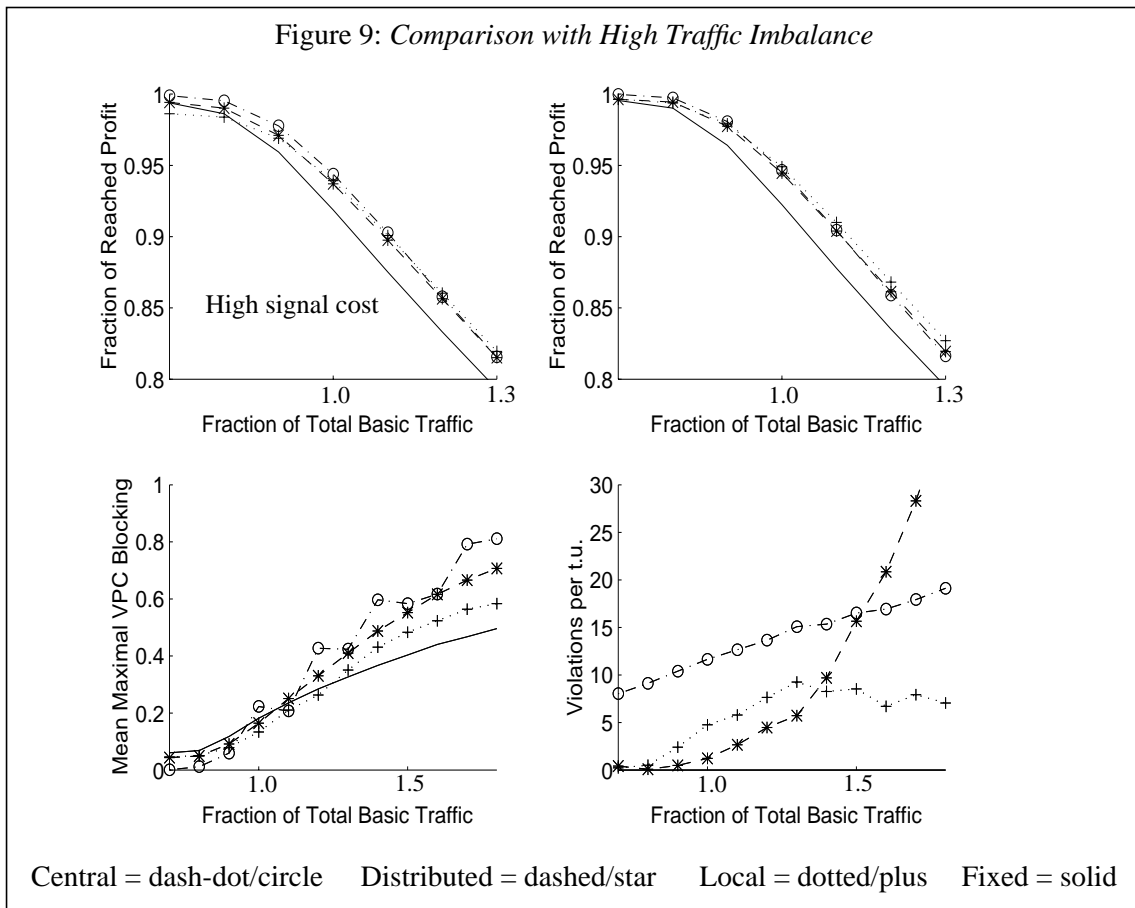
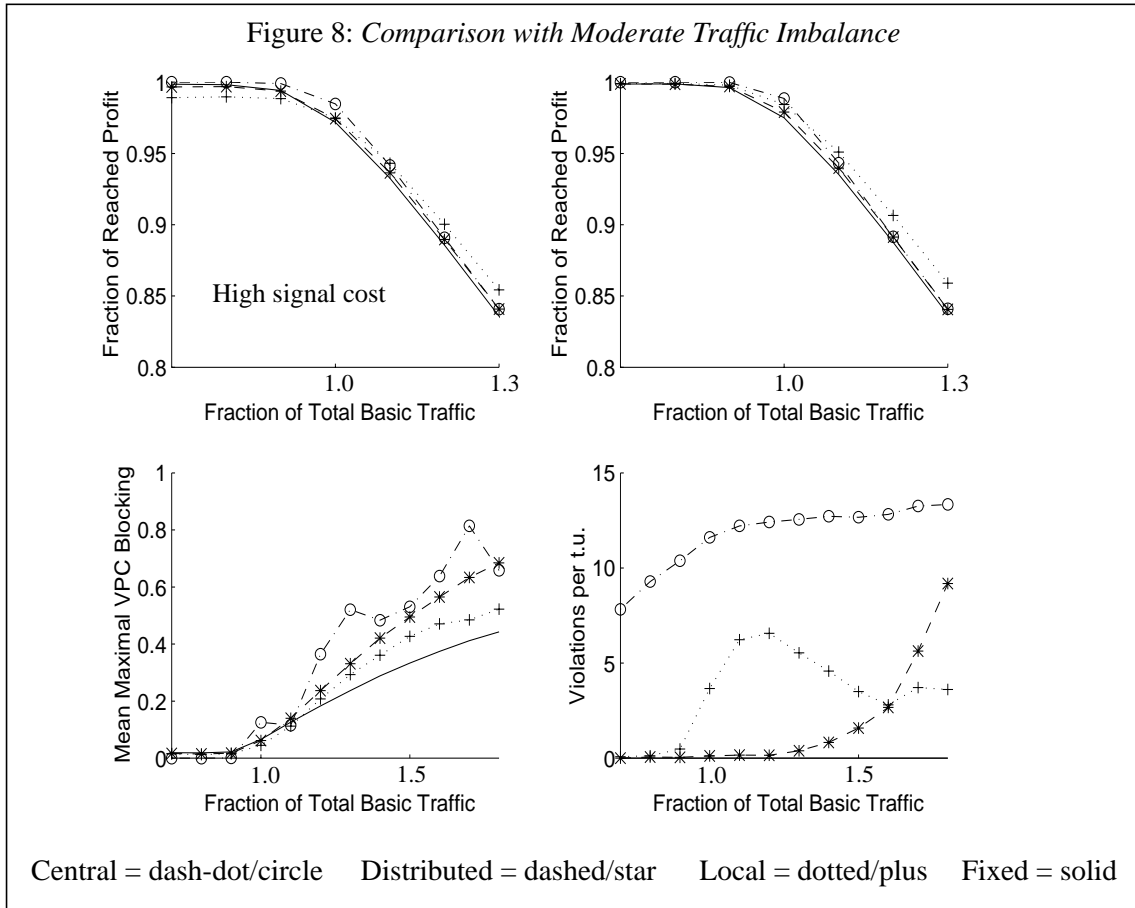
(Both approaches use case 1 for high signal cost and case 2 for the low signal cost.)

Fig. 8 and 9 show the performance for different traffic imbalance situations. All diagrams but one show results for a low signal cost ( $10^{-4}$ ). Fig. 10 and 11 show the actual number of generated control messages and the amount of alternative routed calls.

Table 1 shows the main characteristics of the different approaches.

### 6.1 Central Approach

The profitability is good but the large number of link violations is a clear drawback. It use a minimal amount of control messages as seen in fig. 10. This approach calculates a nearly optimal trunk reservation for each link which in fact reserves more capaci-



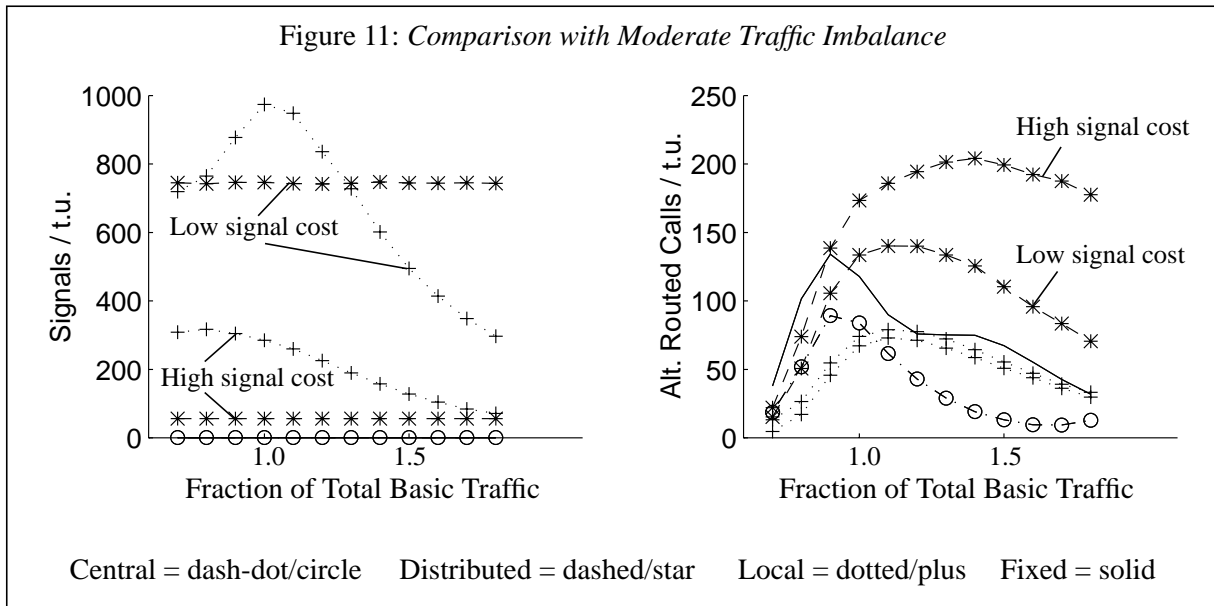
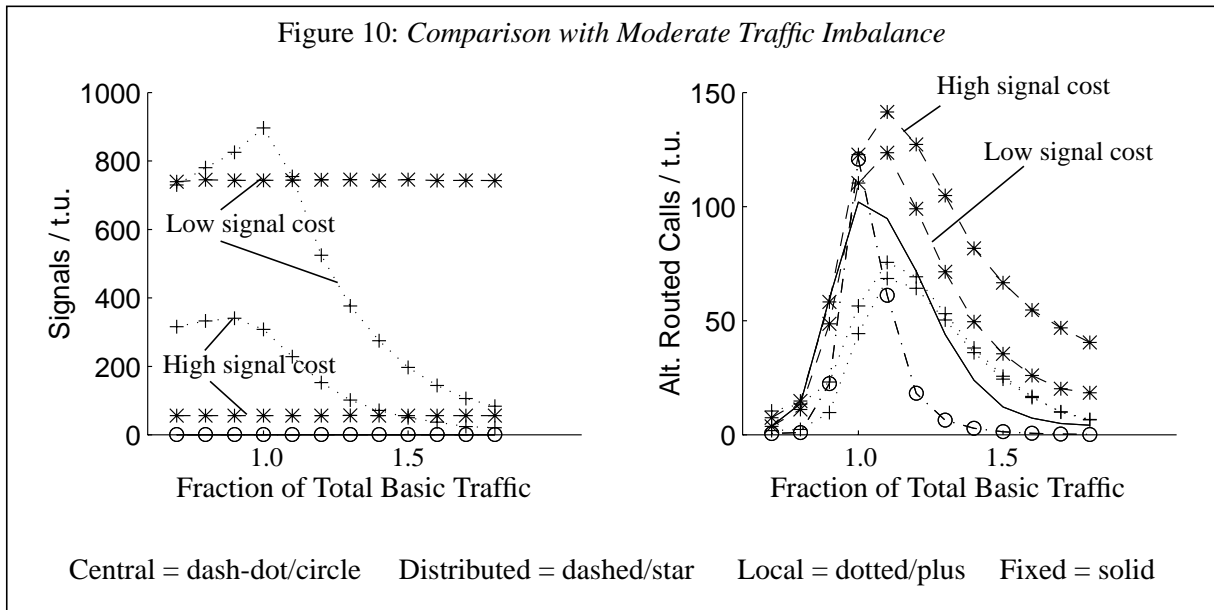


Table 1: Main Characteristics of the Different Approaches

Approach	+	-
Central	<ul style="list-style-type: none"> <li>Moderate amount of control signals</li> </ul>	<ul style="list-style-type: none"> <li>Link violations.</li> <li>Network management center needed.</li> <li>Large networks increase the complexity of the calculations.</li> </ul>
Distributed	<ul style="list-style-type: none"> <li>Simple.</li> </ul>	<ul style="list-style-type: none"> <li>Link violations.</li> <li>High number of control signals.</li> <li>Computation power at each node needed.</li> </ul>
Local	<ul style="list-style-type: none"> <li>Simple and “self-regulating”.</li> <li>Limited amount of link violations.</li> </ul>	<ul style="list-style-type: none"> <li>Inability to detect low total traffic load.</li> <li>Needs exponential call holding times.</li> </ul>
Fixed	<ul style="list-style-type: none"> <li>OK for moderate traffic imbalance.</li> <li>No link violations or control signals.</li> </ul>	<ul style="list-style-type: none"> <li>Lack of flexibility.</li> </ul>



ty for direct traffic than the other approaches. In the case of using a trunk reservation of one capacity unit on each link the number of alternative routed calls becomes nearly the same as for the fixed approach and the profitability drops somewhat.

## 6.2 Distributed Approach

As the traffic load becomes heavier the number of link violations starts to increase because the capacity changed will be more utilized. As seen in fig. 10 and 11 the number of alternative routed calls are relatively high. The number of actual link violations are about the same when having only the PVPC as when having several VPCs. It is possible to reduce the violations by increasing the trunk reservations from one to two capacity units. The number of alternative routed calls is reduced to the level as for the local approach but the profitability decrease a little. The computations needed are simple but the complexity is instead moved to the management of control messages (i.e. timeouts, delays). When making changes in the algorithm all nodes needs to be updated.

## 6.3 Local Approach

The local approach sends less control signals when there traffic load is high because there will be less deallocations and more unsuccessful allocations (fig. 10,11). As seen in fig. 8 the function for capacity allocation is not designed for the  $T_u$  of 0.01 because the fraction of wanted profit should look like the curve with  $T_u = 0.1$  (high signal cost). An allocation function should be designed for a very small blocking probability to give more profit for small traffic load. This depends on the inability to detect overall low traffic load which in turn forces the average blocking to the predefined limit. It should be pointed out that in this evaluation the used function will in general give the result that the capacity needed during the next time interval is the actual number of used capacity units plus one.

Fig. 8 and 9 show the results when no guard band is used for the local approach. If a guard band is not used the profit gets slightly better because the guard band will be utilized as ordinary capacity. However, by doing this the link violations will increase (from almost none) and the maximal VPC blocking will increase slightly, but the link violations will still be less as compared to the central approach.

It can be seen in fig. 8 that the link violations increase when OVPCs is being used but decrease when the traffic load increases because the capacity assigned to the VPCs will freeze when all VPCs wants

more capacity. There will still be violations for high traffic load as there are major shifts in the traffic pattern. The amount of alternative routed calls is less than for the other ones (fig. 10,11) because the probability of having enough capacity on the direct VPCs is greater for this approach.

## 6.4 Fixed Approach

It is seen that for high traffic imbalance (when some links are heavily overloaded) the fixed allocation is not as good as the other approaches. The fixed approach shows good performance even for moderate traffic imbalance. It does not need a guard band to cope for link violations which means that there is more capacity available for this approach. Due to the lack of flexibility, the mean busy hours traffics have to be measured and a proper capacity allocation done once and for all off line.

## 7. Conclusions

We have developed a type of distributed VPC management policy and described it in detail. The method can use many iteration cycles to improve the network performance, but the number of control messages will increase correspondingly.

We have compared this to three fundamentally different approaches for VPC bandwidth management and evaluated the pros and cons of each approach (table 1). It seems as if the local approach is an interesting alternative to the otherwise so frequently studied central approaches.

It has to be pointed out that in this comparison the updating intervals for the different approaches has not been properly selected to optimize the profit.

## 8. Further Work

It is expected that further development of the bidding strategy and method of ACAP iterations of the distributed approach will increase the amount of handled traffic, and there are still many ways to decrease the number of management messages further [17].

The link violations can be reduced by delaying the capacity reallocation until the number of affected calls reduce enough or by moving ongoing calls.

An integration of the local approach into the central and distributed approaches will be evaluated with the intention to reduce link violations and at the same time improve performance.

The optimal updating intervals is to be calculated.

Statistical multiplexing is restricted to within VPCs. One way to increase multiplexing gain is to group VPCs together. Using the local approach there might be no need for group VPCs [18] and it could simplify the trade-off between VP and VC routing [4].

Having the OVPCs seen as backup-VPCs will enable a self-healing network [10,11,13] by integrating fault management into the bandwidth management.

## 9. Appendix A

The networks have been made with a program that generates networks with ten nodes. The total arrival rate of calls is about 6500 calls per time unit and call holding times are assumed to be negative exponentially distributed with a mean holding time of 1 time unit. For each origin-destination pair an offered traffic was assigned to give 1% expected loss for a given transmission capacity. (When reserving guard bands the blocking increases.) This basic traffic was modified to yield different situations by the use of "busy center". Traffic between busy center nodes were increased randomly between 10-30%. Traffic between nodes outside the busy region were decreased randomly between 10-30%, and the traffic between a busy center node and a node outside the center was modified randomly between -10% and +10%. After the modification the traffics have been normalized to give the same total amount of offered traffic as before. The resulting greatest increase is 43% and greatest decrease 30%. We also consider a case of more extreme imbalances with limits 20% and 60% (instead of 10% and 30%). The resulting greatest increase is then 97% and greatest decrease 60%.

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