Comparisons of Different VPC Capacity Management Methods in ATM Networks

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Abstract

The fact that there is a lack of comparisons between methods for VPC management makes it important to evaluate fundamentally different methods. We have tried to find representatives of different ways of calculating the capacity distribution. A central approach uses global information about demands and resources [1, 2], while decentralised approaches can be categorised into iterative and local. The local approaches that we have evaluated [3, 4] uses the number of ongoing connections to decide how much capacity that is needed during the next updating period. An iterative approach uses a distributed way of calculating the capacity distribution [5, 6, 7]. By evaluating these, we have then been able to do a survey over the performances.

Key words: QoS, ATM Capacity Management, Resource Allocation

1 Introduction

There are a lot of different methods for virtual path connection (VPC) management [8] to improve the performance. They mainly differ in the objective function(s) to be optimised, the number of different paths between node-pairs, and constraints like having a target maximum call blocking probability. This makes conclusive comparisons very difficult. However, some general aspects can be mentioned. The problem with a comparison is to give costs for control messages and processing which enables calculation of comparable numbers. One can consider to have an upper limit on the number of messages that can be handled within a certain time interval in a switch. If there exists a signalling network with a fixed capacity (out-band signalling), a certain amount of the link capacity can be regarded as belonging to the signalling network. This capacity is not included in the dynamic capacity allocation. If for instance RM-cells are used (in-band signalling), a cost can be given on messages, which is related to the loss in revenue due to less handled customer traffic. In [9] a cost model based on transmission, switching and setup costs are investigated. This shows that the optimal policy is having both VPs and VCs. In [10] a cost-benefit study is done. The cost of traffic carrying capacity is related to the control costs. When capacity is cheap relative to control, it becomes economic to use VPCs and to periodically update the reservations. In [11] the total network cost is considered including the architecture and VPC management. In this evaluation we consider in-band signalling and we do not consider different network architectures and costs related to hardware. All of the capacity in the network is free to use and the evaluations is done with a call-by-call simulation. We have evaluated seven approaches. A central, two iterative, two local, a fixed, and one which do not use reservations in advance.
2 Different Approaches

2.1 A Central Approach

In the central approach (denoted as CENT) a network management center (NMC) monitor current demands to all nodes periodically. At the end of each such cycle, the NMC collects all estimates of user demands from which a VPC network is designed, i.e. a capacity distribution for all demands. Capacity is distributed one capacity unit (c.u.) at a time. (One c.u. can at least accommodate one connection, considering the statistical multiplexing on call-scale.) This is first done in an attempt to equalise the VPC connection setup blocking probability (CBP) to be less than the target maximum VPC CBP (MAXCBP). In other words, capacity is distributed as long as any VPC has an estimated CBP larger than the target MAXCBP and it is possible to allocate capacity to such a VPC. The remaining capacity is distributed to maximise the total handled traffic. For this we use the concept of marginal utilisation ($MU$). The $MU$ is the extra number of connections that the VPC is expected to carry if allocated an extra c.u. For each VPC, the $MU$ is also divided with the number of traversed links to maximise the total number of handled connections in the network. When the new capacity allocation has been calculated, the information concerning each node is gathered together and sent at the same time (i.e. one control message is considered enough). The time to calculate the capacity allocation is estimated to take 5-10 seconds. We have used dynamic alternative VC routing (DAR), with trunk reservation ($TR$) for direct traffic. The $TR$ parameter on each link is calculated by minimising the rate of lost revenue [12].

The problem of finding both the VPC topology and the VPC capacities is a capacity non-linear integer-value multi commodity flow problem and as such is NP-complete [13]. To solve this one can use a heuristic algorithm, so no guarantee that the final solution is a global optimum can be made. Since the state is always changing, this is not a serious drawback in practice.

2.2 An Iterative Approach

An approach, which is a compromise in the amount of information needed for the VPC management, is an iterative one (Fig. 1). Because of the scarce appearance of iterative approaches in the literature, we have developed one denoted as ITER. (A central approach can be distributed to all of the nodes, but we do not define it as an iterative approach.)

This approach distributes information about the offered traffics among the VPCs. The offered traffics are used when distributing the resources on each link. Each node independently decides when a resource reallocation is to be started. However, the decisions are made periodically.

The method iterates on the hop length of the VPCs. Capacity is “freezed” for the longest VPCs first and in the last iteration the one hop VPCs get the rest of the unreserved capacity. The sequence number in the control messages tells the hop length of the VPCs to be given additional capacity. The number of iterations is thereby dependent on the hop length of the longest VPC in the network. If more than one VPC is used between node-pairs, the currently allocated capacity is needed for the calculation of the $MU$ for each VPC, e.g. a node has to know how much capacity that is reserved in total for a certain node pair. After each and every iteration the resulting allocations are delivered with new messages. The algorithm does not get more complex for big networks, and the approach is not dependent on an NMC.
2.3 An Approach based on Game Theory

An iterative approach which is based on analytical results has also been selected for comparison reasons. We consider the so called Gauss-Seidel approach as described in [7] (denoted as NON-COOP in the sequel). All the nodes updates their capacity reservation on the outgoing VPCs periodically and independent of the other nodes. To control the interaction among the different VPCs a cost function is used that depends on the availability of capacity. Only one VPC updates the reserved capacity at a time, based on information on the total capacity reserved by all other VPCs on the path. This results in a two-step process. A VPC first enquires the minimum amount of free capacity on the traversed links. The path is locked from updates from other VPCs. Then the optimal capacity allocation is computed and capacity is either requested or released. Finally, the path is made available to other updates. The order in which the VPC updates their capacity does not matter. Available capacity for a particular path \((VPC_i)\) is found by sending messages. The result is used when calculating how much capacity they ought to have.

Two methods for the iterative calculation can be used: Gauss-Seidel and Jacobi. The Gauss-Seidel method allows only one VPC to be updated at a time. The Jacobi method works in a synchronised way, where all the nodes are informed of the current link loads and calculate the wanted capacity at the same time. We select a method based on the Gauss-Seidel that has been altered to take into account the actual load situation on the different links [7]. By introducing a parametrised cost functions (1,2) the user’s allocation functions (or strategies) can be adjusted by for example the network manager. The wanted capacity is the one that minimise the following cost function:

\[
J_i = \sum_{(u,v)} F_i^{uv} (C_i^{uv}, C^{uv}) + G_i(C_i)
\]

\[
F_i(C_i, C) = C_i \left( \alpha_1 + \frac{\alpha_2}{(1 - \frac{C}{B})^n} \right)
\]

\[
G_i(C_i) = \begin{cases} 
1/(\kappa_i - E_{C_i}(A)) & , \kappa_i > E_{C_i}(A) \\
\infty & , otherwise 
\end{cases}
\]
$\kappa_i$ is the minimum guaranteed capacity. In our implementation it is estimated by setting it to the capacity that will give an expected CBP equal to the target MAXCBP for the basic traffics. In the evaluation we can not guarantee this to be the upper constraint of CBP. In (1) the cost is summed up for all traversed links, where each traversed link is denoted as $(u, v)$. In (2) $\alpha_1$ represents a fixed cost per c.u., and $\alpha_2$ represents a unit cost attributed to congestion on the link. Congestion is (loosely) defined as the situation when the reserved capacity $C$ approaches the link capacity $B$. Parameter $n$ determines how early congestion is detected. As in [7] we have set $\alpha_1 = 0.01$, $\alpha_2 = 0.001$, and $n = 1$.

The cost function (1) should account for the following trade-off. On the one hand, each user should try to minimise the CBP, which is a decreasing function of the reserved capacity. On the other hand, reserving capacity becomes more difficult as the available capacity decreases and should thus be costlier. Function (2) accounts for the availability of the capacity as perceived by $VPC_i$. Function (3) accounts for the effect that the amount of reserved capacity has on the performance of that VPC.

According the Kuhn-Tucker optimality we will get a so called Nash equilibrium point if:

$$ F_1'(C_i, C) = -G_1'(C_i) $$

This means that all capacity is allocated in a way so that (1) is minimised for all VPCs. Many iterations of reallocations is required to get to this “point.”

### 2.4 A Local Approach

We denoted this approach as ISOLA (as in isolated) to distinguish it from an adaptive approach (described in Sect. 2.5). A flow chart of our approach [3, 4] is shown in Fig. 2. This approach is based on the one developed by Mocci et al. [14]. Their method allocates just enough VPC capacity to meet the target CBP constraints during a given interval from the allocation instant. In [15] a simplified allocation function is presented, which does not depend on the actual offered traffic:

$$ N(n) = \lfloor n + K(\varepsilon, T_u, n) \cdot \sqrt{n} \rfloor, $$

where $N$ is the required capacity, $n$ is the number of currently active connections, and the factor $K$ depends on the target CBP $\varepsilon$, updating interval $T_u$, and the actual occupancy state $n$, at time zero. It should be noted that this kind of confidence interval like dimensioning occurs in various contexts. For example in [16] from 1914, the capacity for the outgoing cables from a switch are dimensioned when the ingoing traffic is known (by the busy hour). This can in fact be related to the division of traffic to different VPCs. In [17] a similar scheme is used for the calculation of needed resources in burst and connection level.

The idea of this approach is to handle traffic variations on a short time scale, i.e. larger than the mean interarrival time. (Reallocation triggered by each new arrival and departure affects both cost and stability.) When more resources is needed, an increase request is sent. When less capacity is needed, capacity decrease messages are sent.

### 2.5 An Adaptive Local Approach

The adaptive local capacity reservation approach is denoted as ALCRA. Some gain can be made by applying different $K$-values in (4) to different node pairs, and by adaptive tuning of the $K$-value according to present conditions. The latter implies that the safety margin $K$ is adjusted up if there is little competition for resources and vice versa. The degree of competition can be
judged per VPC from the measurement of free capacity on the route [4]. In this case we will get an adaptive decentralised approach. The main difference to other decentralised approaches are the use of the number of ongoing connections. Therefore, we denote this approach and the isolated one as local approaches.

### 2.6 A Call-by-Call Approach

We also evaluate an approach that do not use VPCs (NOVPC), the first option when selecting a path is the shortest one and secondly the shortest paths to and from a via node is tried (as in DAR). The hop-by-hop allocation is also used for the other approaches as a complement to DAR (with the same trunk reservation) along the shortest path. We denote this as link routing (LINKR). If this does not succeed the connection is rejected.

### 3 Evaluated Parameters

#### 3.1 Profitability

The “profitability” is used to enable a reasonable evaluation of the overall performance by combining gains and costs. In our evaluation the performance is based on the reached profitability. Profitability is a normalised measure where 100% profitability means that all connections are handled without any overhead costs. (100% is infeasible for high traffic load situations.)

\[
\text{Profitability} = \frac{\text{Calls}_H \cdot (1 - C_{VC}) + \text{Sigs} \cdot C_S + \text{VP}_u \cdot C_C + (\text{AltR} + \text{LinkR}) \cdot C_{VC}}{\text{Calls}_O}
\]  

The number of handled calls (connections) is denoted as \( \text{Calls}_H \), the number of offered calls as \( \text{Calls}_O \) and the number of messages as \( \text{Sigs} \). \( \text{AltR} \) is the number of alternate routed calls and \( \text{LinkR} \) is the number of link routed ones. The number of changes of reserved capacity in the nodes as \( \text{VP}_u \). \( C_{VC} \) is the VC link setup cost (0.05 according to [10]) including control and selection of VPI and VCI numbers (and an extra cost for switching), \( C_C \) is the cost for updating reserved capacity in a node (0.01), and \( C_S \) is the cost for a control message (10⁻⁴).

The profit of handling one connection is set to one unit. To be able to handle connections, several control messages (by means of control messages or RM-cells) have to be used and these affect the total profit. Let us say we use RM-cells that need some of the resources, which becomes unavailable for paying customers. The cost can be related to an average phone call.
An upper bound on the cost is overhead costs being equal to the profit of a call, \textit{i.e.} on the order of one. A lower bound can be obtained as follows. Assume that messages consist of single RM-cells and that a phone call uses 167 cells/second, having a mean holding time of \(\approx 60\) seconds. The RM cell would then consume resources to the amount of \(1/(167\cdot 60)\), \textit{i.e.} giving a cost of \(\sim 10^{-4}\). This cost might be too optimistic. Partly because one can use speech compression and taking into account that there are also costs other than the ones related to bandwidth and buffer space, \textit{e.g.} processing.

A comparison can not rely on one measure only. Partly because the measure of the profitability can be discussed from different points of views, like in-band or out-band signalling; should the capacity of the signalling network be taking into account, and so forth. In the following sections complementary measures are discussed.

\section*{3.2 Control Messages}

The number of control messages that can be handled by a switch is limited. Measurements on commercial ATM switches available today shows a mean value of maximum handled messages of 10–50 per second [18]. New technology will, however, increase the speed of the switches. In the evaluations we set the signalling CPU service time to 20 ms and simply measure the maximum number of messages per node and t.u.

\section*{3.3 Connection Setup Blocking Probability}

It is important for a dynamic capacity allocation scheme to be robust and able to handle unexpected traffic changes. Evaluations of the performancies should be done for different traffic loads and distributions in the networks. The MAXCBP is important since the impacts of large CBP on redialling as well as fairness among the customers must be taken into account.

In [19] the Erlang bound is used for calculating a so-called robustness index. This is computationally complex when having dynamic VPC capacity reallocation.

It is my opinion that a target MAXCBP is better to use than a fraction of the Erlang bound limit. In many studies an upper bound of the CBP of 10\% has been used. This might limit effects like redialling and customers getting so disappointed that they rather move to other telecom-providers. In case of having a large MAXCBP, we think one could see the situation as having an underdimensioned network. For robustness one could study the performance when getting a MAXCBP of, for example, from 0–25\%.

Having a general overload makes the effect of the bandwidth management noticeable, because the mean MAXCBP will level out at the upper bound (at the target MAXCBP) for a certain interval of the overload-traffic, until it starts to increase again when the overload gets too much for the network (and management function) to handle. This “break-point” will give the maximum of traffic load that still could be considered acceptable for customers (if they occur infrequent enough).

To get a detailed overview of the CBP performance of a certain VPCNM strategy, the distribution of different CBPs among the different VPCs could be investigated as a complement (\textit{e.g.}: 0\%–0.1\%, 0.1\%–1\%, 1\%–3\%, 3\%–10\%, 10\%–20\%, >20\%).
4 Assumptions

In this evaluation we implement predefined routes and preressed resources by means of VPCs upon which individual virtual channel connections (VCCs) are established and terminated for each connection. In fact, we adaptively form a complete network of VPCs, which constitutes a higher layer which is logically independent of an underlying physical network.

We have compared the previously described approaches together with a fixed approach (FIXED) which does not reallocate the VPC capacities, but it is a central approach that use the mean traffics.

In this study ten fully connected non-hierarchical networks with ten nodes each are used (which can be seen as core networks). As a test of robustness we use a kind of high imbalanced (HI) node overload (hot spot/busy center situation) together with general overload (GO) where the traffics have been changed proportionally (see appendix A). Our test networks have the capacity to handle the mean traffics with 1% CBP. The target MAXCBP is set to 0.2.

For the sake of simplicity we limit the numerical examples of this study to the case of a single, uniform service class. However, the results are readily extended to multi-service networks. Multiplexing in the burst-scale (e.g. for VBR services) is hidden in the use of effective bandwidth [20, 21] hence extensions to bursty traffics is straight forward. We consider traditional telephone traffic. Requests for connections arrive at independent negative exponentially distributed intervals for all node pairs which means that the statistical multiplexing gain in the call-scale can be determined by the Erlang’s B-formula. The offered traffics are estimated by arrival counting. The connection holding time is assumed to be negative exponentially distributed with unit mean. We neglect the effect of redialling.

The nodes have both VP and VC routing capabilities and a fully meshed network of VPCs is formed so that all nodes have direct VPCs to all other nodes. We have found very little benefits from using several paths using our traffic patterns. Therefore, only the shortest path in number of hops is used. (This also decrease the need of considering the increase in effective bandwidth when traffic is divided into paths with smaller capacity.) A VCC between two nodes is normally routed over the corresponding, direct VPC. The one-link VPCs are able to use all unreserved capacity on the link they use, unless a link reservation has temporarily been done during some reallocation phase.

All approaches use one c.u. /connection (i.e. the finest granularity). Reallocations are done periodically and they use the same networks and traffic patterns. The updating interval \( T_u \) has been set to 3 t.u.s (optimal for HI-traffic) for the central, link-iterative, and Gauss-Seidel scheme, and for the local methods \( T_u \) is set to 0.1.

As a compliment to VPC rearrangements, we have applied dynamic alternative routing by means of DAR. Two control messages are used to determine the status of the transit nodes. A central approach can use a special algorithm for global optimization of trunk reservation, TR. The local and iterative ones can not use this algorithm, since they do not have access to global information. One can set the TR to a fixed optimal value for normal traffic loads and it has been set to 3.

The ISOLA approach try to maximise the network’s unused capacity without violating the target CBP, while ALCRA try to utilise all of the capacity by allowing a relatively large allocation factor \( K = 3.0 \). This also gives an indication of a light load situation where the allocation formula can use a traffic measurement instead of the actual number of allocated connections (and at the same time decrease the number of reallocations). CENT and ITER reserve practically all of the capacity.
5 Results

Figures 3 and 4 gives the profitability as a function of load for all approaches discussed. CENT is as expected generally better than the other approaches. The differences are, however, not big. CENT has an advantage of being able to calculate an optimal $TR$, and the capacity is allocated on an end-to-end basis for each VPC. Using the measure of profitability, the NOVPC gets much worse than FIXED due to the amount of VC setups. For high general overload ALCRA outperforms the others due to frequent reallocations but on the same time giving high maximal VPC CBPs. It seems as if the setting of $TR$ is less critical for the local approaches. It should be noted that in (4), the number of ongoing connections include alternative routed ones.

For the situation with high traffic imbalance, ITER performs better than in the case of general overload. ISOLA is worst for low load since it do not detect the low load. For ALCRA, when using the mean value of of measured free capacity along the paths (instead of the minimum), the profitability decrease to the same level as for ISOLA. This means that it is important to set the $K$ according to the most congested link. The use of an additional VC allocation on one-hop VPCs increases the profitability in the same order as the use of an adaptive $K$ does. The increase of profitability when using DAR is about the same as the use of both adaptive $K$ and link routing.

We have made NONCOOP to iterate the allocation 5 times at each update instant but the convergence to a steady and stationary allocation could not be observed. Noncooperative games often exhibit complex behaviour as for example instability. The number of iterations should, according to [7] be much more and subsequently making the approach iterating all the time. In our evaluation, the extra gain in making many iterations is low, which means that there has to be a trade-off between the cost of many iterations and the extra benefit of getting close to a steady Nash equilibrium point. If the free capacity is divided by the number of VPCs (as done in the so called Jacobi scheme) the capacity allocation seems to converge, but small changes will disturb the scheme and suddenly converge to another steady state of the capacity distribution. We have seen that the cost function that takes the link loads into account gives a better performance. The
far most important mechanism to use for increasing the profitability, is the ability for one-hop VPCs to use all unreserved capacity on the link. Without this extension the performance can be worse than for FIXED, and using link routing will further increase the performance for high loads.

As can be seen in Fig. 5 the mean MAXCBP gets high for the decentralised approaches for high traffic loads. This depends on these approaches way of allocating capacity link-by-link. It is only CENT that can control the maximum VPC CPB.

For all approaches does the amount of alternative routed connections highly depend on the load (seen in Fig. 7). This is explained by the fact that the number of alternative routed connections is low for low traffic load and increases with the traffic. For high traffic loads, however, trunk reservation prevents alternative routing which results in a decrease. For NONCOOP the amount of unreserved capacity leads instead to an increased number of link allocations (Figs. 9 and 10).

For all decentralised approaches the amount of unreserved capacity is large but decrease when load is increased. ALCRA can utilise the low load indication when the allocation factor gets large enough.

The decentralised approaches decrease the number of reallocations for high loads (seen in Fig. 13), because no changes can be made, i.e. no VPC enter a situation when less resources is required. The difference between ISOLA and ALCRA is significant. ALCRA can detect a low
load \( \hat{A} \) by measuring a lot of free capacity and thereby allocating capacity by using the mean traffic instead of the actual number of ongoing connections. When the adaptive \( K \) gets \( \geq 3 \) the following allocation function is used:

\[
N = \lceil \hat{A} + 3.0 \sqrt{\hat{A}} \rceil.
\]
For NOVPC the number of total control messages per time unit (t.u.) is huge, and therefore left out from some of the figures. The number of link routed connections/t.u. is ranging from 8000 to 11000 the GO situation. For HI the amount of control messages is ranging from 11000 to 12000. The maximum number of messages/t.u./node is ranging from 1000 to 1700 when having a general overload. For high traffic imbalance the amount of control messages is ranging from 700 to 1300.

For the local approaches, the number of control messages/node/t.u. can easily be handled and the amount is perhaps less than one could expect considering the small updating interval. Less control messages are sent when the traffic load is high because there will be less deallocations and more unsuccessful allocations.

To evaluate the effect of alternative routing we study the performance of CENT in a GO traffic situation. Figures 17 and 18 show the profitability and mean MAXCBP for the possible combinations of routing schemes. The target MAXCBP is set to 20%. For comparison reasons we also show the results for FIXED (straight line without circles). The extra profit of also using LINKR when having DAR is minimal. For DAR to work a TR has to be used. It is also clear that dynamic capacity reallocation is the most important mechanism to increase profitability, when the traffic load is higher than anticipated. At an overload of \( \sim 10\% \) the effect of DAR is equal to the dynamic capacity reallocation. FIXED can not utilise the fact that the statistical

![Figure 15: Maximal number of control messages for a node, GO](image1)

![Figure 16: Maximal number of control messages for a node, HI](image2)

![Figure 17: Profitability for GO.](image3)

![Figure 18: Mean MAXCBP for GO.](image4)
The target MAXCBP is set to a value that is supposed to be an acceptable decrease in service at occasional high traffic load situations. Figures 19 and 20 show profitability and mean MAXCBP when the target MAXCBP is set to 10%, 20%, and 30%. A more constant CBP is noted for the 20%-line for traffic loads between ~1.2–1.3. This shows the effect of the target MAXCBP. (The reason why this does not show up for the 10%-line is the large step between the evaluated traffic loads.) These figures show another aspect than Figs. 17 and 18. When using DAR, an increased target MAXCBP will increase the possibilities to increase the utilisation. An interesting observation is that for increasing load, the bad effects of large mean MAXCBP occurs before the benefits of increased profitability. This means that at very high load it is important to have the right trade-off between target MAXCBP and the total handled traffic.

Table 3 describes the findings from the comparisons. An important aspect of an approach is its scalability. As seen in the performance they all have a reasonable amount of signalling (expect NOVPC). It is therefore more important to look at the complexity of the calculation needed for the capacity distribution. The decentralised approaches are the simplest ones but are also heavily dependent on the control messages to work properly. The local approaches is more robust in the sense that a lost message only affects one VPC temporarily. Both the iterative approaches will depend on all VPCs and a small change somewhere will have effect on the whole capacity allocation in the network. The timing and selection of updating interval has to correspond to the size of the network.

We have also evaluated ALCRA, CENT and FIXED in a 50 node network. The number of VPCs on a link is ranging from 49–250. The total number of VPCs in the network is 1225. The TR is set to 5% of the basic capacity [11] for both approaches since the computing time for the optimal setting is large. The calculation of Erlang’s B-formula is approximated and speeded up by using the program described in [22]. The link routing is not used. DAR can only be used if the VPC hop count is less than or equal to the hop count of the shortest path + 5. ALCRA use $T_s=0.5$. Tables 1 and 2 show the performance of the three approaches for HI and GO traffics and Figs. 21 and 22 show the distribution of CBP among the node pairs. The overallocation is calculated as the number of times at connection setup the number of ongoing connections on any link on the path are more than can be handled (resulting in increased cell loss probability for the corresponding VPCs on the link). It should be noted that the presented value is not precise and it is highly time dependent.
Table 1: Comparisons in a 50-node network, HI with network load of 1.0.

<table>
<thead>
<tr>
<th></th>
<th>ALCRA</th>
<th>CENT</th>
<th>FIXED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean total CBP [%]</td>
<td>5.9</td>
<td>4.0</td>
<td>7.7</td>
</tr>
<tr>
<td>Mean maximum CBP [%]</td>
<td>34.4</td>
<td>28.6</td>
<td>32.4</td>
</tr>
<tr>
<td>Mean maximum messages/node/t.u.</td>
<td>430</td>
<td>69</td>
<td>24</td>
</tr>
<tr>
<td>Overallocation</td>
<td>0</td>
<td>3.5 \cdot 10^{-6}</td>
<td>0</td>
</tr>
<tr>
<td>Mean unallocated capacity [%]</td>
<td>9.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reallocations/t.u.</td>
<td>12000</td>
<td>2200</td>
<td>0</td>
</tr>
<tr>
<td>Profitability</td>
<td>89.2</td>
<td>91.0</td>
<td>87.6</td>
</tr>
</tbody>
</table>

Table 2: Comparisons in a 50-node network, GO with network load of 1.2.

<table>
<thead>
<tr>
<th></th>
<th>ALCRA</th>
<th>CENT</th>
<th>FIXED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean total CBP [%]</td>
<td>10.8</td>
<td>7.1</td>
<td>9.4</td>
</tr>
<tr>
<td>Mean maximum CBP [%]</td>
<td>28.5</td>
<td>21.5</td>
<td>19.1</td>
</tr>
<tr>
<td>Mean maximum messages/node/t.u.</td>
<td>507</td>
<td>92</td>
<td>19</td>
</tr>
<tr>
<td>Overallocation</td>
<td>0</td>
<td>6.4 \cdot 10^{-6}</td>
<td>0</td>
</tr>
<tr>
<td>Mean unallocated capacity [%]</td>
<td>3.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reallocations/t.u.</td>
<td>12700</td>
<td>2200</td>
<td>0</td>
</tr>
<tr>
<td>Profitability</td>
<td>84.6</td>
<td>88.0</td>
<td>86.0</td>
</tr>
</tbody>
</table>

Figure 21: Distribution of CBP, HI.

Figure 22: Distribution of CBP, GO.
Table 3: Main characteristics of the different approaches.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENT</td>
<td>• Able to change the VPC topology.</td>
<td>• NMC is needed.</td>
</tr>
<tr>
<td></td>
<td>• Optimal TR.</td>
<td>• Large networks increase the complexity of the calculations.</td>
</tr>
<tr>
<td></td>
<td>• Few control messages.</td>
<td></td>
</tr>
<tr>
<td>ITER</td>
<td>• Simplified calculation of capacity allocation by the use of iterations.</td>
<td>• Complex message handling.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Not good in general overload.</td>
</tr>
<tr>
<td>NONCOOP</td>
<td>• Simplified calculation of capacity allocation by the use of iterations.</td>
<td>• Complex message handling.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Not good for high traffic imbalance.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Many iterations &amp; stability problems.</td>
</tr>
<tr>
<td>ISOLA &amp; ALCRA</td>
<td>• Can be made simple.</td>
<td>• Unreserved capacity at low loads.</td>
</tr>
<tr>
<td></td>
<td>• Good profitability.</td>
<td></td>
</tr>
<tr>
<td>FIXED</td>
<td>• Few control messages.</td>
<td>• Lack of flexibility.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low profitability.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High CBP.</td>
</tr>
<tr>
<td>NOVPC</td>
<td>• High utilization.</td>
<td>• Huge number of messages.</td>
</tr>
</tbody>
</table>

6 Conclusion

We have compared fundamentally different approaches for VPC capacity management and evaluated the pros and cons of each approach (Table 3).

The central approach calculates a nearly optimal trunk reservation for each link. It also has the ability to find new paths and to order them in an optimal way. It can also take into account the loads on different links. For the 50 node network it seems as if it is difficult for CENT to guarantee that capacity is not overallocated. If CENT use the same method for capacity reallocation that the local approaches do, i.e. when capacity is decreased, ongoing connections must first disconnect, the profitability only gets ~80% for HI traffic. If CENT starts a global reallocation, it will in this case be virtually no overallocations. This is probably due to the large amount of VPCs on the links, which means that not all capacity is utilised. This is also known as the fragmentation effect of VPC allocation. This effect will be less in smaller networks (the number of VPCs on a link is smaller) but in this case the negative effect of waiting for connections to end before decreasing reserved capacity is very small. Otherwise, some sort of “guard band” can be used to decrease the probability for these overallocations. The amount of guard band will also depend on the load situation. The need for guard band can be decreased if requests for allocation increase are delayed. One can say that a controlled reallocation should be used for small networks and abrupt (global) reallocation should be used in big networks. For the GO traffic the profitability for ALCRA and CENT can be improved if a longer measure interval is used for estimating the traffic demands.

We have developed a type of decentralised and link-iterative VPC management policy. The method uses iteration cycles to reallocate the capacity. The computations needed are simple but the complexity is instead moved to the management of control messages (i.e. timeouts, delays).

We have evaluated an iterative approach based on the Gauss-Seidel method. It seems as if the scheme is a bit tricky to use. Much capacity will not be reserved, which makes link routing very important to increase the amount of handled traffic. Otherwise, the performance can get much worse than for the fixed approach that do not alter the capacity distribution. (DAR does not help). Having a large network will result in longer locking times of the links while computing the capacity allocation. The number of iterations needed at each update instant will
increase. This will, together with link routing decrease the scalability of the approach since long VPCs will starve in a big network, i.e. never get a chance to reserve capacity.

We have proposed a type of local VPC capacity management policy (isolated and adaptive) that uses regular updates and a simple allocation function to determine the needed capacity for the coming updating interval. With our proposed, simple procedure based on averages for setting its unknown parameter \( K \), the number of parameters is limited to one, viz. the current number of active connections. We have seen that ALCRA is robust with respect to traffic load situations, accuracy of traffic measurements or forecasts, the TR setting, and the numerous combinations of VPCs. Using a simplified model with an average background-traffic for the estimation of \( K \)-free capacity–traffic load relation works well although the actual distributions of the number of VPCs per link cover a wide range. The method takes advantage of the benefits from both VP and VC routing, i.e. enabling fast CAC and using multiplexing of VPCs. In other words, a local approach combines the benefits from both hop-by-hop allocation (dynamic routing) and dynamic capacity allocation (transport routing). This is a result of the ability to quickly adapt to changes in the capacity demands. We also notice that the method of signalling is easy to implement. If link routing is omitted the profitability will only decrease slightly. For the 50 node network having a general overload, ALCRA is not as good as CENT and FIXED, mainly because of the larger update interval. The update interval was chosen to decrease the maximum number of messages per t.u. to any node. It could possibly be decreased since the maximal length of the control message queue is 50 and the mean number is 25.

The mean MAXCBP gets high for the decentralized approaches for high traffic loads. This depends on these approaches way of allocating capacity link-by-link. It is only CENT that can control the maximum VPC CPB. On the other hand, reserving a small amount of capacity for many-hop-VPCs will decrease the CPB for these. It is possible to reserve different amount depending on the number of hops each VPC have. In a capacity request message the number of hops can be included. The node will have a table to get the amount of VPC hop count trunk reservation. The longest VPC will be able to allocate all capacity that is left. An evaluation has been done with having 2 connections reserved for each “class” of VPC hop length. The mean MAXCBP will, for ALCRA, be very similar to NOVPC with only a slight decrease in the profitability in high load situations. The mean MAXCBP of 0.2 will be reached at a load of 1.3 instead of 1.2.

The fixed approach shows good performance for low and moderate traffic imbalance and low loads. For high traffic load and high traffic imbalance (when some links are heavily overloaded) the fixed allocation is not as good as the other approaches. The fixed approach does not use any control messages, except the messages for DAR.

Using NOVPC results in lots of control messages, which decreases the profitability very much.

It seems as if the decentralised approaches are interesting alternatives to the otherwise so frequently studied central approaches. They may also complement each other. The central one has the ability to find VPCs and order them (i.e. finding which one is to be used) and a local one can fine-tune the capacity allocation. A local approach can be used when capacity is paid for, i.e. not more than “enough” capacity is to be reserved. At the other side, a network provider can allocate all capacity and an NMC is useful to control the network.

7 Future Work

For the local approaches, it remains to find a relation between the actual traffic load and the optimal \( T_u \), to simplify and automate the setting. A lower limit of \( T_u \) is also needed, especially
for big networks. The adaptive setting of $K$ should also be further analyzed. A central approach has to decide when controlled reallocation is to be used and when it should be avoided. This can be determined by evaluating the dependency to the number of VPCs and the traffics on these. The impact of different types and classes of traffics on the performance should be evaluated.

A Test Networks

The test networks have been made with a program that generates networks with $N$ nodes. Connection holding times are assumed to be negative exponentially distributed with a mean holding time of 1 time unit. User demands are fully characterised by a sequence of known end-to-end traffic demand matrices $A(k)$ (of size $N \times N$), where $a_o,d(k)$ denotes the traffic from $o$ to $d$ at time $k$, ($k = 1, ..., M$) (see Fig. 23). The time index $M$ indicates intervals such as hour, day of week, or day of year. For slow traffic changes the traffic intensity is changed 10 times from $a_o,d(k-1)$ to $a_o,d(k)$ during 10 t.u.s. The traffic is then held steady during 20 t.u.s. These time instances $t_j$ for changing the traffic is varied by a normal distribution with a coefficient of variation is set to 0.1. The calculation of $t'_j$ is done with the algorithm by Box and Muller (1958):

$$t'_j = \sqrt{-2\ln(U_1) \cdot \sin(2\pi U_2)},$$

where $U_1$ and $U_2$ are uniform distributions on [0,1]. These are also scaled so that the total time for 10 traffic changes is 10-T.

For each origin-destination pair an offered traffic was assigned to give 1% expected loss for a given transmission capacity. This basic traffic was modified to yield $M$ different load situations by the use of “busy center” (Fig. 24). Traffics between busy center nodes were increased randomly between 20 and 60%, traffics between nodes outside the busy region were decreased randomly between 20 and 60%, and the traffic between a busy center node and a node outside the center was modified randomly between -20% and +20%. After the modification the traffics were re-normalised to give the same total amount of offered traffic as before. The network load is then defined as the fraction of this total basic traffic. The resulting greatest increase is $\sim 90\%$ and greatest decrease $\sim 55\%$. With $N = 10$, the total traffic offered to the network at any time is typically about 6500 Erlangs for a network load=1.0.
References


