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COMPARISONS OF DIFFERENT APPROACHES FOR VPC CAPACITY MANAGEMENT

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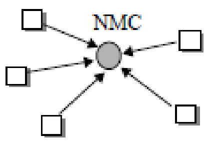
Abstract : The management of VPC is to reduce the call blocking probability, increase responsiveness, stability, and fairness. The management functions in the evaluations use statistical multiplexing of VCCs and deterministic multiplexing for the VPCs, *i.e.* each VPC gets a certain portion of the capacity to be held over a long period of time compared to inter arrival times of new connections. (Statistical multiplexing can be used for VPCs, which can be allowed to exceed their assigned capacity, as long as they conform to some statistically defined parameters.) Fundamentally different approaches for VPC capacity reallocations are compared and their pros and cons are discussed. The capacity is managed in bundles or capacity units (c.u.), to decrease the computation effort for the central and distributed approaches.
Keywords : VPC,VCC,blocking probability,statistical multiplexing,central approach,distributed approach.

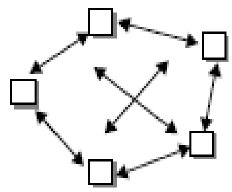
1.INTRODUCTION

The use of VPCs has several benefits but using too many VPCs on a link each having a relatively small amount of capacity, will decrease the statistical multiplexing gain. More important is the possibility that some VPCs can be fully utilized while others have large amount of idle bandwidth.

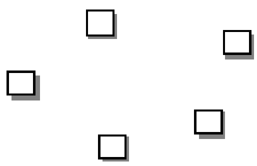
Using frequent rearrangements of the allocated bandwidth, will better utilize the traffic changes, but will also increase the processing load and increase the number of control messages needed for this.The management functions in the evaluations use statistical multiplexing of VCCs and deterministic multiplexing for the VPCs .



(a) Centralized



(b) Distributed



(c) Local, Fixed

Fig 1: Control messages needed for determining VPC capacity reallocation

The evaluated approaches are fundamentally different in the way they work. As seen in Fig. 1 there are basically three ways for getting the information needed to determine the capacity reallocation. The fixed approach do not alter the capacity allocation at all. In this evaluation only the central approach uses global information, i.e. none of the others have a topology database or global

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traffic demand information. The capacity is managed in bundles or capacity units (c.u.), to decrease the computation effort for the central and distributed approaches.

2. A Central Approach

There are many central approaches but they differ in the objectives, constraints, and assumptions [1]. For simplicity we have only evaluated one approach developed by Arvidsson In this method all nodes monitor the offered traffics and report their results to a network management center (NMC). The NMC computes an updated VPC network capacity allocation and returns the results to the nodes for implementation.

The algorithm is a heuristic one so no guarantee that the final solution is a global optimum can be made.The approach uses the following steps when finding the paths and determines the capacity allocation to the VPCs (s = class of service, abbreviated as CoS, o = originating node, d = destination node)

1) Read the tables that provide the relationships between capacities, expressed as units of capacity, and number of VCCs.

2) Read link capacities Co,d and offered traffics As,o,d .

3) Assign high, initially acceptable call loss levels (s,o,d) for all CoSs and all OD-pairs o,d.

4) Find the shortest paths, if any, along which any □ s,o,d-traffics can be granted more capacity.

5) Identify all s,o,d-traffics that suffer from loss levels above (s,o,d) and for which a path is available.

a) If least one such traffic is found, proceed to 6.

b) If no such traffic is found because all (s,o,d) are ultimately acceptable or because no more capacity can be supplied to traffics s,o,d still suffering from unacceptable loss, then stop. c) Otherwise lower (s,o,d) and repeat step 5.

6) Allocate one unit of capacity to each s,o,d-traffic identified above along their shortest paths respectively.

7) If the capacity allocated on each link is within the physical bounds, then repeat from step 4, else:

a) For each s,o,d-traffic, compute the loss L paid if the currently allocated unit of capacity was removed.

b) For each s,o,d-traffic, compute the relative gain G if the currently allocated unit of capacity was removed.

c) Find the traffic s_{max}, o_{max}, d_{max} with the highest gain/loss ratio.

d) Remove the unit of capacity currently allocated to traffic s_{max}, o_{max}, d_{max} and repeat step 7.

Available capacity is successively distributed among VPCs in the order of need and so that a minimum amount of capacity is used in each step. The algorithm terminates when for every VPC either (i) a final, predetermined, desirable loss level has been reached or (ii) no more capacity is available to VPCs which still suffer from high losses.

The tables in step 1 give, for each CoS respectively, the number of simultaneous connections that can be handled by i, i = 1,2..., units of capacity, i.e. the equivalent number of channels (**ENCs**). The ENC is not a sum of equivalent bandwidths but the bandwidth needed to support a particular number of connections, to satisfy a particular QoS. In other words, multiplexing on burst scale is taken into account. The tables are computed from traffic characteristics, GoS demands, buffer space and given target blocking probability.

The initial loss level in step 3 is set to 99%. It is then successively reduced in step 5c by dividing by 1.1 until at 5b the ultimately acceptable level of 1% is reached. Shortest paths in step 4 are determined using the Floyd-Warshall algorithm, with the length l associated to link o,d designed to avoid nodes subject to heavy load and links with little remaining capacity:

$$I(o,d) = \begin{cases} \left(\dfrac{\max(\delta, \max(T'_o, 0) + \max(T'_d, 0))}{C'_{o,d}} \right)^{\frac{1}{\sqrt{N}}} & C'_{o,d} > 0, \\ \infty & C'_{o,d} = 0 \end{cases} \quad (1)$$

Where T^1_n is the total, remaining number of capacity units required by traffics originating from or terminating at n to fulfil our ultimately acceptable blocking level,§ is a very small number denotes the remaining, not yet assigned capacity on link o,d. Finally, realising that equation (1) may favour a series of very high capacity links to direct ones of lower capacity, paths are "flattened" to remove such anomalies. Traffic selection in step 5 aims at keeping variations in grade of service between OD-pairs to a minimum. Noting that this can reduce the total traffic carried by the network, we give slightly preferential treatment to traffics carried on shorter paths by relating the current loss to the requested capacity and obtain a modified loss $\eta_{m_{s,o,d}}(A_{s,o,d})$ on which the need for further capacity is assessed

$$\eta_{m_{s,o,d}}(A_{s,o,d}) = \frac{E_{m_{s,o,d}}(A_{s,o,d})}{\ln(h_{s,o,d}+1)},$$

where $E_m(A)$ is the Erlang B-formula, A the offered traffic, m the number of channels currently available, and h is the number of links included in the proposed, shortest path from o to d. In other words, we compute losses $E_m(A)$, which are modified to $\eta_m(A)$, and then compared to $\varepsilon_m(A)$ Allowing for non-linear equivalent bandwidths, we sum circuits rather than bandwidths and compute the number of circuits for each route of the OD-pair individually and then sum to get m. $L_{s,o,d}$ in step 7a is the s,o,d-traffic that the most recently added unit of capacity to VPC s,o,d is expected to carry

$$L_{s,o,d} = A_{s,o,d}\left(E_{m_{s,o,d}}(A_{s,o,d}) - E_{m'_{s,o,d}}(A_{s,o,d})\right),$$

where m and m' respectively refer to the number of channels currently available and what would be available if the most recent added unit of capacity was removed. Again, m and m' are determined by summing the values for each physical route.

$G_{s,o,d}$ in step 7b is the sum of all losses that can be avoided at the same point if traffic s,o,d was selected to lose its most recently added c.u.

$$G_{s,o,d} = \sum_{s'=1}^{S} \sum_{o'=1}^{N} \sum_{d'=1}^{N} I(\Re_{s,o,d} \cap \Re_{s',o',d'} \neq 0) L_{s',o',d'},$$

Where $s' = s, o' \neq o, d' \neq d$ and $\Re_{s,o,d}$ is the set of links traversed by the shortest path for s,o,d and I(•) is an indicator function taking the value of 1 if its argument is true, otherwise 0.

The method aims at distributing the available capacity among traffics and OD-pairs in a fair way, yet so that the total carried traffic is maximised.

3. A DISTRIBUTED APPROACH

An approach which is a compromise in the amount of information needed for the VPC management is a distributed one. The greatest advantage of this approach is the way it periodically tunes into a good network capacity allocation, by an iterative method which distributes information about the offered traffics among the VPCs.

In Fig. 2, state 0 shows the paths are established by broadcasting messages. This is a totally distributed way of establishing the VPC topology. After each iteration the capacity allocation gets better. To be able to accomplish this, information on offered traffics must be distributed to the other nodes. The management is done with help of four types of control messages [4,5]:

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

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 .When the paths have been selected VPC establishment messages are sent to update the routing tables.

The BIDs convey originating traffic intensities to destination nodes along the different paths. We

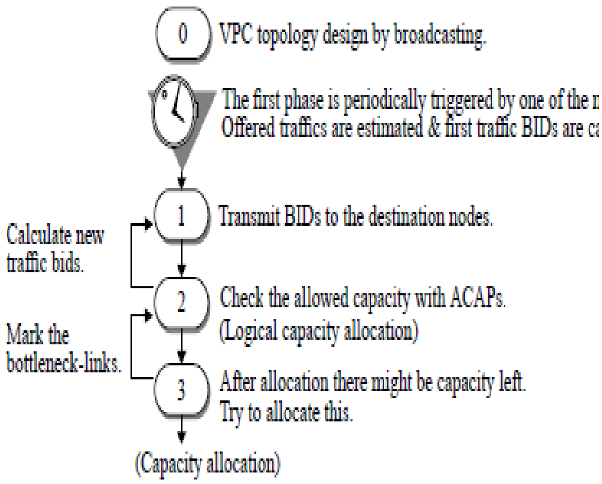

Fig2: The Principle of the Distributed Approach.

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. From this follows that the nodes only get as much information as they need, to be able to calculate capacity allocations on the links directly attached to it. 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. To be able to maximize the utilization of the capacity, we use the concept of marginal utilization (MU).The MU is the number of extra calls the VPC is expected to carry if allocated an extra capacity unit. The calculation of MU is based on the Erlang Bformula with f(C) as a function that gives the number of connections for a certain capacity and the traffic as T:

$$MU = (E_{f(C)}(T) - E_{f(C+1)}(T)) \cdot T$$

In our evaluations we use f(C) as a linear function which simply multiplies the capacity with 10.BIDs are always followed by a determination of available capacity by means of ACAPs.

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. Each reallocation is divided into three parts: first traffic bid, subsequent bids, and a capacity allocation part. The **first traffic bid** (see Fig. 2) is triggered by one of the nodes thereby making all nodes transmit BIDs. The VPC with the smallest number of hops is favoured and is labelled FVPC,

Path	A	B	C	D	E
1	100	100	100	100	100
2	100	80	50	10	10
3	100	60	25	3	10
4	100	40	12	0	10
5	100	20	6	0	10

Table 1: Different distributions for the first BID.

while the others are referred to as optional VPCs and labelled **OVPCs** [6]. The measured offered traffics are sent on the FVPCs. Different strategies for the first bid are given in Table 1. The table shows the percentage of the offered traffic sent as a BID on the different paths. Path 1 is the FVPC. Fig .3 shows the results for different first-bid distributions. The mean blocking probabilities are given for each choice of the number of paths. The OVPCs are tested for available capacity by transmitting BIDs which are fractions (10%) of the offered traffics.

. 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 B-formula given a specified target blocking probability p. The available capacity C_i can handle

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a certain amount of traffic t_i calculated from (2), i.e. using the

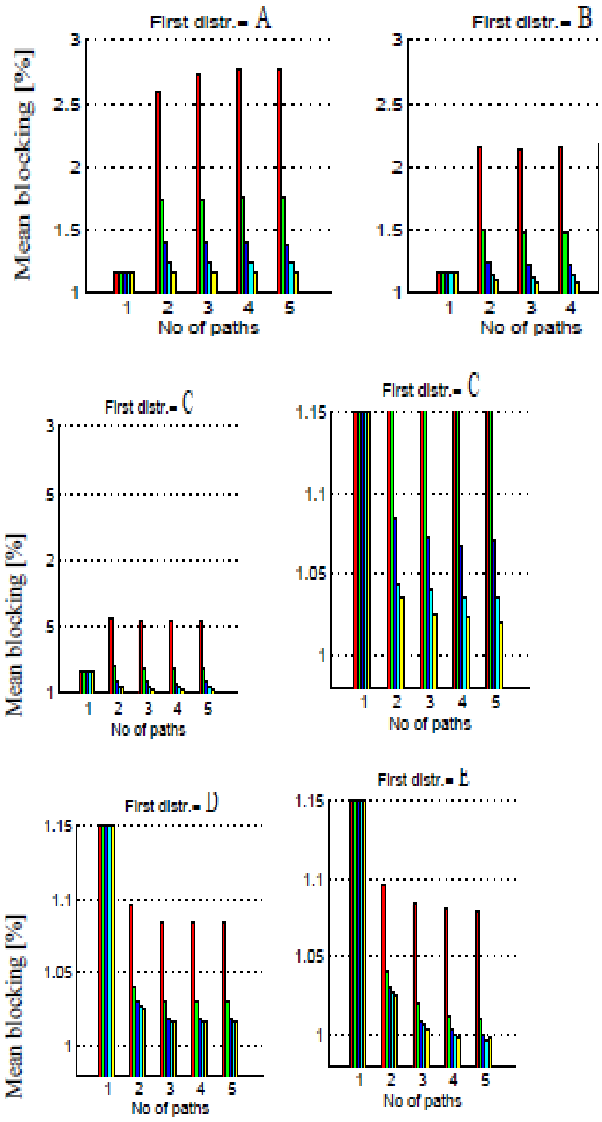


Figure 3: Results for different first BID distributions.

Erlang B-formula "backwards." The index i specifies the path (for FVPCs the index i is equal to 1), and in our study p is set to 1%

$$t_i : E_{C_i}(t_i) = p \qquad (2)$$

If the total amount of allowed capacity is greater or equal to C, only as many VPCs are used that together have enough capacity. The number of needed VPCs is denoted by k. The traffic bids on these VPCs are set to t_i in (2). The capacity on the last used VPC Ck is modified to:

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

The next traffic bids are now calculated from (2).VPCs with an index greater than k will get a zero bid. On the other hand, if the allowed capacity is not enough, the subsequent traffic bids are set proportional to the t_i, summing over all VPCs that have been given any capacity

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

Each new bid cycle means an iteration between state 1 and 2 as in Fig. 2.

When all bid cycles are done the process of **capacity allocation** is carried out. This corresponds to the second iteration loop between state 2 and 3. The purpose is to make any unused capacity available for allocation by ACAPs. This can be repeated a few times to enable more unused capacity to be distributed to VPCs. The last cycle will allocate unused capacity to one hop VPCs .

The benefit of having one two-hop VPC is less than two one-hop VPCs. This means that longer VPCs must have less priority in the distribution process than shorter ones. This has been implemented by dividing the MU by a cost parameter.

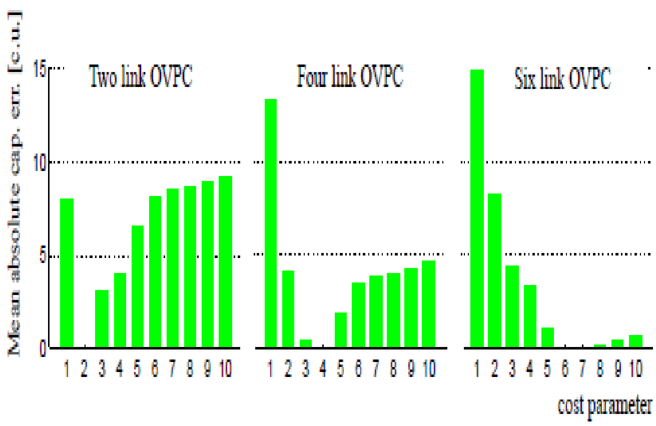


Figure 4: MU cost parameter for OVPCs.

Fig. 4 shows the absolute value of the difference between the optimal capacity and the allowed capacity from our approach when the MU is divided by different cost parameters. The results shown are averages over a set of traffic mixes for the two VPCs.

It is seen that the cost parameter appears to be the number of traversed links (Fig. 4) and we have seen that the optimal OVPC cost does not depend on the traffic variations, nor on the link capacity.

We have seen that the same capacity allocation is found by maximizing the modified MU as when minimizing the total number of blocked calls [8].

Even if we do not penalize long VPCs, these will find it difficult to get capacity on all of the traversed links, compared to shorter VPCs. This indicates that shorter VPCs should be penalized more than long ones, to increase the fairness. A similar consideration can be made to give many hop VPCs the same possibility to get an OVPC. By restricting the cost parameter for a long OVPC, this will get both a better possibility to get capacity, and the use of it will increase the possibility to avoid a congested part of the network .

4. A LOCAL APPROACH

The concept of virtual path was simultaneously introduced by Sato et al. [7] and by Telecom Australia researchers. Sato et al. change the capacity in steps. These steps correspond to the capacity needed for an integral number of connections, which is called the step size. In [8], the authors argue that the optimal step size can be obtained by considering a relationship between the network utilization and the processing load required in the nodes. Since the approach is triggered at each call arrival and call release, the cost related to an increased processing load has to be related to the revenue. The so called normalized processing load is the number of reallocations divided with the number of call arrivals and departures. This measure is used to constrain the actual reallocations. If more capacity is needed a fixed step of increased capacity is requested. If less capacity is needed, i.e. the needed capacity is less than a capacity threshold below the allocated capacity, the capacity is decreased. To equalize the differences in call blocking probability among the different VPCs, capacity increase is done in different steps for the different VPCs, dependent on their traffic intensities. To provide flexibility for the increase and decrease of the capacity, Wu et al. [9] proposed an adaptive bandwidth control scheme that selects either a large step size or a small step size. This scheme is capable of improving the network utilization compared to the scheme with an optimal chosen fixed step size. A look-ahead method has also been explored in [10]. In this method, the increase is requested in advance when the unused capacity of the VPC becomes smaller than some predetermined amount. Baba et al. show that an improvement in terms of call blocking probability can be achieved using this method. Bruni et al. have in [11] evaluated an approach that has periodic updating intervals, and meets a certain call blocking constraint. They find the optimal step size, the optimal updating interval, and threshold for the capacity reallocation. The threshold introduces a hysteresis to decrease the number of reallocations. The results show that no threshold is needed and that the step size should be 1, i.e. the most accurate allocation possible.

Our local approach is implemented as follows. A periodic management procedure is used in each node (Fig. 5).

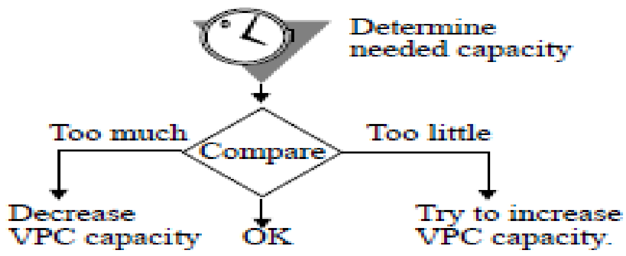


Fig5: The principle of the local approach.

Each node makes a decision about whether to seize or release capacity on the VPCs originating from that node. This removes the dependence between processing load and the capacity reallocatione. The decision is based on the actual number of occupied connections on each VPC. From a pre calculated table or a function the needed capacity for the next interval is given by the current number of active calls and the estimated traffic arrival intensity. The approach uses a look-ahead scheme. 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).

This approach is based on the one developed by Mocci et al. [12]. The method allocates just enough VPC capacity to meet the target blocking constraints during a given interval from the allocation instant. This calls for the calculation of the average blocking probability over a finite time interval of a system in a transient state. The time dependent state probabilities are determined from the Markov chain in Fig. 6. New calls arrives with an intensity of to a loss system containing N ENCs. The call holding times are exponentially distributed with unit mean.

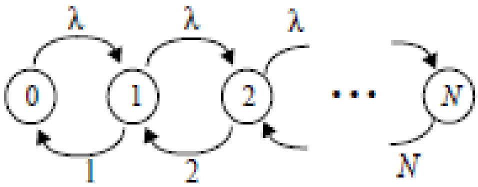


Fig 6: Markov chain for the occupancy state.

The problem is to find the , *i.e.* the probability to be in state *i* at time *t* with the initial conditions $P_n(0)=1$ and $p_i(0)=0$ for $i \neq n$.

The average blocking probability in the next interval with the actual occupancy of *n* trunks is

$$b(n) = \frac{1}{T_u} \int_0^{T_u} P_{N|n}(t)dt \ . \qquad (3)$$

We try to find the *N* for which *b*(*n*) is less than the target blocking. The system equations is described with a vector equation: p(t)= A.p(t). One way to solve it is with the aid of the eigenvectors of *A*.

The calculation can be simplified by the method of Virtamo and Aalto [13]. They have done a computation of the finite system with the help of an infinite system as seen in Fig. 7. This can be done by adding an external source *s*(*t*), injecting probability mass to state *N*+1 in such a way that the probability of *N*+1 keeps a fixed relation to that of state *N* in order to guarantee zero net flow of probability between these states.

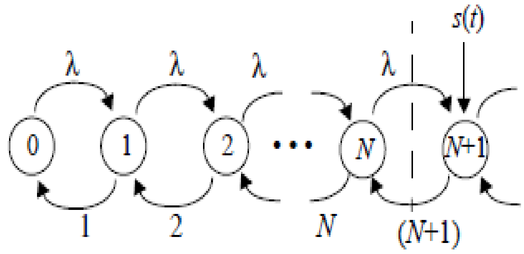


Fig 7: The modified Markov chain

By calculating (3) for different traffics and occupancy states, a capacity allocation table can be built. As already seen, the calculation is dependent on the traffic intensity, the target blocking probability, and the updating interval. simplified allocation function is presented:

$$N(n) = n + K(\varepsilon, Tu, n, \lambda)\sqrt{n} \qquad (4)$$

where N is the required capacity, n is the number of currently active calls, and the factor K depends on the target blocking probability ε, updating interval T_u, and the actual occupancy state n, at time zero, and the traffic intensity A simplification is made to make N only depend on n, and T_u, in the following way. Let us say that the a The average blocking b(n), can be calculated from the previous formulation of the problem for a given average number of arrivals during a mean holding time is . Most of the time the mean occupancy , is almost equal to λ with a standard deviation of $\sqrt{n}$. The factor K can be seen as a safety factor which adds extra capacity in units of the standard deviation of the occupation state. If the allocation function is evaluated for different λ and K adjusted according to n instead, the allocation function achieves a nearly constant blocking probability over a wide range of λ. The average blocking b(n), can be calculated from the previous formulation of the problem for a given λ. When having a small blocking probability the state of occupancy n, is nearly Poisson distribution with parameter :

$$p_n(\lambda) = \frac{\lambda^n}{n!} e^{-\lambda} .$$

The overall blocking probability *B*, gets:

$$B(\lambda) = \sum_{n=0}^{\infty} p_n(\lambda) \cdot b(n, \lambda).$$

For a specific *T*u and , the value of *K* can be determined for different λ Once again, λis replaced with *n*, making (4) only depend on *n*, , and *T*u.

By using formula (4), the needed capacity is calculated. The idea of this approach is to handle traffic variations on a short time scale, *i.e*. larger than the mean inter arrival time but smaller than the average call holding time.

Two types of messages are needed [8]:

- Allocation request (ALLOC) + Answer
- Deallocation (DEC)

The capacity request message ALLOC, is sent on the VPC to find out the capacity allowed for the whole path. This means that a VPC will get the minimum allowed capacity on the series of links. The amount of available capacity is stored in the ALLOC on successive links. When it reaches the end node, indicating the available capacity, an answer message is sent back to the originating node. (ALLOC is in fact the same message as ACAP in the distributed approach.)

When an originating node determines that capacity should be released, a DEC is sent. The capacity reservation is decreased on each traversed link. No answer message has been used for this message.

5. Comparisons

5.1 presumptions

We have compared the three previously described approaches together with a fixed approach which does not reallocate the VPC capacities, and an approach which do not use VPCs but establishes connections call-by-call and hop-by-hop. In our study we have used fully connected non-hierarchical networks with ten nodes. All approaches use several VPCs between each node pair. The reallocations are done periodically and they use the same networks and traffic patterns . The central and distributed approaches use the same updating interval . For the central, distributed, and local approaches we have used a capacity unit which can accommodate ten connections.

We have used dynamic alternative routing with two VPCs in series. The local and central approach try to maximize the network's unused capacity without violating the predefined blocking probability, while the distributed approach utilizes all of the capacity. The fixed approach only uses the FVPCs, and the capacity allocation remains constant.

5.2 Profit

Our evaluation is based on the reached profitability. The profitability is a normalised measure where 100% profitability means that all calls are handled without any overhead costs.

$$\text{Profitability} = \frac{\text{Calls}_{\text{Handled}} - (\text{Messages} \cdot \text{Cost})}{\text{Calls}_{\text{Offered}}} \quad (5)$$

The profit of handling one call is set to one unit.

Let us say we use RM-cells which need some of the bandwidth which becomes unavailable for paying customers. The cost can be related to an average phone call. Suppose that a phone call uses 167 cells/ second, then the RM cell could be given a cost of 1/ (167·seconds per mean holding time) which is ~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 higher message cost, the messages can be seen as having an overhead, *e.g.* standardized control messages such as TMN messages. The profitability is used to enable a reasonable evaluation of the overall performance by combining gains and costs.

For the distributed approach we have evaluated modifications of the use of the cost parameters. Even if the utilization is maximized when using the cost parameters, we have decided not to penalize the FVPCs and we have modified the cost parameters for the OVPCs by subtracting the number of hops of the FVPC and added one. For example, given a FVPC with 2 hops and an OVPC with four hops, the cost parameter for the OVPC is changed from four to three (4 - 2 + 1 = 3). If they have the same length they will be equally treated.

5.3 Link Violations

Another interesting aspect is the occasional occurrence of link violations . These are caused by excess calls on VPCs which have been granted less capacity and that are not disconnected in time before new calls arrive 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 the 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. The amount of link violations depends not only on the guard band, but also on the actual network and traffics [8].

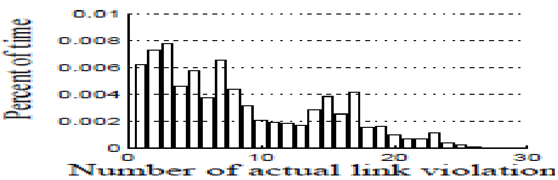
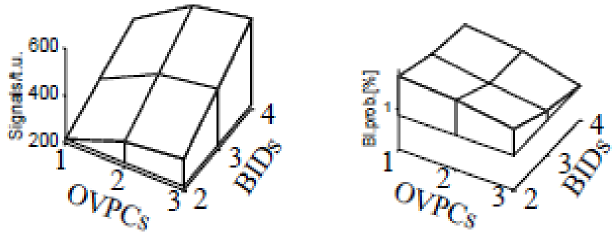


Fig 8: An example of a violated link.

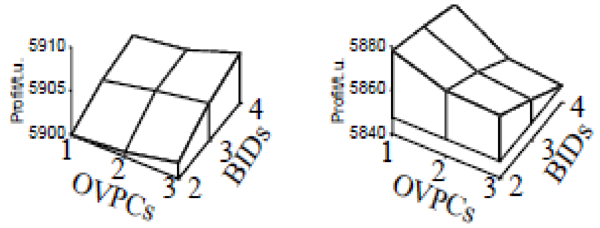
6. Results

Our comparison is based on the fraction of profitability reached (5), the link violations per time unit, the mean total network blocking probability, and a measure of the maximal VP blocking.

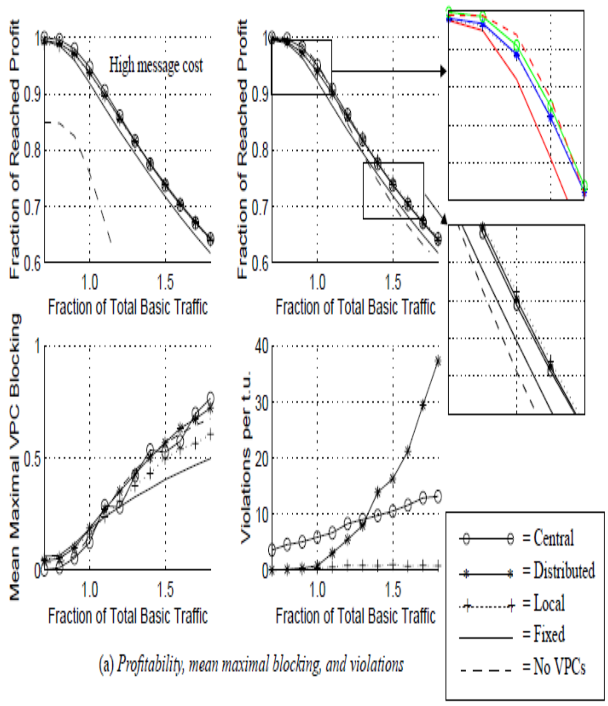
Fig.9 shows how the total mean network blocking decreases as the number of control messages increases for the distributed approach. Fig.10 shows two different costs for control messages and their impact on the total profit. As seen in Figs. 9 and 10 the number of OVPCs and BIDs to use depends on the actual message cost. This implies that we need to make evaluations for different message costs. The distributed approach is evaluated for two cases, labelled distributed 1 and 2 with the settings given in Table 2. The local approach is evaluated in Table 3.



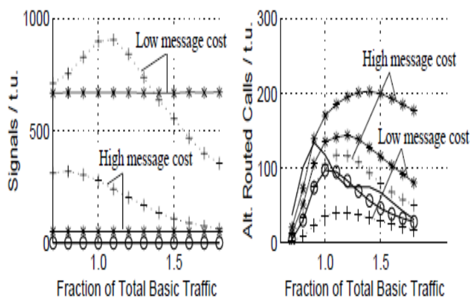
(a) *Number of messages* (b) *Mean total blocking*



(a) *Signal cost = 10^{-4}* (b) *Signal cost = 10^{-1}*



(a) *Profitability, mean maximal blocking, and violations*



(b) *Number of messages*

Fig 11: Comparison with high traffic imbalance for different total traffic loads.

Case	OVPCs	BIDs	ACAPs	Message cost
Distr. 1	0	1	1	10^{-1}
Distr. 2	2	4	4	10^{-4}

Table 1: Parameter settings - Distributed approach.

Case	OVPCs	T_u	Message cost
Local 1	2	0.1	10^{-1}
Local 2	2	0.01	10^{-4}

Table 2: Parameter settings - Local approach.

Fig.11 shows the performance with high traffic imbalance (20-60% change of the mean traffics. All diagrams but one show results for a low message cost (10-4).

The comparison was made to see what kind of characteristics distinguish the approaches, not to determine the best one. Therefore, none of the approaches has been optimized regarding the updating interval or any other special method used individually.Table 4 shows the main characteristics of the different approaches.

Profitability

It can be seen in Fig. 11a that all approaches have very similar profitabilities. The central approach shows the best profitability when the traffic load is less or equal to the nominal traffic load. For the hopby- hop routing the profitability is actually greater than the central approach when the message cost is low, but decrease rapidly when the traffic load increases.

The function for capacity allocation for the local approach is not designed for the short *T*u in the case of having a low message cost.An allocation function should be designed for a very small blocking probability to give more profit for a small traffic load. A problem with this approach is the inability to adapt to an overall low traffic load which in turn forces the average blocking to the predefined limit. Fig. 11 shows the results when no guard band is used for the local approach

The fixed approach shows good performance for low and moderate traffic imbalance. For high traffic imbalance the fixed allocation is not as good as the other approaches. The main reason for the good performance is that no guard band is used, *i.e.* more capacity is available. The use of a guard band will decrease the number of link violations but the profitability will also decrease.

The use of DAR will always increase the profitability. How the guard band and the DAR effects the profitability, link violations *etc.* can be seen in Table 5. Here the distributed approach is used in a case with basic traffic load. (Guard. = Guard band, bl. = mean call loss probability [%], Max bl. = Mean max VPC bl. [%], Vio. = Link violations per t.u., Profit. = Profitability.)

Guard.	DAR	bl.	Max bl.	Vio.	Profit.
No	Yes	1.7	4.9	1.50	98.26
Yes	Yes	2.1	6.2	0.12	97.91
No	No	2.7	7.5	0.73	97.28
Yes	No	3.2	9.1	0.01	96.77

Table 5: DAR and guard band effects.

Link Violations

The behaviour of the link violations is quite different for each approach. For the central approach the large number of link violations is a clear drawback.

For the distributed approach the number of link violations starts to increase when the traffic load becomes heavier because the capacity will be more utilized. The number of violations is about the same when having only the FVPC as when having several VPCs. It is possible to reduce the violations by increasing the trunk reservations from one to two capacity units.

The local approach does not need a guard band. Since we do not use the control that avoids the over allocation, the link violations will increase and the maximal VPC blocking will increase slightly, but the link violations will still be less when compared to the central approach. It can be seen that the link violations increase when OVPCs are used, but decrease when the traffic load increases because the capacity assigned to the VPCs will freeze when all VPCs want more capacity. There will still be violations for high traffic loads as there are major shifts in the traffic pattern.

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The fixed approach and hop-by-hop routing does not suffer from link violations. For the fixed approach the capacity allocations are kept fixed. This means that it does not need a guard band, thus giving more capacity available for this approach.

Control Messages

The central approach uses a minimal amount of control messages. It calculates a nearly optimal trunk reservation for each link which in fact reserves more capacity for direct traffic than the other approaches. Increasing the trunk reservation from one to two capacity units on each link, the number of alternative routed calls decreases and the profitability drops somewhat.

In the distributed approach the number of alternatively routed calls is relatively high because the allocations do not become as efficient as in the central or local approach. If the trunk reservation is increased from one to two capacity units, the number of alternative routed calls is reduced to the same level as for the central approach, but the profitability decrease a little.

The local approach sends less control messages when the traffic load is high because there will be less deallocations and more unsuccessful allocations. The amount of alternatively routed calls is low, because the probability of having enough capacity on the direct VPCs is high for this approach. This can be explained by the packing of the capacity on the FVPCs which means that capacity on OVPCs is minimized, *i.e.* making better use of the resources.

The fixed approach does not use any control messages, except the messages for alternative routing. For the hop-by-hop routing connection establishment is done for each call along the shortest path.

This gives about 7000 signals/t.u for the lowest traffic load situation in the figures which decreases the profitability very much as seen in Fig. 11a.

Approach	Pros	Cons
Central	• Moderate amount of control messages. • Able to change the VPC topology. (Using group-VPCs)	• Many link violations. • NMC is needed. • Large networks increase the complexity of the calculations.
Distributed	• Simplified calculation of capacity allocation by the use of iterations. • NMC not involved.	• Link violations. • High number of control messages. • Computation power at each node needed.
Local	• Can be made simple. • Can avoid link violations.	• Inability to detect low total traffic load.
Fixed	• OK for moderate traffic imbalance. • No link violations or control messages.	• Lack of flexibility. • NMC involved.

Table 4: Main characteristics of the different approaches.

6. Conclusion

The central approach has the ability to find new paths and to order them in an optimal way. It can also determine the loads on different links.

The distributed approach uses simplified calculations, and the local approach uses only local information to adjust the capacity allocation for the VPCs.

The development of a distributed approach has filled a gap among the approaches and has enabled us to compare fundamentally different approaches for VPC capacity management and to evaluate the pros and cons of each approach (Table 4). By means of marginal utility, this approach can give hints of where additional capacity is needed in the network.

It seems as if the local approach is an interesting alternative to the otherwise so frequently studied central approaches.. The central one has the ability to find VPCs and order them and the local one can fine-tune the capacity allocation and easily avoid link violations. The parameter *K* can be adjusted to the special link load situations on different paths.

As seen in Fig. 11a the local approach shows high profitability.

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