#9

A Study of a Distributed Approach for VPC Network 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 made. 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 centralised one. Our results show that the distributed approach is an interesting alternative.

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 handling of quality-of-service (QoS) parameters. This is also called virtual subnetworking, which subdivides the traffic into more homogeneous groups.

There are always variations in the telecommunications traffics. Traditional networks have been dimensioned for the so called busy hour to cope with the maximum traffics. This means that much of the capacity will stay unused. By using VPCs the capacity allocation can be managed dynamically. In our study the traffic variations are met by reshaping the VPCs in order to match the current demands. 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. The idea of local and distributed approaches is to increase the robustness and improve performance as in [6] compared to a central approach, which is depending on a central computer [2,3,9]. By assigning costs for control messages and rejected calls the methods can be compared, and in this paper we describe a distributed approach and compare it with a centralised one.

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 optional VPCs are labelled OVPCs.

The 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 as in [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 origin node puts the received routes in a table. The different selection criteria evaluated are shortest, link disjoint, and node disjoint paths. Paths are then ordered by the number of links and the total physical distances. When a limited set of VPCs have been selected the VPCs are established by sending 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 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 allowable capacity with ACAPs.

2.4 Available Capacity Message (ACAP)

ACAP messages are sent on each VPC to find out the maximum 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 need it the most as indicated by a bottleneck flag. (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 make the management work in a cost effective way. (Updating more often than the traffic changes 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 triggered 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 allowed capacities are received by the ACAP answer messages, after the first traffic bids, the OVPCs are ordered by their allowable capacity. The **subsequent bids** are based on the allowable capacities. If the estimated offered traffic is T , the needed capacity C can be calculated with the ErlangB formula giving a specified blocking probability p . The allowable capacity C_i can handle a certain amount of traffic t_i calculated from (1). The index i specifies the path, and in our study p is set to 1%.

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

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

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

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:

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

VPCs with an index greater than k will get a zero bid. If the allowed capacity is not enough the traffic bids are set proportion-

ally to the t_i s.

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

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 distribute any unused capacity by a new round 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.

3. Results

We have used ten non-hierarchical networks (in the VC sense) each having ten nodes (which can be seen as a core ATM network). The evaluation has been done with homogenous traffics with the same QoS demands and Poissonian traffic arrivals. Multiplexing in burst scale (i.e. 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). To simulate the traffic variations ten different busy hour patterns were generated for each network by randomly selecting a busy centre. Offered traffics to the busy centre nodes were increased randomly between 10-30%. We also consider a case of more extreme variations, results within brackets refer to an upper limit of 80% rather than 30%.

3.1 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 centre. The results from different selection criteria, three OVPCs, three BIDs, no ACAP iterations, and no alternative routing are as follows:

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)

*) The results can be compared to a fixed VP bandwidth management, optimized for the basic traffics and having no OVPCs.

3.2 Cost of OVPCs

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 many hop VPCs must have less priority in the distribution process than shorter ones.

Figure 1: Test model

This has been implemented by dividing the MU by a cost parameter. (This is only done during the first traffic bid and PVPCs have not been penalized.)

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 traversing all links as in figure 1.

If we let the traffic on all direct link VPCs be the same it is possible to give the following expression of the total traffic handled by the network:

$$K \cdot T_A \cdot (1 - E_{CA}(T_A)) + T_B \cdot (1 - E_{CB}(T_B)) \quad (2)$$

T_A = Traffic on VPC A, C, D..., T_B = Traffic on VPC B.
 C_A = Capacity on VPC A, C_B = Capacity on VPC B.
 $E_{CA}(T_A)$ = Blocking probability for VPC A.
 $E_{CB}(T_B)$ = Blocking probability for VPC B.
 K = Number of hops for VPC B.

The optimal capacity distribution can easily be found by changing the capacity on VPC A until the optimum of (2) is found. The resulting cost parameter gets equal to the number of hops for the VPC. We have also evaluated more complex networks than the one in figure 1, and seen that the choice of cost parameter gets the same.

3.3 Fairness

We have seen that by subtracting the number of hops for the PVPC from the number of hops for the OVPC, the VPs are treated more equally. The iterations of ACAP are used to allow multi-hop paths to get extra capacity. (VPCs traversing more links are more likely to traverse a bottleneck link.) 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)

3.4 Profit

The cost for a control message (by means of RM-cells using some of the bandwidth) affects the total profit. Figure 2 shows how the total mean network blocking decreases as the number of control messages increases. Figure 3 shows two different costs for control messages 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 a RM cell, the cost can be related to a phone call. Suppose that a phone call use 167 cells/second, then the RM cell could be given a cost of $1/(167 \cdot \text{seconds per mean holding time}) \sim 10^{-4}$. 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.

Figure 2: Mean Total Blocking and Number of Signals

Figure 3: The Profit for Different Signal Costs

3.5 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. To better cope with this "guard bands" of one extra capacity unit on each link have been used. (A better dimensioning is possible.) This capacity will not be allocated to any particular VPC. The amount of link violations depends on the actual network.

Figure 4 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.

Figure 4: Example of a violated link

3.6 Comparison to a Central Approach

To see the profit of having a central approach for VP network management 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 centre periodically with the same frequency as for the distributed approach. The centre computes an updated VP network bandwidth allocation and returns the results to the nodes for implementation.

In this evaluation we have used dynamic alternative routing [15], i.e. if a 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 via node is selected (at random) for use the next time a call needs to be rerouted.

Our comparison between the distributed and the central approach 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 profit per time unit. The distributed approach is evaluated in two cases labelled distributed 1 and 2. The first case used only the PVPC, one BID, one ACAP iteration, and a signal cost of 0.1. Only the PVPC is used (to decrease the number of signals). This limits the amount of reallocations which in turn gives less link violations. Case 2 used two OVPCs, three BIDs, three ACAP iterations, and a signal cost of 10^{-4} (more iterations does not decrease the blocking much further).

For medium traffic variations the results are:

Approach	Mean	Max VP	Violations	Profit
Fixed	1.79	5.59	0	5866
Distributed 1	1.18	4.00	0	5896
Distributed 2	1.03	3.69	0	5911
Central	0.41	1.51	0.055	5948
Optimal	0	0	0	5973

The optimal case is a hypothetical case with no lost calls and no signal costs.

When increasing the traffic variation up to 80% the results are:

Approach	Mean	Max VP	Violations	Profit
Fixed	6.94	17.14	0	4748
Distributed 1	4.04	13.69	0.802	4896
Distributed 2	2.84	12.11	2.508	4957
Central	2.67	9.60	3.566	4966
Optimal	0	0	0	5103

When comparing these profits with the profit of the optimal case, the central and distributed approach reach 97% of it and the fixed VP management reaches 93%.

It is seen that either approach improves profits as compared to the static allocation. The distributed approach is less profitable than the central one. This is expected as the central approach has the ability to calculate some sort of optimum capacity allocation. However, when the traffic variations increases the difference decreases.

Fig. 5 show the performance for different traffic variation situations. All diagrams but one show results for a low signal cost (10^{-4}). The diagrams show a measure of the maximal VPC

blocking probability, the number of link violations, and the fraction of profitability reached, e.g. if all calls are handled without any costs, the reached profitability is 100%.

The large number of link violations for the central approach is a clear drawback, but it use a minimal amount of control messages. This approach calculates a nearly optimal trunk reservation for each link. 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.

For the distributed approach the traffic load becomes heavier the number of link violations starts to increase because the capacity changed will be more utilized. It is possible to reduce the violations by increasing the trunk reservations from one to two capacity units. 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.

4. Conclusions

This paper has described a type of distributed VP management policy. The method can use many iteration cycles to improve the network performance, but the number of control messages will increase correspondingly.

The central approach is more profitable (as expected), but only by a small fraction (half a percent), and the difference gets smaller as the traffic variations increases. We have seen that the distributed approach makes less link violations.

The calculations done by the distributed approach are very simple and the method is fast. A management centre is not needed. When considering fault management the distributed approach could be able to share some of the functions [10,11,14].

5. Further Work

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

The amount of handled traffic will increase if the number of VPs on a link decreases (the bigger the better) and a trade-off between VP and VC routing should be considered [4].

The amount of guard band has to be studied.

The distributed strategy will also be compared to a local strategy as the one described in [5]. The importance of comparing the different approaches is stated in [13].

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Central = dash-dot/circle Distributed = dashed/star Fixed = solid

Figure 5: Comparison with High Traffic Variations