DIMENSIONING FSAN (FULL SERVICE ACCESS NETWORKS) AND BBL (BROADBANDLOOP) ACCESS NETWORKS

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ABSTRACT

This paper compares two technologies for ATM access networks, BBL (BroadbandLoop) and FSAN (Full Service Access Networks), and discusses methodologies for dimensioning these networks. Several resource management strategies, based on the virtual path concept, are considered. Statistical multiplexing both at the service and call level is studied. It is seen that the network topology and the service characteristics allow several simplifications in the call and cell level dimensioning processes. The dimensioning procedures are illustrated through some case studies.

1 INTRODUCTION

The FSAN [1] is an initiative that aims the large-scale introduction of broadband optical access networks, through the definition of a basic set of common requirements. These networks should be able to deliver existing and future services not yet completely defined. The BroadbandLoop network [2] is a specific full-service access network, based on ATM technology, which provides for a graceful introduction of fiber into the local loop when the bandwidth demand increases. This network has been developed within BBL project, from the European program ACTS - Advanced Communications Technology and Services (ACTS 038).
The deployment of multi-service broadband access networks is severely constrained by cost factors. A key issue to be discussed is whether or not signalling functions should be included in the network elements. The signalling raises the price of the system but allows for more efficient resource management strategies. In an ATM based access network, the resources can be managed through the use of VPs (Virtual Paths). Different solutions impose different requirements in terms of signalling functions.
The dimensioning of an ATM network is determined by the network topology, the resource management strategy and the service characteristics [3]. We assume fixed routing and study both service segregation in VPs and service multiplexing in a single VP. The dimensioning of each service can be partitioned in two levels. Call level dimensioning determines the number of circuits required to achieve a specified GoS (Grade-of-Service). Cell level dimensioning determines the bandwidth to be allocated to each circuit, in order to achieve a specified cell level QoS (Quality-of-Service).
In this paper we present methodologies for dimensioning the BBL and FSAN networks under different resource management strategies. Section 2 presents the BBL and FSAN networks and the supported services. Section 3 proposes the resource management strategies under study. Section 4 and section 5 present the call level and cell level dimensioning methods. In order to illustrate the dimensioning methods, some case studies are discussed in section 6.

2 BROADBANDLOOP AND FSAN SYSTEMS AND SUPPORTED SERVICES

BBL and FSAN systems are ATM access networks [4] [5] [6] [7] targeted to connect end-user terminals to the ATM transport network. BBL and FSAN networks are very similar in terms of network elements and physical interfaces. Both technologies assume that the core network is based on a SDH

(Synchronous Digital Hierarchy) ring with an ATM switch connected to service provider nodes, and one OLT (Optical Line Termination) attached, as represented in Figure 1. In the general case, the VPI/VCI values of each cell, forward them to the final destination or discard them. Therefore, the bandwidth allocated to each ONU is configurable at the ATM level. The upstream transmissions from the ONU are

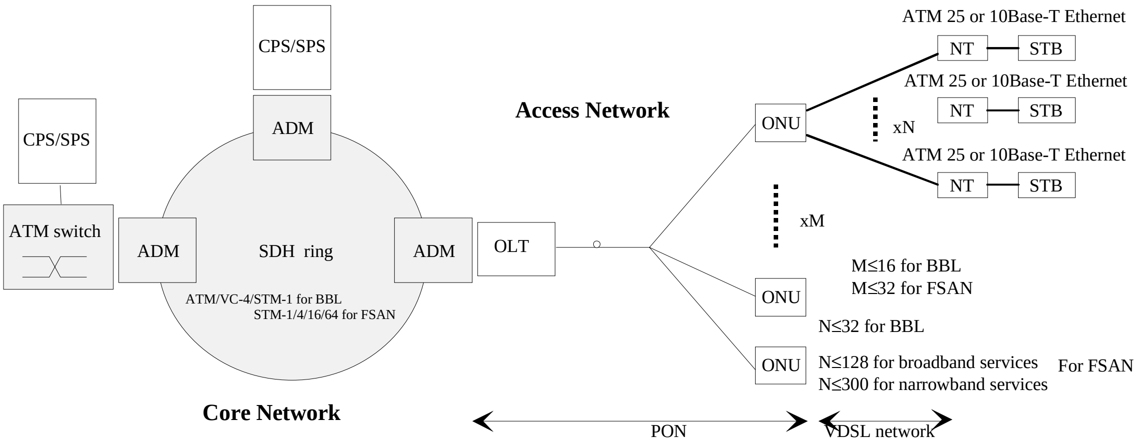


Figure 1. BroadbandLoop system architecture.

system can include several access networks and the SDH ring provides connectivity between the access networks and the ATM switch. This connectivity is implemented between the ATM switch and the OLT by means of SDH VC-4 containers (155 Mb/s). We will refer to the ATM switch as the OAS (Outside ATM Switch).

The access network consists of an OLT that performs the adaptation between the core network and the access network, a single fibre ODN (Optical Distribution Network) based on a PON (Passive Optical Network), up to 16 (BBL) and 32 (FSAN) ONUs (Optical Network Units) at the customer ends, and VDSL (Very high bit rate Digital Subscriber Line networks) as the distribution network in BBL and in FSAN with FTTCab (Fiber To The Cabinet)/C (Curb)/B (Building) technologies. In FSAN we also have FTTH (Fiber To The Home) with fibre from the OLT to the subscriber [8]. In BBL, each ONU is able to serve a maximum of 32 NT (Network Terminations) with 25 Mb/s ATM interfaces, each one corresponding to a subscriber. In FSAN, the number of subscribers attached to each ONU may reach 128 if the services supported are all broadband and 300 if the services are narrowband [9]. In BBL, between the NT and the subscriber, the possible interfaces are 25 Mb/s ATM and 10 Mb/s Ethernet. Thus each BBL PON accepts a maximum of 512 end-users. We assume that only a percentage of these users may be subscribing a given service; this is the *service penetration*.

The optical part of the access network is an upgradeable system that enables operators to match closely their network investments with the traffic they need to support. In the downstream direction of the PON the information is broadcasted to all ONUs. They receive the stream and, depending on the controlled by the OLT using SCMA (Sub-Carrier Multiple Access) technique in BBL and TDMA (Time Division Multiple Access) technique in FSAN [10]. In the BBL case, the system can be upgraded both in upstream and/or downstream directions with modules inserted between the OLT and the ONU that is upgraded. Upgrades can be installed whenever the operator requires.

In the copper part of the BBL access network, there are two types of FTTC (Fiber To The Curb) ONUs that differ on the bandwidth of the VDSL lines. The symmetrical ONUs have VDSL lines with 13 Mb/s in both directions. The asymmetrical ONUs have VDSL lines of 51.5 Mb/s in the downstream and 1.6 Mb/s bandwidth in the upstream direction. These values were defined not only because of technical reasons (low-cost hardware components that are available for these line rates) but also for the system to be able to provide both symmetric and asymmetric type of services. FSAN refers the need to upgrade the system, but does not specify the upgrade modules. Therefore we have the freedom to choose the maximum number of modules that can be inserted in the access network and its bandwidth.

Within the BBL project, a set of services were selected for consideration in the dimensioning of the BBL system. These services [4] were grouped in residential and business: *residential* services are FIA (Fast Internet Access), MPEG-2 VoD (Video-on-Demand), MPEG-2 DVB (Digital Video Broadcast); *business* services are FIA, Vc (Video-Conference) and LLI (LAN-to-LAN Interconnection). FSAN [1] also addressed Videotelephony, Distant Learning, Telemedicine, POTS/ISDN and ATM SVC (Switched Virtual Connection).

Different service characteristics impose different requirements in the network dimensioning procedures. All services are considered real-time which means that some bandwidth should be reserved for each service to guarantee the specified QoS. For this purpose services can be classified in conversational *versus* retrieval, switched *versus* permanent and symmetrical *versus* asymmetrical. In *retrieval* services (FIA, VoD, DVB), VCCs are requested only from an user attached to the PON to an outside destination. In *conversational* services (Vc, LLI), VCCs can also be requested between users internal to the PON. In *switched* services (FIA, VoD and Vc), VCCs are established on-demand by the ATM control plane while in *permanent* services (DVB and LLI) circuits between peers are always available and configured at the management plane. Switched services require dimensioning at call level. In *symmetric* services (Vc and LLI) VCCs require the same resources in both directions, and in *asymmetric* services (FIA, VoD and DVB) much more resources are requested in the downstream direction than in the upstream direction. Note that residential services are all asymmetric and business services are mainly symmetric. Consequently, a symmetrical VDSL interface is adequate for business users while asymmetric are adequate for residential users. We consider that symmetric ONUs are used only for business services and the asymmetric ONUs are used only for residential services.

3 RESOURCE MANAGEMENT STRATEGIES

There are two important issues related to resource management: how VPCs are configured and how VCCs (either permanent or switched) are multiplexed within the same VPC or between different VPCs. In terms of VPC configuration, one aspect that has direct impact on the cost of the system is whether or not resource management mechanisms, namely CAC (Call Admission Control) and UPC (Usage Parameter Control), are implemented in the different network elements. We propose three different VPC design strategies:

- VPCs between each ONU and an outside ATM switch (Figure 2.a). This strategy can be used when no CAC functions are available on the OLT and ONUs. This is a tunnelling solution where there must be a different VPC between each attached terminal and the OAS in order to enable it to identify the cells from each terminal. We assume that there are UPC functions in the ONUs, configurable at the management plane, to prevent non-contracted traffic generated by terminals to influence the QoS of other communications.
- VPCs between each ONU and the OLT (Figure 2.b) and an extra VPC between the OLT and an outside ATM switch to support communications with the outside. This strategy is used when there are CAC functions implemented only in OLT. For each ONU, there must be a different VPC between each attached terminal and the OLT in order to enable the OLT to identify the cells from each terminal. Like in the previous strategy, we assume that there are UPC functions in the ONU. However, it is possible to consider (since OLT and ONUs are from the same manufacturer) the implementation of UPC functions in the ONUs at the control plane, i.e. each request for a call establishment (from an user terminal) is received at the OLT (through the appropriate VPC) that sets up the appropriate UPC parameters on the ONU (using perhaps a proprietary solution) before confirming to the terminal the call establishment.
- VPCs between each ONU pair (Figure 2.c) and extra VPCs between each ONU and an outside ATM switch to support communications with the outside. This strategy is suitable when there are CAC (and UPC) functions only in the ONUs. In this case, OLT acts just as a VP cross-connect.

Another alternative is to have CAC functions implemented in both ONU and OLTs. The 2nd VPC design strategy also applies and the dimensioning procedures can be reused with minor modifications.
In FSAN two resource management strategies were considered [11]: the direct VP connection between terminal equipment and the ATM switch, and the VC (Virtual Circuit) arrangements in access network (a VP connection between the terminal equipment and a multiplexing element which belongs to the access network - usually this multiplexing element is the OLT - and another VP connection between the multiplexing element and the outside). These strategies correspond respectively to the first and second strategies in BBL. In the direct VP connection there are two possibilities of bandwidth allocations: using PBR allocation and using statistical multiplexing between different VC inside a VP, that means between different services (subscribed to one service node) of one subscriber. In the VC arrangements there are 4 possibilities of bandwidth allocation: (i) using PBR allocation, (ii) using statistical multiplexing (with the addition of the possibility of statistical multiplexing in the multiplexing element), (iii) using bandwidth sharing and statistical multiplexing (in the downstream the bandwidth required in the connection between the multiplexing element and the service node is the sum of the bandwidths required in the connection between the terminal equipment and the multiplexing element,

with no cell loss in this direction; in the upstream direction there is statistical multiplexing in the multiplexing element, with the possibility of cell loss), (iv) using subscriber controlled bandwidth sharing (the subscriber activates the VP between him and the multiplexing element only when using the VP).

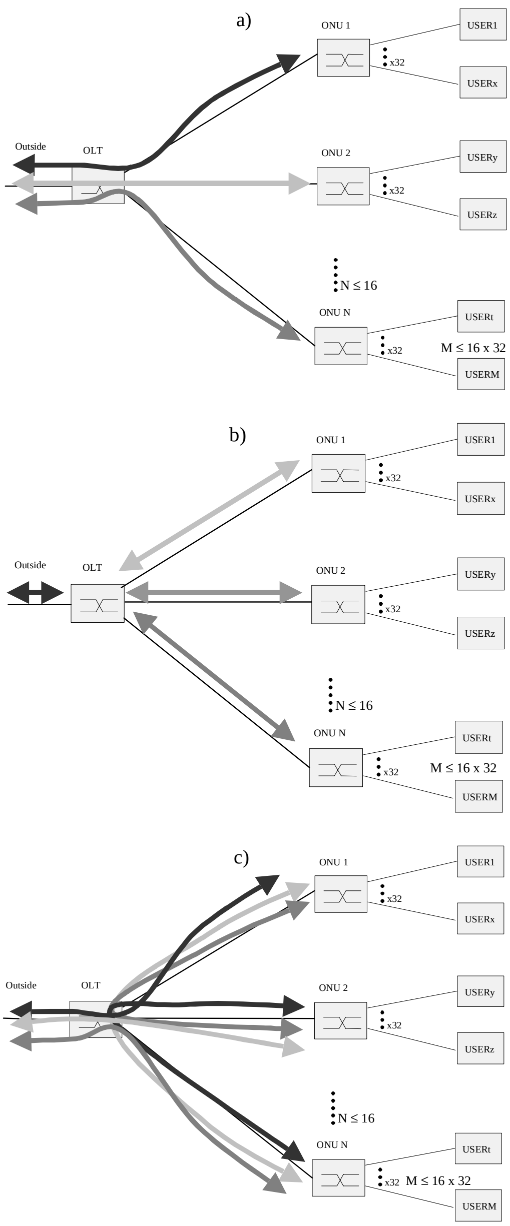


Figure 2. a) VP connections between each ONU and an outside ATM switch; b) VP connections between each ONU and the OLT; c) VP connections between each ONU pair.

In terms of VCC multiplexing, BBL system is designed with four output buffers per interface in both the OLT and ONUs. Thus each service can be allocated a distinct buffer allowing the set-up of a logical network with reserved resources per service (with any of the VPC design strategies presented above). Although having one buffer per service facilitates resource allocation and management, there is no constraint on the number of services per buffer in a BBL system. This is also true for FSAN. In this way, we may have only a single buffer for all services, some buffers each one for a set of services, or, as in the case of BBL, one buffer per service.

4 CALL LEVEL DIMENSIONING

The call level dimensioning calculates the number of circuits in each VP required to provide a specified GoS. We have considered the call blocking probability as the GoS parameter. The system can be modelled at call level through a multidimensional birth-death process, where the state of the system corresponds to the number of calls in progress for each traffic class. A traffic class is determined by the origin-destination pair, the route, the bandwidth per call and the traffic intensity. The origin-destination pairs can be two ONUs, one ONU and the OLT, one OLT and the OAS or one ONU and the OAS. We assume the following symmetry condition: the percentage of traffic that goes out of the PON (and of each ONU) is the same that goes into the PON (and of each ONU). In some cases, the model can be simplified to allow the exact calculation of the blocking probability (e.g. through the Erlang B formula or through multi-rate Erlang B computations). In other cases, the complexity associated with the resolution of the multidimensional birth-death process, makes it necessary to resort to reduced load approximations, for single or multiservice networks.

The resource management strategies addressed in FSAN and in BBL are similar, with the exception of the 3rd strategy which is only considered in BBL. Therefore the dimensioning methodologies will be the same for both networks.

We will study two extreme situations concerning the way services are combined in the output buffers of the statistical multiplexing nodes: (i) one buffer per service (there is only statistical multiplexing between the cells belonging to the same service – the *no service multiplexing* case) and (ii) one buffer for all services (there is statistical multiplexing between the cells of all services – the *service multiplexing* case). The first case was already addressed in [7]. Here the CAC algorithms are simpler but the bandwidth required in each connection will be slightly greater. In the first case, there will be one VP per service whereas, in the second case, a single VP will carry all services. An intermediate situation would be to have a number of services larger than the number of buffers and more than one buffer. In this case we would have to apply traffic clustering rules [12] to aggregate or separate services in the different buffers.

In practice users are arbitrarily distributed by the 16 ONUs of a PON. The impact in terms of dimensioning can be studied by considering another two extreme cases: (i) users equally distributed in the 16 ONUs (maxONUs - here the bandwidth in the connections ONU ↔ OLT is minimum but the number of needed ONUs is maximum) and (ii) users distributed in the minimum number of required ONUs (minONUs - here the bandwidth in the connections ONU ↔ OLT is maximum but the number of required ONUs is minimum).

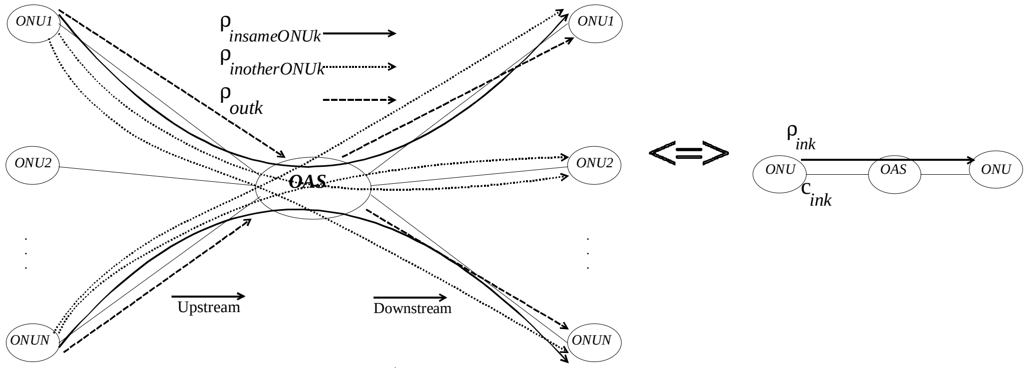


Figure 3. Traffic classes of service k in the 1st strategy and equivalent model (maxONUs).

4.1 VP connections between each ONU and an outside ATM switch

Figure 3 shows the different types of traffic classes for each service in the maxONUs case. The OLT is only a cross-connect, thus it is not represented in the figure. One end-user may establish a connection of service k with another one in the same ONU ($\rho_{insameONUk}$), in another ONU ($\rho_{inotherONUk}$), or in another PON (ρ_{outk}). The traffic of service k that crosses each VP between the ONU and the OLT in the downstream and upstream directions is given by $\rho_{ink} = \rho_{insameONUk}+(N-1)\rho_{inotherONUk}+\rho_{outk}$. We make the assumption that call blocking in the upstream and downstream directions are independent. In the case of retrieval services, only the traffic classes from the ONU to the OAS and vice-versa exist. Thus, for these services, $\rho_{ink} = \rho_{outk}$. For each origin there are 17 possible destinations (16 internal to the PON and one external) in the specific case of BBL. Thus there is a total of 272 traffic classes of the same service. However, due to the symmetry of the system this is equivalent to a single resource shared by a single class, in the no service multiplexing case (here the resource is the VP of each service), or to a single resource shared by multiple classes, in the service multiplexing case (here the resource is the VP where all services are multiplexed). In the no service multiplexing case, the Erlang B formula can be used. We will denote the Erlang B formula by ErB(ρ , c), where ρ is the traffic intensity and c the number of circuits. The number of circuits c_{ink} of each VP (in the connection between the OLT and the ONU) and c_{outk} (in the connection between the OLT and the outside) can be derived from GoS = ErB(ρ_{ink},c_{ink}) and $c_{outk} = N\times c_{ink}$, where N is the number of ONUs. In the service multiplexing case, several methods can be used to calculate the call blocking probabilities: multi-rate Erlang B computations [13], direct Knapsack computations [14], Labourdette approximation [15] and Siebenhaar approximation [16]. The first two methods calculate an exact value of the call blocking probabilities. In this paper, the direct knapsack method was used. Here, the blocking probability of a class k call is given by $GoS_k = \sum_{c=C-b_k+1}^{C} q(c)$, where C is the service rate of the buffer (i.e. the bandwidth of the VP), and b_k is the bandwidth of service k, $q(c)=\frac{g(c)}{G}$, $G=\sum_{c=0}^{C} g(c)$, $g(c)=\frac{1}{c}\sum_{k=1}^{K} b_k \rho_{ink}\, g(c-b_k)$.

Figure 4 shows the traffic classes in the minONUs case. There are two types of ONUs: type m (with the maximum number of users, offering a total load of ρ_{inmk}) and type r (with the remaining users, offering a total load of ρ_{inrk}). This is the j-th ONU in Figure 4. There are also two types of VPs: type m (from a type m ONU to the OAS and vice-versa), with c_{inmk} circuits, and type r (from a type r ONU to the OAS and vice-versa), with c_{inrk} circuits. The traffic that goes out of an ONU of type m will be less than the same traffic in the maxONUs case. In the no service multiplexing (service multiplexing) case the Erlang B formula (multi-rate computations) can be used in type m VPs provided that:

$$\rho_{insameONUmk} + (j-2)\rho_{inotherONUmk} + \rho_{inotherONUmrk} + \rho_{outm1k} = \\ = \rho_{insameONUmk} + (j-2)\rho_{inotherONUmk} + \rho_{inotherONUrmk} + \rho_{outm2k}$$

and in type r VPs provided that:

$$\rho_{insameONUmk} + (j-1)\rho_{inotherONUrmk} + \rho_{our1k} = \\ = \rho_{insameONUmk} + (j-1)\rho_{inotherONUmrk} + \rho_{outr2k}$$

Since, due to symmetry, $\rho_{outm1k} = \rho_{outm2k}$ and $\rho_{outr1k} = \rho_{outr2k}$ the remaining condition is that $\rho_{inotherONUmrk} = \rho_{inotherONUrmk}$. This is only true for PONs with a number of ONUs multiple of 4. The number of circuits in type m and type r VPs and in the connection between the OLT and the OAS can be calculated from GoS = ErB(ρ_{inmk},c_{inmk}), GoS = ErB(ρ_{inrk},c_{inrk}) and $c_{outk} = (j-1)\times c_{inmk}+c_{inrk}$, in the no service multiplexing case, and from multi-rate computations in the service multiplexing case.

A PON with a number of ONUs different than the previous one, will have to be dimensioned through a reduced load approximation, as described in [5]. This system is asymmetric because the traffic that goes out of an ONU is different from the traffic that goes into an ONU of the same type, thus preventing the use of the Erlang B formula. Again, in the case of retrieval services, only the traffic classes from the ONU to the OAS and vice-versa exist. Here the Erlang B formula (or multi-rate computations) can always be used provided that the symmetry conditions, $\rho_{outm1k} = \rho_{outm2k}$ and $\rho_{outr1k} = \rho_{outr2k}$, hold.

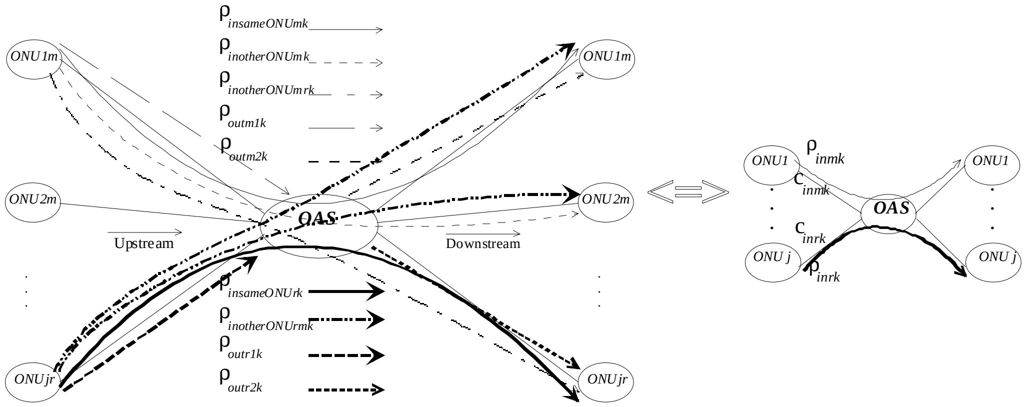


Figure 4. Traffic classes of service k in the 1st strategy and equivalent model (minONUs).

4.2 VP connections between each ONU and the OLT

In this case all traffic classes cross two VPs. The simplified model is shown in Figure 5. An upstream VP is shared by traffic classes that will be switched to VPs with different capacities, one VP with c_{outk} circuits to the OAS and another with c_{ink} to the destination ONU. This is also the case for downstream VPs. It is no longer possible to use the Erlang B formula or multi-rate computations and we have to resort to a reduced load approximation. The (approximate) blocking probabilities of internal VPs (ONU ↔ OLT), L_{ink}, and external VPs (OLT ↔ OAS), L_{outk}, in the no service multiplexing case are:

$$L_{ink} = ErB\left[\begin{array}{l}\rho_{insameONUk}\left(1-L_{ink}\right)+\rho_{outk}\left(1-L_{outk}\right)+\\ \left(N-1\right)\rho_{inotherONU\ k}\left(1-L_{ink}\right), c_{ink}\end{array}\right]$$

$$L_{outk} = ErB\left[N\times\rho_{outk}\left(1-L_{ink}\right), c_{outk}\right]$$

and the call blocking probabilities in each class are $B_{outk} = 1-(1-L_{ink})(1-L_{outk})$ and $B_{ink} = 1-(1-L_{ink})^2$.

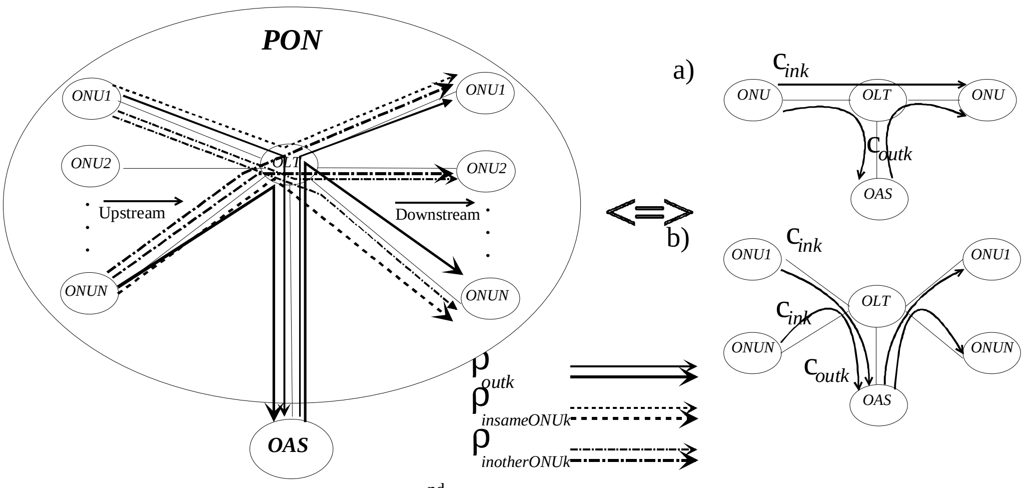


Figure 5. Traffic classes of service k in the 2nd strategy and equivalent model for a) conversational and b) retrieval services (maxONUs).

In service multiplexing case, the Knapsack [17] or Erlang [18] reduced load approximations can be used. As an example, the (approximate) blocking probabilities of internal (ONU ↔ OLT) and external (OLT ↔ OAS) VPs are, using the Knapsack approximation:

$$L_{in1} = Q_1 \begin{bmatrix} \rho_{insameONU\ 1}(1-L_{in1}), \rho_{out1}(1-L_{out1}), \\ (N-1)\rho_{inotherONU\ 1}(1-L_{in1}),..., \\ \rho_{insameONUK}(1-L_{inK}), \rho_{outK}(1-L_{outK}), \\ (N-1)\rho_{inotherONU\ K}(1-L_{inK}), c_{in} \end{bmatrix}$$

$$L_{out1} = Q_1 [N \times \rho_{out1}(1-L_{int1}),..., N \times \rho_{outK}(1-L_{inK}), c_{out}]$$

…

$$L_{inK} = Q_K \begin{bmatrix} \rho_{insameONU\ 1}(1-L_{in1}), \rho_{out1}(1-L_{out1}), \\ (N-1)\rho_{inotherONU\ 1}(1-L_{in1}),..., \\ \rho_{insameONUK}(1-L_{inK}), \rho_{outK}(1-L_{outK}), \\ (N-1)\rho_{inotherONU\ K}(1-L_{inK}), c_{in} \end{bmatrix}$$

$$L_{outK} = Q_K [N \times \rho_{out1}(1-L_{in1}),..., N \times \rho_{outK}(1-L_{inK}), c_{out}]$$

where $Q_k = 1 - \sum_{c=0}^{b_k} q(c)$, $q(c)$ is the one defined in subsection 4.1, and the call blocking probabilities in each class are B_{outk} = 1-(1-L_{ink})(1-L_{outk}) and B_{ink} = 1-(1-L_{ink})^2.

Again, in the case of retrieval services, only the traffic classes from the ONU to the OAS and vice-versa exist. In the no service multiplexing case the network topology reduces to a tree and exact blocking probabilities can be obtained through a convolutional algorithm [19]. The call blocking probabilities are:

$$B_{out} = \frac{g(c_{out}) + g_i(c_{in}) \sum_{c=0}^{c_{out}-c_{in}-1} g_{(i)}(c)}{\sum_{c=0}^{c_{out}} g(c)}, \qquad i=1,\ldots,N$$

where $g_i(c) = \begin{cases} \rho_{in}^c / c!, c = 0,...,c_{in} \\ 0, c > c_{in} \end{cases}$

$ge_k = [g_k(0), g_k(1),..., g_k(c_{out})]$ and $g(c) = [ge_1 \otimes ... \otimes ge_I](c)$.

$\otimes$ denotes the convolution operator, $g_{(k)}(c)$ is the convolution of all the g_l's except for l=i and $[ge_1 \otimes ... \otimes ge_I](c)$ is the c-th element of the resultant vector of the convolution.

In the service multiplexing case we have to resort to reduced load approximations for multi-service networks. The minONUs case uses similar dimensioning methods [5].

4.3 VP connections between each ONU pair

In this strategy, each traffic class has resources reserved end-to-end. Therefore in the no service multiplexing case, the Erlang B formula can always be used. There are two types of VPs: internal (ONU ↔ ONU) requiring c_{inVPk} circuits and external (ONU ↔ OAS), requiring c_{outVPk} circuits. The number of circuits in each VP can be calculated from ErB($\rho_{inotherONUk}$, c_{inVPk}) and ErB(ρ_{outk}, c_{outVPk}). Finally, the number of circuits (required by each service) in the OLT ↔ ONU links is $c_{ink} = (N\text{-}1) \times c_{inVPk} + c_{outVPk}$ and in the OLT ↔ OAS links is $c_{outk} = N \times c_{outVPk}$.

5 CELL LEVEL DIMENSIONING

We consider two bandwidth allocation methods: at the Peak Bit Rate (PBR) and using effective bandwidths. PBR allocation assumes that the traffic source is always transmitting at maximum rate. The effective bandwidth is the bandwidth per source when statistical multiplexing is taken into account. In general, it depends on the number of sources, on the source model, on the buffer capacity and on the cell level QoS parameters. We use an effective bandwidth model based on large deviations theory that considers de cell loss ratio as the QoS parameter [20]. This model is additive (i.e., the bandwidth per source is independent of the number of sources), applies to multiple services and can be extended to feed-forward networks [21] (i.e., the effective bandwidth in a cascade of multiplexing buffers is never higher than the effective bandwidth at the entry buffer). This result is required for the 2nd VPC design strategy. In the 1st and 3rd VPC design strategies there is statistical multiplexing in the ONUs an in the OAS. In the 2nd one, all the network equipments have statistical multiplexing: the OAS, the OLT and the ONUs.

6 CASE STUDIES

The dimensioning of an access network consists in determining the number of VC-4 containers in each PON and (if required) the number of upgrade units (both in downstream and upstream directions), for the specified values of service penetration and quality of service (at call and cell level). In these case studies we consider the specific case of a BBL access network, with 16 ONUs and a maximum of 32 subscribers per ONU. The SDH ring is composed by several VC-4 containers each one with 155.52 Mb/s. The downstream baseband bandwidth in the PON is 155.52 Mb/s with an upgrade module to each ONU of 51.84 Mb/s. In the upstream direction the baseband bandwidth available to each ONU is 9.72 Mb/s, with the possibility to upgrade each one with modules of 51.84 Mb/s.

We have considered three different scenarios: (i) a residential scenario where all users connected to the system have residential profile, (ii) a business scenario where all users have a business profile and (iii) a mixed residential and business scenario. We assume that traffic in LLI is a mixture of the following services: Fast File Exchange, Fast Fax and POTS [24]. Table 1 to Table 3 list the call and cell level parameters considered for the selected services. Traffic sources were assumed to be represented at cell level by an IDP (Interrupted Deterministic Process), defined by the PBR, the number of cells in the ON state (burst length) and the percentage of time in the ON state (utilisation). At the call level, the arrival process was assumed to be Poisson with rate BHCA (Busy Hour Call Attempt), and the call duration was assumed to be exponentially distributed with mean MCD (Mean Call Duration).

Table 1. Service traffic parameters at the call level

	Services				
Traffic Parameters	*VoD* [23]	*IA*	*VD*	*LLI*	*Vc* [24]
MCD (sec)	7200	4	--	*	3600
BHCA (calls/hour)	0.03	30	--	*	0.5

* presented in Table 3

Table 2. Service traffic parameters at the cell level

	Services				
Traffic Parameters	*VoD* [22]	*IA*	*VD*	*LLI*	*Vc*
PBR (Mb/s) (downstream)	6	2	4	*	0.384
Burst length ON (cells)	417	10 [10]	--	*	27
Utilisation (%)	66.(6)	50	100	*	66.(6)
PBR (Mb/s) (upstream)	0.128	0.128	--	*	0.384

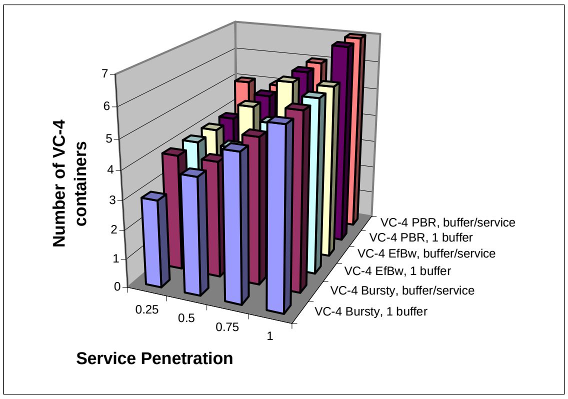
* presented in Table 3

Table 3. Traffic parameters of the LLI services

Direction of traffic	***Traffic parameters***	***Fast File Exchange***	***Fast Fax***	***POTS***
Call level	MCD (sec)	5	5	100
	BHCA (calls/hour)	0.1	2.5	3.6
Cell level	Burst length ON (cells)	10	--	--
	Utilisation (%)	50	100	100
	PBR (Mb/s)	2	2	0.064

Figure 6 shows some results for the case of a residential scenario with the 1st VPC design strategy, the maxONUs distribution of users with and without service multiplexing in the ONUs and the OLT. To compare the PBR and the effective bandwidth allocation methods we also used services with an utilisation 3 times lower than the ones defined in Table 2 (denoted Bursty in the figure). The figure shows the required VC-4 containers and upgrade modules for specific values of service penetration (assuming the same value for all services). With an increase in the service penetration, the number of VC-4 containers and upgrade modules increases. The number of VC-4 containers is large, because in this VPC design strategy there is no statistical multiplexing in the OLT and all communications cross the connection between the OLT and the OAS.

Since the residential services are asymmetric there is in general no need for upgrading the residential ONUs in the upstream direction. In the downstream direction, upgrades are required in a large number of ONUs. The use of effective bandwidth allocation decreases the number of required modules. More bursty services (with lower utilisation factors) result in a higher waste of resources when PBR allocation is used. For example, for a service penetration of 100%, the PBR allocation requires 7 VC-4 containers and the effective bandwidth allocation with Bursty services requires 6. In the service multiplexing case (compared to the no service multiplexing case), the required number of upgrade modules and VC-4 containers is slightly reduced because there is statistical multiplexing between all services. For example, for a service penetration of 75%, the effective bandwidth allocation requires 6 VC-4 containers with no service multiplexing and 5 with service multiplexing.



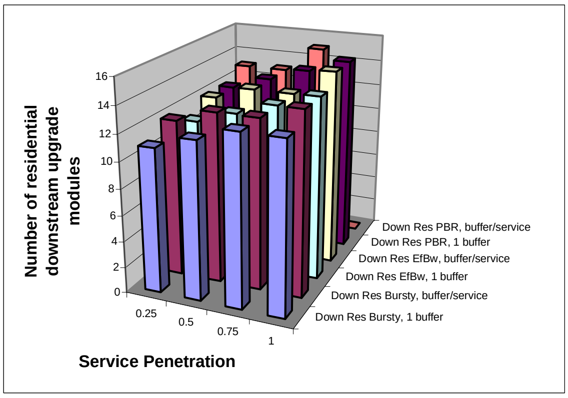


Figure 6. VC-4 containers and residential downstream upgrade modules in a residential scenario with the 1st strategy (max ONUs).

Figure 7 presents results for the case of a business scenario with 4 business ONUs, the 1st and the 2nd VPC design strategies respectively, maxONUs distribution of users, 25% of calls are between end-users in different PONs and without LLI connections. The number of VC-4 containers reduces to 1 for all cases in the 2nd strategy because only 25% of the calls cross the connection between the OLT and the OAS, and due to the existence of statistical multiplexing in the OLT. Since the business services are symmetric there is the need to upgrade the business ONUs in the upstream direction. In this case, the number of upgrade modules both in the downstream and upstream direction increases in the 2nd strategy.

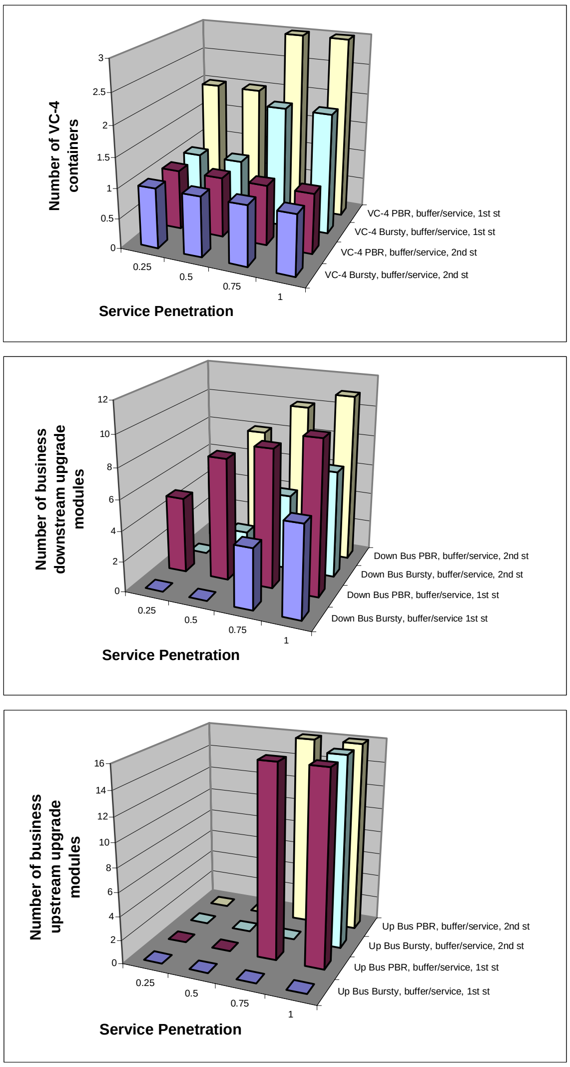


Figure 7. VC-4 containers and business downstream and upstream upgrade modules in a business scenario with the 1st and 2nd strategies (max ONUs).

Figure 8 shows some results for the case of a mixed scenario with 4 business ONUs, the 1st VPC design strategy, maxONUs and minONUs distribution of users, 25% of calls are between end-users in different PONs, with 4 LLI connections in each ONU an with no service multiplexing. With a small service penetration, the bandwidth requirements are lower than the ones with the users equally distributed by the 16 ONUs. For example, for a service penetration of 25% and a GoS of 0.1 %, 12 downstream upgrade modules are required when users are equally distributed by the 16 ONUs and only 2 when users are concentrated in the minimum number of ONUs.

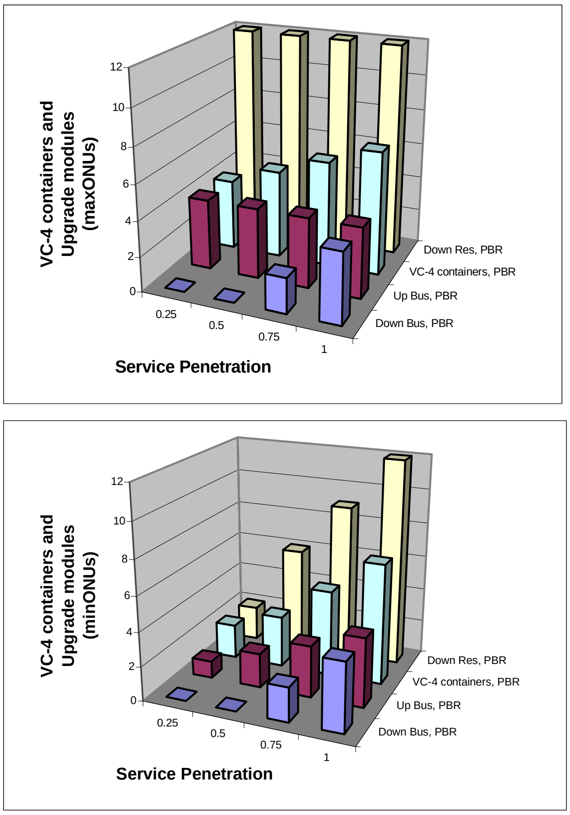


Figure 8. Modules in a mixed scenario with the 1st strategy (max ONUs and min ONUs).

Figure 9 shows the comparison between the number of VC-4 containers required in the 1st , 2nd and the 3rd strategies, respectively. In the 2nd strategy this number decreases, not only because of the statistical multiplexing at the OLT, but also because traffic internal to the PON is not required to go to the OAS. In the 3rd strategy the existence of a VP per traffic class and the lack of statistical multiplexing in the OLT increases the number of VC-4 containers. For example, for a service penetration of 100%, a GoS of 0.1% and PBR allocation, the 1st strategy requires 7 VC-4 containers, the 2nd requires 3 and the 3rd requires 6.

7 CONCLUSIONS

Methodologies for dimensioning the BroadBandLoop and FSAN ATM access networks under different resource management strategies were presented. We considered statistical multiplexing both at the service and call level. The network topology and the service characteristics were seen to allow several simplifications in the call and cell level dimensioning processes. The dimensioning procedures were illustrated through some case studies.

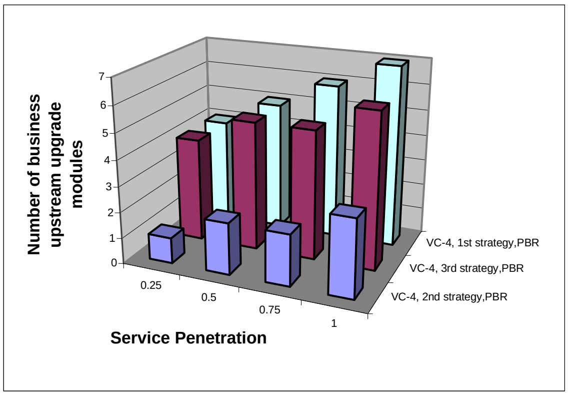


Figure 9. VC-4 containers in a mixed scenario with the 1st, 2nd and the 3rd strategies respectively (max ONUs).

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