ATM over ADSL: The "Best-Effort" PVC Provisioning for ATM Call Flow

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Abstract

Asymmetric digital subscriber line (ADSL) is the latest copper-wire access technology that has the capability to deliver data rate up to 8 Mbps in downstream and up to 640 kbps in upstream. The ADSL Forum has also defined the model for ADSL/ATM connections. ADSL can be connected to ATM core network through the access network called digital subscriber line access multiplexer (DSLAM). This paper is a compendium of research addressed on ATM over ADSL. Considering ATM over ADSL, a new method of "best-effort" specified bit-loading algorithm is developed via Hartley-Shannon capacity considerations. The specific research tasks performed refer to provisioning permanent virtual channels for ATM specific calls on the ADSL access lines. Feasibility of including switched virtual channel is also considered. Relevant call-blocking probabilities and bandwidth utilization are ascertained. Simulation results based on Poisson arrival of different classes (QoS specified) traffics, are obtained pertinent to the algorithms derived. The procedure allows a quick evaluation of blocking probabilities and the bandwidth utilizations involved. The relevant analytical pursuit is new and no comparable effort is addressed in the literature.

1 Introduction

A new option on the applications of asynchronous transfer mode (ATM) refers to provisioning of service offerings enabled by ATM into the home and small offices. Known as ATM-centric ADSL, relevant strategy essentially considers the palette of ATM services offered by a provider over a digital subscriber line (DSL).

As defined by the ADSL Forum, the architecture of ATM over ADSL consists of a cell-based ADSL transmission (as opposed to the option based on frames) whereby, all user traffics (other than the baseband POTS/ISDN) are streamed as ATM cells between customer premises equipment (CPE) and a device known as the ADSL access multiplexer (ADSLAM) situated at the service provider's ADSL point-of-presence (POP). (The CPE located at the user-end is referred to as an ADSL terminal unit/remote or ATU-R.)

An elaboration of Fig. 1 to include of ATM in the ADSL reference architecture is presented in Fig. 2. In Fig. 2a, the access node interface to packet, broadband, video or service networks are shown on the right hand side. Depending on the transport mode employed by the user, conversion to (and from) ATM may be performed as indicated by the lines at the bottom of Fig. 2a.

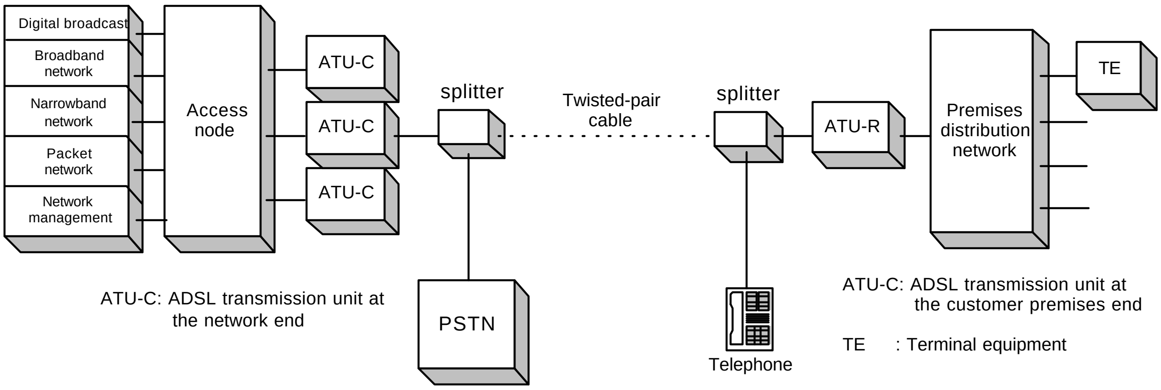


Fig. 1: A model of ADSL connection

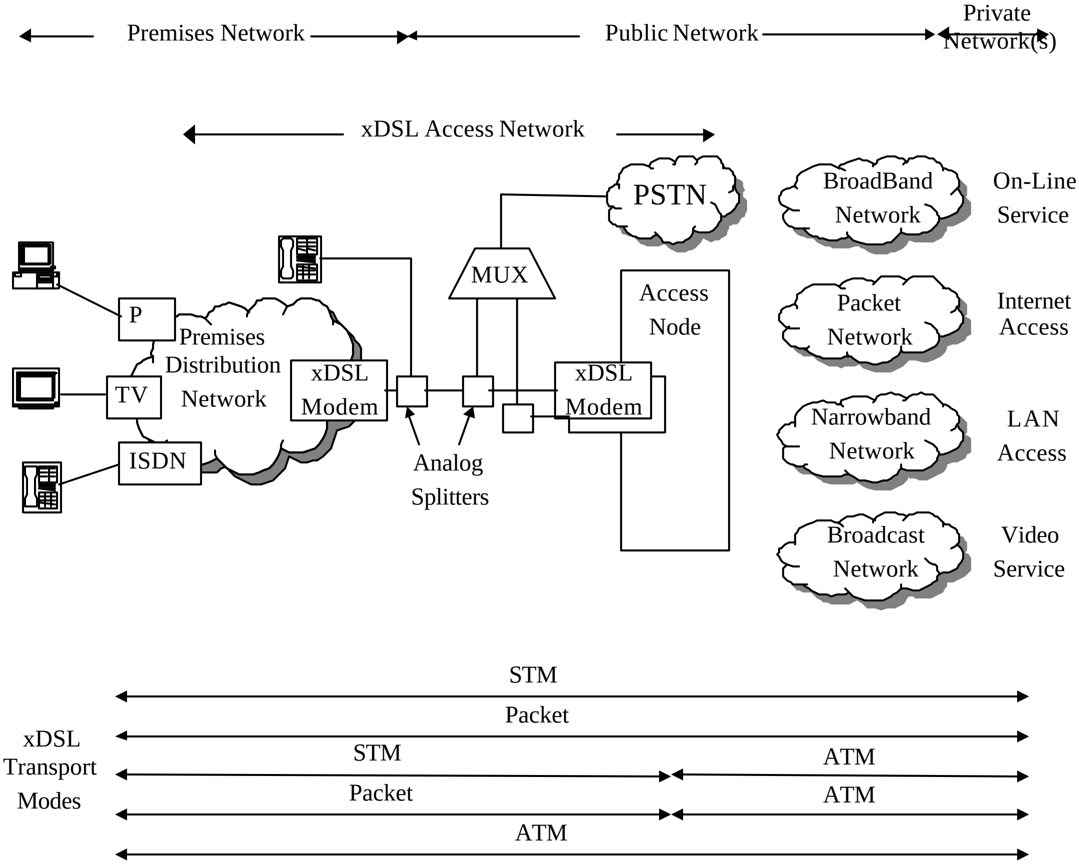


Fig. 2a: Digital subscriber line (xDSL) reference model

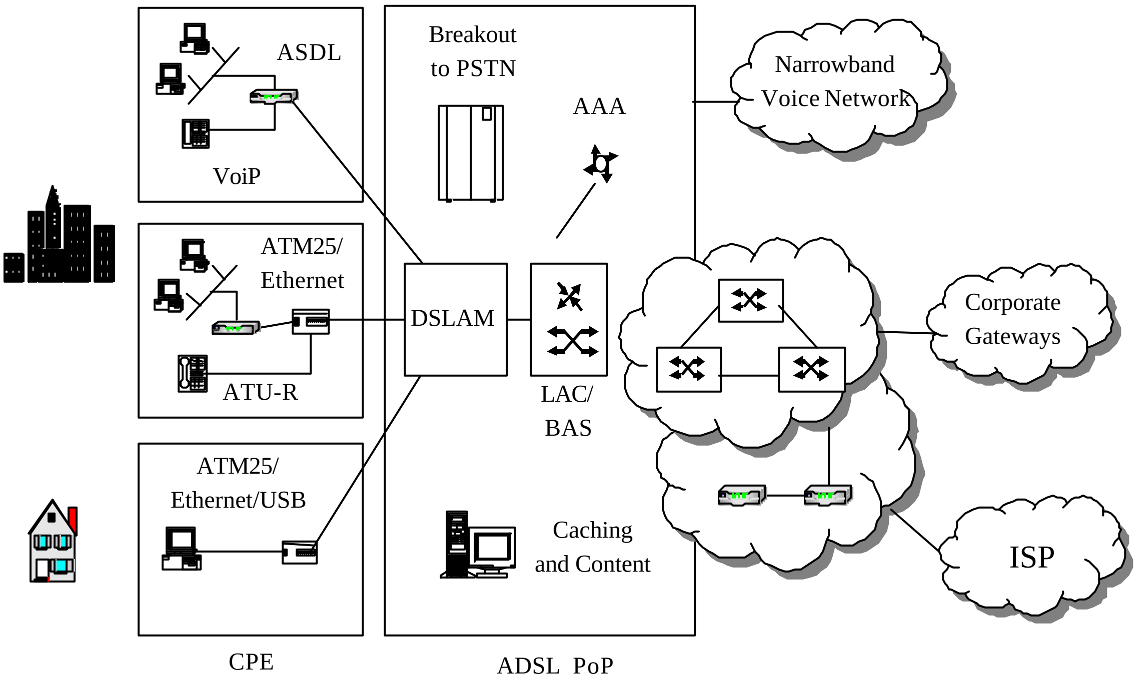


Fig. 2b: ADSL reference architecture

Referring to Fig. 2b, it can be seen that ADSL modems (within the ATM-based DSLAM) aggregate multiple ADSL local loops and forward the traffic access to one or more ATM upstream links. Use of ATM in this environment leads to advantages in terms of user security, QoS support for parallel sessions over single ADSL link by assigning multiple virtual channel connections (VCCs), possible voice support (via voice telephony over ATM, VTOA) and an ability to implement end-to-end Layer 2 virtual private networks (VPNs), where required.

In its simplest configuration, the ATU-R acts as a bridge between the ADSL loop and a local ATM25 (25 Mbps ATM on copper media) or Ethernet interface. This interface connects to a PC, a LAN hub or switch or a router. An alternative model may allow a PC equipped with an ADSL modem to connect directly to the local loop [1]-[8].

1.1 ATM-centric ADSL: Upstream and downstream connections

ADSL subscribers connect to the upstream services and gateways via a Permanent virtual channel (PVC) centric model, where the service provider preprovisions the required ATM connections. (In future deployment of user specified Switched virtual channels (SVCs) across ADSL is also contemplated).

In this upstream mode, the DSLAMs should be intelligently capable of interpreting the signaling messages between an upstream ATM switch and the DSLAM.

The present chapter is devoted to model the capability of ATM over ADSL architecture in providing QoS support guaranteed on the VCs commensurate with the sophistications of the DSLAM. The user VC can be terminated at the local point-of-presence (PoP) or at a distant gateway (as shown in Fig. 2b).

The modeling attempted here refers to a typical implementation scenario as follows: Suppose a service provider wishes a connectivity between third-party Internet service providers (ISPs) and users/customers as a part of a newly activated ADSL service. (The associated procedures, which the end-users must follow should be no different than those used in a preexisting dial-up service).

Illustrated in Fig. 3 is a model architecture of ATM over ADSL. The ADSL service provider is assumed to deploy necessary hardware and software to allow user connectivity to upstream ISPs. An end-user may connect to the ADSL provider via point-to-point protocol (PPP/ATM) across the ADSL local loop. At the provider's PoP, the user's domain (ISP) is authenticated (within the scope of authentication, authorization, and accounting (AAA) functions) and the user's PPP session is tunneled via L2TP to the user's native ISP. Here, the user undergoes full authentication and assigned an IP address belonging to the ISP.

For implementation as a traffic-engineerable data network, the ADSL infrastructure is currently available on wide-scale supported by a number of telecommunications service providers. This network contains a number of potential traffic-engineerable components. They are, DSLAM (digital subscriber line access module) I/O interface line card, DSLAM to ATM I/O multiplexer, ATM to DSLAM I/O multiplexer, ATM I/O card, ATM backplane throughput, ATM buffers, ATM PVCs, ATM to ISP (internet service provider) multiplexer.

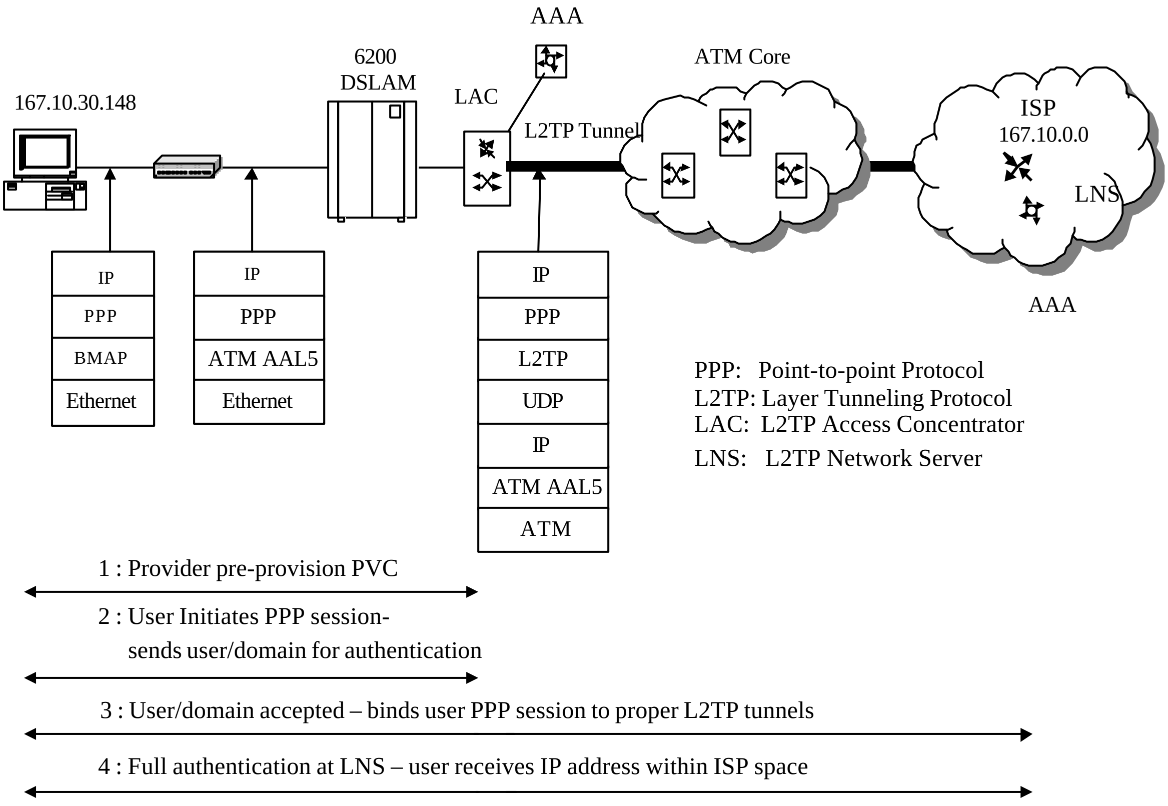


Fig. 3: The architecture of ATM over ADSL

1.2 Downstream from the DSLAM is connected to user PCs

As stated earlier the analysis pursued here refers to preprovisioning of PVC by the service provider from the user and the DSLAM (in Fig. 3).

The permanent VCs facilitated provides a specified QoS defined by the traffic parameters in an ATM layer traffic contract. The QoS parameters negotiated are:

- Bandwidth (BW)
- Cell-loss ratio (CLR)
- Cell-transfer delay (CTD)
- Cell-delay-variations (CDV).

The traffic mix consists of ADSL bytes encapsulated in ATM cells. There are a variable number of ABR AAL5 PVCs as well as AAL1 and AAL2 CBR and VBR PVCs associated with the ATM over ADSL support and the relevant traffic consists of various mixes constituted by:

- 1.5 Mbps downstream by 25 kbps upstream “best-effort delivery” data (ABR); here, the bit rate may not drop below an average of 256 kbps over an hour

- 384 kbps by 384 kbps CBR data on up- and downstreams

- 1.5 Mbps by 1.5 Mbps VBR video on up- and downstreams.

Suppose the traffic supported on the network corresponds to the so-called QoS class based on “best effort” service. Here, the user parameters are adapted on “best effort” considerations to the dynamics of network resources. The bit-rate refers to the available bit-rate. Additional CBR and/or VBR traffic may also be supported as indicated before [9], [10].

The connection-oriented service across the DSL is assumed to be established by network management or provision actions and left up indefinitely as PVCs. This PVC service connectivity is made by appropriate physical wiring, equipment configuration commands, service provider’s provisioning procedures or combinations of these actions. These actions are not time-constrained. They may take several minutes to several weeks depending on the requirements warranted.

The PVC in ATM context refers to the VPCs/VCCs provisioned in the ATM UNI call structure head via VPI/VCI fields.

The present study is aimed at establishing a provisioning procedure towards assigning PVCs for the information from the user-side flowing as the upstream at the ATU-R modem. The envisioned PVC assignment should correspond to a loading algorithm that matches the bit rates of the information from the CPE on a “best effort” basis to the DSL subchannels of the upstream part of the spectrum. These subchannels correspond to discrete set of multitone (DMT). The placement of bits (or bit-loading) at a given rate on to appropriate subchannels, in essence, is an orthogonal FDM (OFDM) or multicarrier modulation (MCM) process.

Now, what is the “best effort” strategy to be pursued for “loading” the subchannels in the upstream mode, by specifying appropriate PVCs? Relevant considerations are addressed in the following section.

2 The “Best-effort” Loading Algorithm to Allocate the PVC

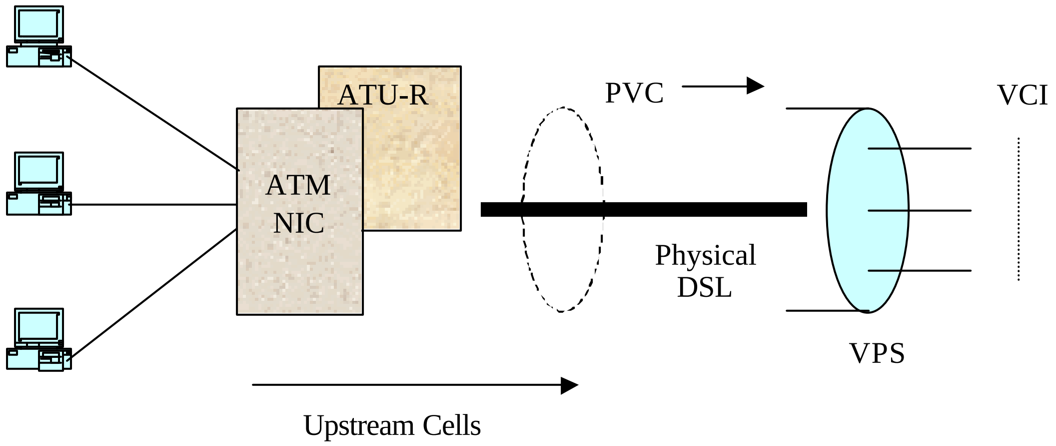


Fig. 4: The provisioning of PVC to the upstream cell flow

The ATU-R can be regarded as smart regulator that performs provisioning of PVC to the upstream cell flow. That is, it assigns VPI/VCI to the cells consistent with the rate class of the bits of a given cell; and, this assigned VPI/VCI should match the resource, namely, the subchannel capacity of the DSL.

This PVC allocation (based on appropriate subchannel loading) can be done on a probabilistic, best-effort QoS guarantee, say, the cell-loss probability not exceeding L, a small number. And, provisioning PVC is done on the basis of an observed statistics of the traffic over a period of time.

The PVC refers to a static route defined in advance. It is also possible to support the growing user population with PVCs. Suppose there are i = 1, 2, ..., I service types being supported and Type-i call is assumed to have a QoS metric, Q_i. The PVC call arrival process of Type-i can be assumed to follow the Poisson statistics with a rate λ_i. Further, all call arrival processes are independent of each other. The call duration of service Type-i, has hence, an exponential distribution with a parameter, μ_i. Again, all call duration are presumed to be independent of each other. Let $\{N_1, N_2, \ldots N_i\}$ be a set with the random variable N_i denoting the number of Type-i calls.

Let the call-types, {i} be of three categories denoting respectively, i=1, for the “best-effort delivery” ABR data (256 kbps on upstream), i = 2 for the 384 kbps CBR data (on upstream) and i = 3 for the 1.5 Mbps VBR data (on upstream).

The ABR service refers to the category of call in which the network delivers limited cell-loss, if the end-user responds to flow control feedback. Further, the ABR service is not concerned about cell-transfer delay (CTD) nor does it control the cell-delay variation (CDV). It is essentially specified for data bits (such as text file transfers), where the semantic attributes are more critical than any delay sensitive issues. It is intended to be supported on AAL#5 in the ATM adaptation. As mentioned earlier, the service-category of call-type-i = 1 refers to this ABR profile. In addition, the traffics to be supported on the ADSL upstream are the constant bit rate (CBR) call-type-2 and a variable bit rate (VBR) call-type-3.

In reference to this scenario, as above, the end-to-end protocol architecture consists of facilitating PVCs for the call-type-1 and SVCs for the call-types-2 and 3.

The PVC and SVC assignment attempted here is assumed to be performed by a smart allocation module. The required functional aspects of such a module are as follows.

- The allocator (at the user-end) receives bandwidth and/or QoS-specific requests for upstream VCs. These are permanent virtual circuits
- The allocator should perform capacity allocation for the VCs consistent with the DMT subchannels on the access line
- The SVCs are switched virtual circuits, which are established and disconnected dynamically via a signaling protocol
- Both PVCs and SVCs are multiplexed onto the single physical access line.

In order that the allocator to support optimal call acceptance for the SVC, the system can be assumed to operate under certain constraints on QoS-specified and bandwidth reservation policy.

The QoS-specified constraint is imposed by the ABR traffic for which a best-efforts connection is facilitated so that the cell-loss is minimal (without any CTD/CDV requirements). This connection, as stated earlier, is on a logical PVC.

The bandwidth reservation policy is concerned with the call-type-2 and 3. That is, the allocator upon receiving relevant BW requests (for call-type-2 or 3), it must seek out the contention and assign the VCs vis-à-vis the DMT spectrum subchannel, not already occupied by the PVC on static basis, Fig. 5 illustrates the relevant concept.

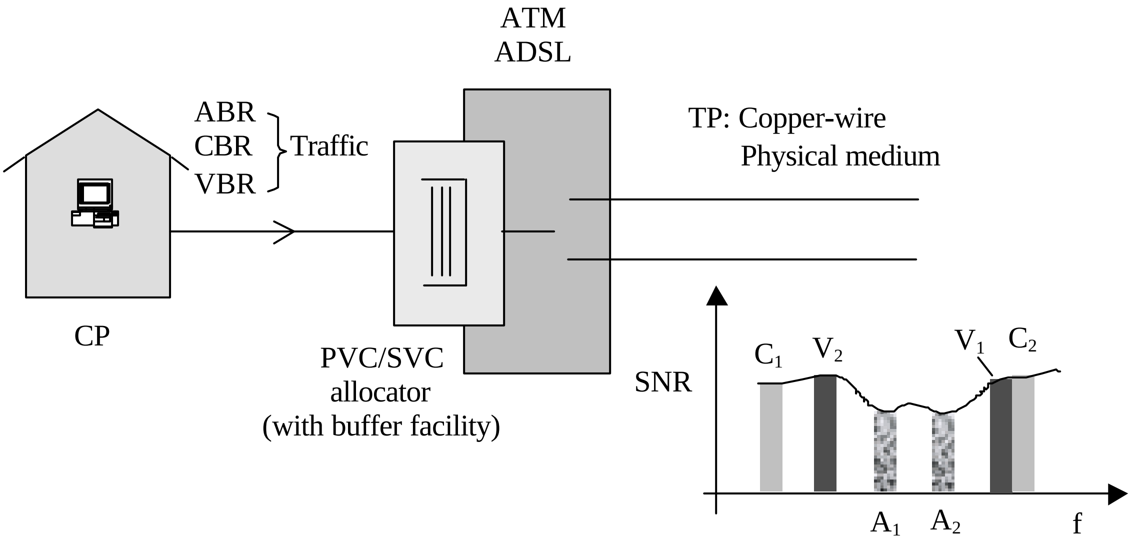


Fig. 5: PVC/SVC allocations.
(A$_1$, A$_2$ etc: Low SNR subchannel ⇒ PVCs for ABR traffic
C$_1$, C$_2$ etc: SVCs for CBR traffic
V$_1$, V$_2$ etc: SVs for VBR traffic.
The SVC allocations are based on bandwidth reservation policy)

3 Allocation Policy

Consistent with the details indicated above, the VC allocation policy can be summarized as follows:

- The ABR traffic is statically given PVCs and the subchannels are identified on the basis of “the best” available SNR conditions. The ABR traffic can be retained at a preallocator buffer until these PVCs are available. That is, ABR traffic “can wait” since CTD/CDV is of no concern; and, “the best” efforts PVC allocation facilitated (seeking the “the best” available SNR conditions) will satisfy the QoS constraint on the cell-loss (or BER) imposed.
- The second policy governs the BW reservation. For the other two traffics namely, call-type-2 (CBR) and call-type-3 (VBR), there are two possibilities of SVC allocation: First, the VBR traffic (call-type-3) can be considered as a higher priority transmission compared to call-type-1 in terms of CTD/CDV considerations. Therefore, the remaining subchannels (namely, those left over after the PVCs are statically assigned for the ABR (call-type-1) traffic) are shared between call-type-2 and call-type-3 contention basis.

The other possibility is that, a fair bandwidth allocation for call-type-2 and call-type-3 can be pursued at an intuitive level so that no differential treatment between these calls is advocated. That is, contention is presumed and SV connection is given on first-in first-out basis (FIFO) so as to share the available BW on the access line spectrums. For example, this fairness algorithm could be consistents with the ATM Forums max-min fairness. The relevant definition applies in an unambiguous way, if no ABR connections receive BW guarantees (because of a prevailing low SNR conditions on the line due to noisy ambient). (In general, the access to higher BW could lower, be constrained, if the next node imposes a limit on the BW. This condition calls for a maximum and minimum fairness criteria and applies to general ATM and not for ADSL-centric situations). In reference to the ADSL scenario under discussion, if contention between call-type-2 and call-type-3 is ignored, the BW allocation (and SVC designation thereof) follows a uniform fairness suite.

Presently, simulations are performed with relevant explicit algorithms depicting the PVC/SVC allocation policies indicated above in reference to the ADSL upstream conditions. The relevant efforts and results are furnished in the following section.

4 Simulations and Results

4.1 Algorithm to allocate PVCs

Suppose the ABR traffic (call-type 1) rate corresponds to $(\lambda_{1j})_k$ where the index, k specifies the kth duration over which the PVCs are kept static and j is the rate-class of the call and j = 1, 2, ..., J are random values as dictated by the source.

Let C_ℓ be the channel capacity of a subchannel with a bandwidth equal to BW_ℓ and a signal-to-noise ratio, SNR_ℓ. It is presumed that $(\lambda_{1j})_k$ matches C_ℓ in reference to its QoS_j objectives met by SNR_ℓ. Hence, by Hartley-Shannon’s law the following relation can be stipulated:

$$C_\ell = BW_\ell \log_2(1+SNR_\ell) \geqq (\lambda_{ij})_k \qquad (1)$$

If the above identity is satisfied the jth rate-class is assigned a permanent VC designated as PVC_j. Suppose, $\ell = 1, 2, \ldots, L$ with L > J. The matching condition stipulated above will select a maximum of J out of L subchannels to assign J static PVCs.

The remaining (L – J) subchannels are now available for SVC allocations.

Let the call-type 2 (CBR version) be a single-rate class specified by, $(\lambda_{2m})_k$ where m = 1. Likewise, the call-type 3 (VBR version) belongs a set of rate classes specified by $(\lambda_{3n})_k$ where n = 1, 2, ..., N with a burstiness limited to a maximum value of 1.5 Mbps.

Over the specified k traffic-flow durations, the subchannel allocation is specified by the following rules:

- Number of PVCs statically assigned is ${}^{J}C_L < L$
- The remaining (L - ${}^{J}C_L$) SVCs can be dynamically assigned for call-types 2 and 3 on FIFO basis, if there is no contention
- When there is a contention, call-type-3 gets the priority over call-type-2

Suppose the duration k is assumed as 10^6 cell units. The number of subchannel L = 32 where L is identically equal to the total of PVCs and SVCs. Assuming J < L as a random variable, and simulating a randomly varying profile of SNR on L-subchannels, the ${}^{J}C_L$ number of PVCs are identified with the corresponding subchnnels via Eqn. (1).

Next, the call-types 2 and 3 are simulated independently as Poisson arrivals and for each arrival segment, the high priority traffic (namely, call-type 3) of the rate-class λ_{3n} is accommodated on to a corresponding subchannel, if available (and not already occupied by the PVC-specified call-type 1 rate class traffic) and the rate-class λ_{3n} is given a SVC identification otherwise that call is blocked. Should there be a contention between λ_{3n} class-rate traffic considered above and a λ_{2m} class-rate CBR traffic for the same subchannel, the allocation criterion as indicated earlier would not let the λ_{2m} class-rate traffic (of low priority) be assigned a SVC. (That is, it will be blocked.)

When there is no contention, the traffics of rate classes λ_{3n} and λ_{2m} are assigned to their corresponding subchannels as ascertained via Hartley-Shannon's information theoretics.

The simulation process as above can be illustrated as shown in Fig. 6. Suppose k depicts the life-time of the PVCs. During a subinterval of this period, the ${}^{J}C_L$ < (L = 32) number of PVCs are first matched to the corresponding subchannels as shown.

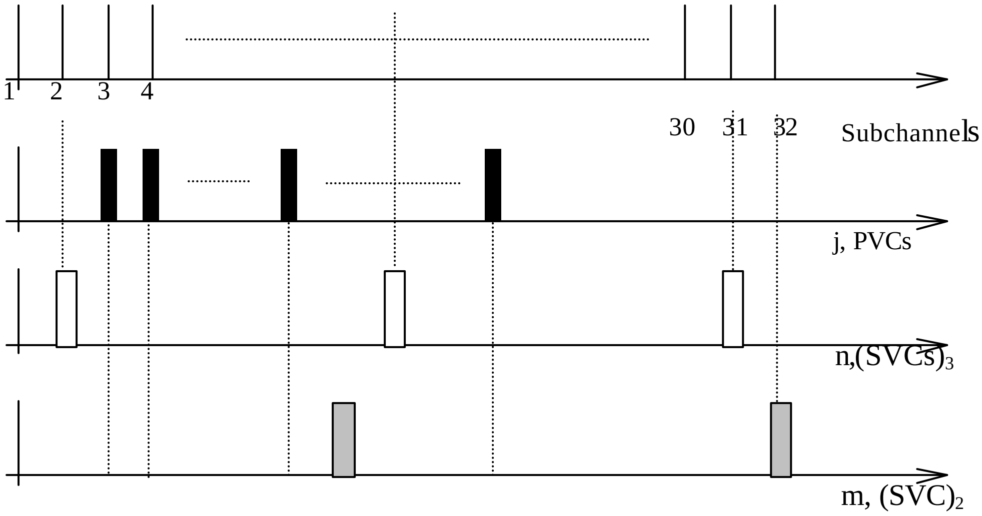


Fig. 6: Subchannel allocation for PVCs and SVCs

In each subinterval of the period k considered, the blocking probability of call-types 2 and 3 are determined. Heuristically, in each class, this (blocking) probability would refer to the number of channels (and hence SVCs) allocated and the number of rate-classes negotiated for the SVC allocation.

These blocking probabilities P_{B2} and P_{B3} [10] for the call-types 2 and 3 respectively can be plotted as function of PVCs facilitated (namely, j) as depicted in Fig. 7.

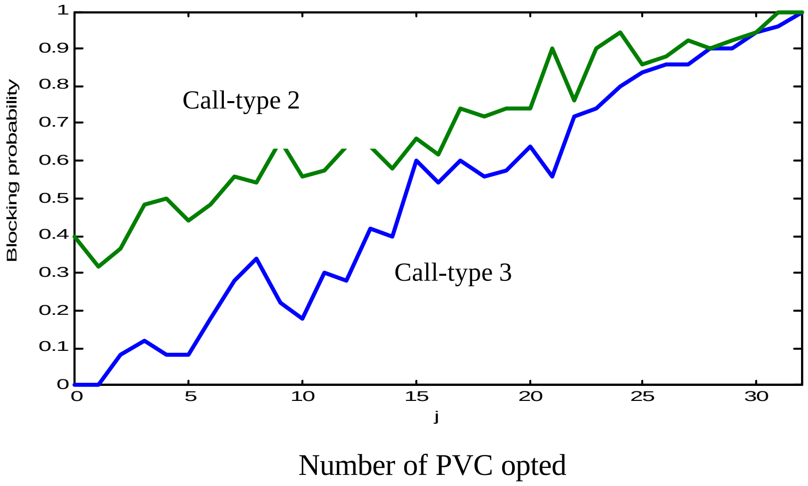


Fig. 7: Blocking probabilities of SVC-specified traffics versus PVCs assigned

The results shown in Fig. 8 correspond to ensemble average of data computed with the 10^6 arrival segments of time over the period k = 10^6 cell-units. In each computational segment of arrival presumed, the corresponding subchannel bandwidth utilization would correspond to: Number of subchannels (or SVCs) assigned X subchannel BW. Specifying these BW utilizations as BWU_2 and BWU_3 for call-types 2 and 3 respectively, their variations with respect to the number of PVCs facilitated can be computed and plotted as shown in Fig. 8. (Again, the results in Fig. 8 refer to ensemble average over 10^6 arrival segments of time.)

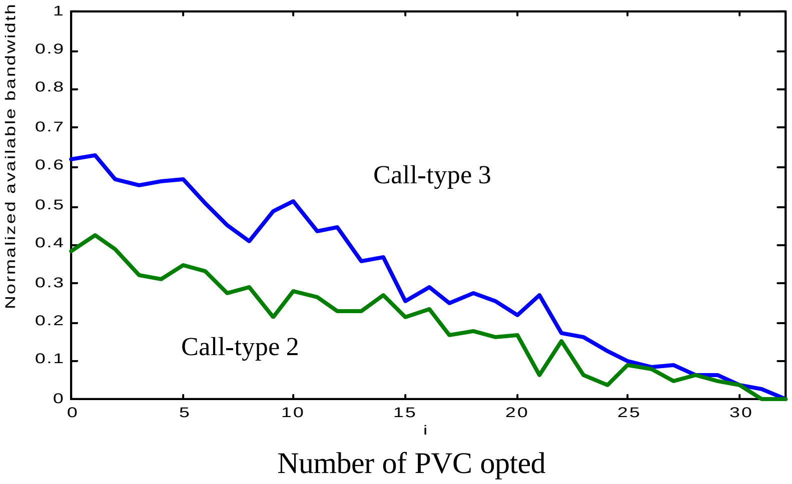
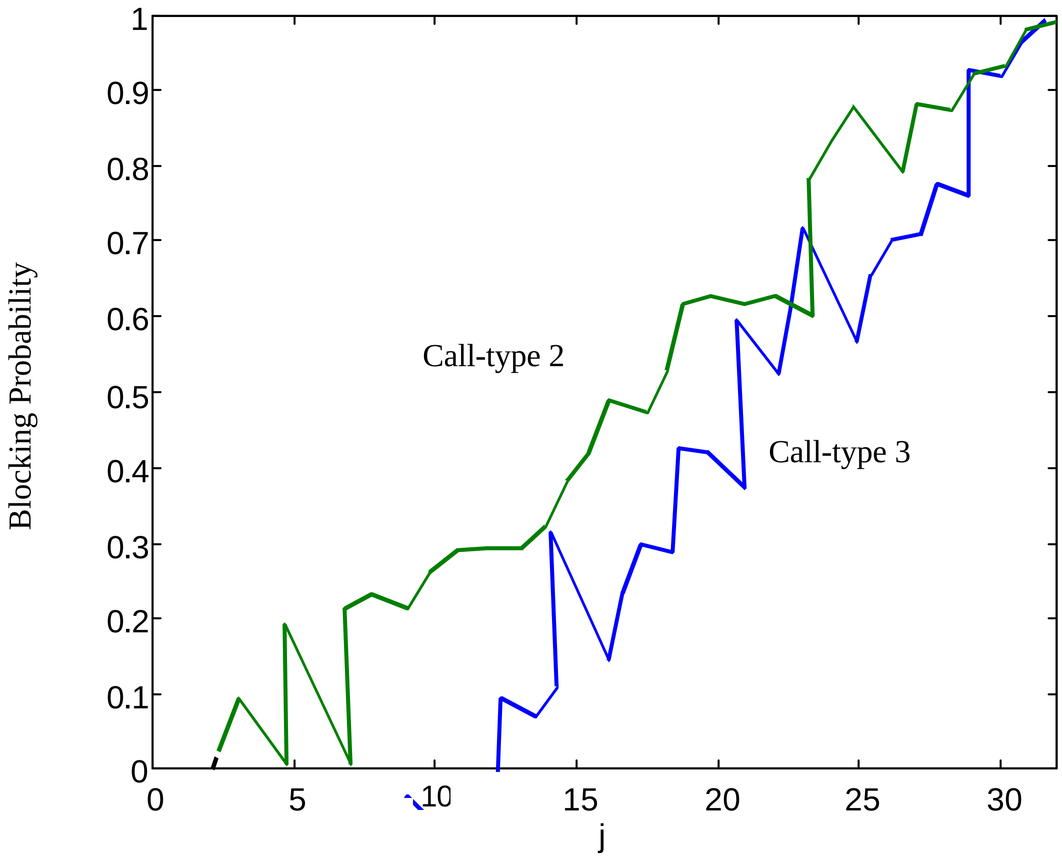


Fig. 8: Bandwidth utilization for call-types 2 and 3

The cell blocking probability can be eased, if the call-types 2 and 3 permit a certain extent of tolerance of SNR (or BER) from the stipulated value by Eqn. (1). That is, instead of totally blocking a cell in accessing the subchannel in the event of a contention as discussed earlier, the rate-class of traffic seeking SVC (and hence a subchannel allocation) can be assigned a nearest-neighbor of the unavailable subchannel. This could however, brute-force the SVC-seeking rate-class traffic into a physical subchannel segment, where the SNR could be poorer (than the compatible value as specified by Hartley-Shannon channel-matching algorithm discussed earlier and specified by Eqn. (1)).

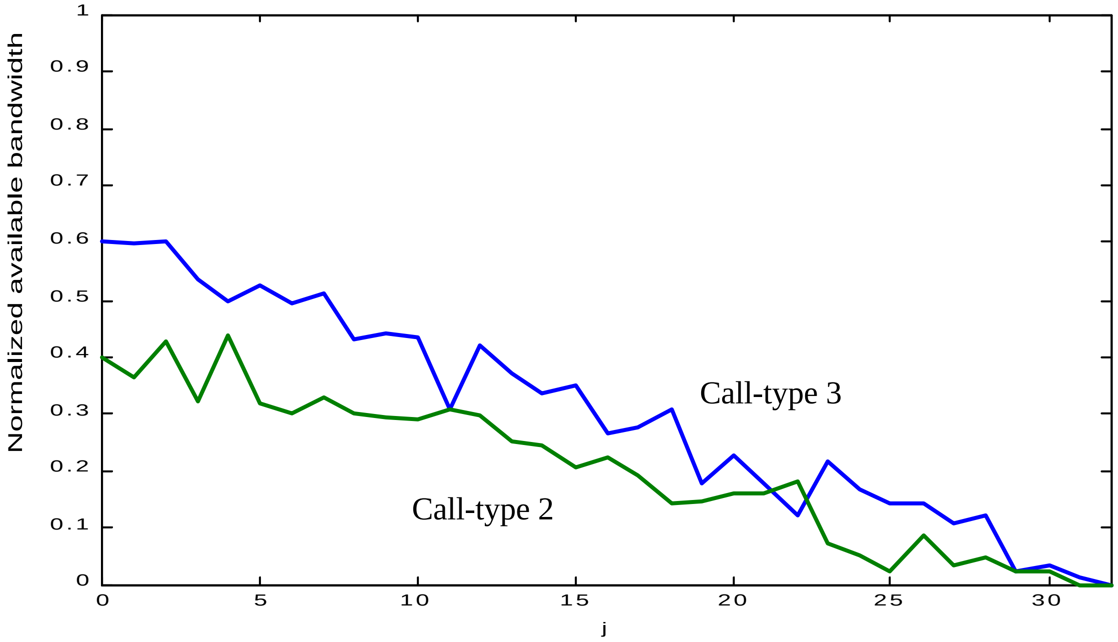
This poorer SNR could be tolerated for the CBR (call-type-1) and VBR (call-type-2) traffics under discussion, inasmuch as they represent more delay-sensitive traffics than semantic transparency constraint transmissions.

With the aforesaid procedure of assigning SVCs with the provisioning of subchannels of less SNR quality, simulated result on blocking probabilities and BW utilizations can be computed. The relevant results are presented in Fig. 9 and 10.



Number of PVC opted

Fig. 9: Blocking probabilities of SVC-specified traffics versus PVCs assigned



Number of PVC opted

Fig. 10: Bandwidth utilization for call-types 2 and 3

5. Concluding Remarks

Considering ATM over ADSL, a new method of "best-effort" specified bit-loading algorithm is developed via Hartley-Shannon capacity considerations. This algorithm allows a smart way of provisioning the permanent VCs and/or switched VCs on the ADSL access lines.

The blocking probabilities involved in implementing the proposed scheme are explicitly derived. Simulation results based on Poisson arrival of different classes (QoS specified) traffics, are obtained pertinent to the algorithms derived. The trend in increase of blocking probabilities and decrease of bandwidth utilization with increased deployment of PVCs is consistent with practical motions on the ATM-centric ADSL systems. The approach of PVC and or PVC plus SVC provisioning presented here is new and computationally inevitable for on-line applications.

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