Journal of Universal Computer Science, vol. 14, no. 5 (2008), 653-672
submitted: 1/11/07, accepted: 28/2/08, appeared: 1/3/08

Cost Model for Bitstream Access Services with QoS Parameters

Laura Rodríguez de Lope
(University of Cantabria, Santander, Spain
laura@tlmat.unican.es)

Klaus D. Hackbarth
(University of Cantabria, Santander, Spain
klaus@tlmat.unican.es)

Abstract: The European Regulator Group (ERG) defines Bitstream Access Service as a wholesale service offered by a broadband network operator with significant market power to an Internet Service Provider, and identifies it as a market subject to regulation. This paper develops a cost model for the Bitstream Access Service under xDSL technology, following the recommendations of the ERG, considering different user classes with differentiated QoS requirements. For this purpose, three traffic engineering methods are analysed: separate virtual tunnels, over-engineering and priority queuing techniques.

Keywords: Cost model, TELRIC, Quality of service, Bitstream access service, over-engineering, priority queuing
Categories: C.2.1

1 Introduction

The worldwide demand for broadband services and the implementation of the corresponding broadband network integration of all currently existing services implies new problems for Telecom Regulation; see [Hackbarth 07]. One of the emergent problems identified is the regulation of broadband access to these services considering xDSL technologies, named Bitstream Access Service (BAS), due to the fact that, in this market segment, the former incumbent operator might have a dominant position, known as significant market power operator (SMPO), against other Internet service providers (ISP).

In general, the European Regulatory Framework recommends National Regulatory Authorities to analyse a set of markets where the incumbent operator has a significant market power. The service under consideration, BAS, is considered in market 12 in the Commission's Recommendation on relevant markets; see [CE 03]. The European Regulator Group (ERG) provides statements and a reference model for the corresponding connection indicating different types of access points to this service; see [ERG 03].

This paper considers the problem of BAS and develops corresponding cost models considering a so-called Total Element Long Run Increment Cost (TELRIC) model. The models developed in this paper not only consider the bandwidth requirement of the BAS but also the statistical parameter of the packet stream resulting from the different services and quality of service (QoS) parameters, mainly a limitation of the average delay in a corresponding network element.

The paper is structured as follows; the second section explains different cost models and justifies the application of TELRIC for the BAS. The third section provides a model for the dimensioning of a network element required from the TELRIC model under the approximation of a Poisson arrival for the packet stream. Three types of traffic engineering methods for QoS provision are discussed. The dimensioning is applied to the first network element in the BAS connection, the DSLAM, under different QoS parameters and different types of Network Node Interfaces (NNI) for the corresponding user classes. Section 4 develops the TELRIC model for BAS and shows the influence of the traffic engineering method on the unit cost of a user in a corresponding user class. Section 5 proposes a model for extending the dimensioning models of chapter 3 to the case of a general packet arrival stream and discusses the consequence to the BAS TELRIC model. The last section provides some conclusions and indicates future work required to improve the dimensioning model and the corresponding TELRIC one.

2 Bitstream access service and cost models

The European Regulatory framework recommends the use of the long run incremental cost (LRIC) standard for controlling dominant operator interconnection rates, which should be cost oriented [CMT 00], [BNA 05]. There are basically two methodologies for LRIC cost standard development:

- TSLRIC, total service long run incremental cost: it considers each service as a cost increment factor.
- TELRIC, total element long run incremental cost: based on network elements.

As network elements are dimensioned according to the service using them, TELRIC allows the economies of scale achieved by different network elements to be distributed among services in relation to the intensity of use that each service makes of the element. Its application assures that the cost allocated to a service is related to the use that the service makes of the network with respect to the rest of services.

Nevertheless, the model can be designed under two different perspectives:

- Top-Down, based on financial accounting.
- Bottom-Up, based on traffic demand.

Top Down modelling, as it is based on the historical costs of a specific operator, implicitly assumes the efficiency of its network. However, the Bottom-Up approach, starting from the traffic demand, models the network of a hypothetic operator. This “efficient” operator should employ the best technology available and should not be influenced by previous decisions about network architecture.

Therefore, the Bottom-Up perspective represents an efficient cost structure, objective and based on available information. Using the traffic demands, it identifies the required network elements to provide the different services. Based on engineering and economic principles, each service is related to the network elements quantities required for producing it and the corresponding cost. Hence, for regulating purposes, the TELRIC model in combination with the Bottom-Up approach is mainly used [BNA 05], [Brinkmann 07], [Hackbarth 05].

The TELRIC cost model under the Bottom-Up approach requires knowledge of traffic at each network element. Since it is necessary for network dimensioning it must reflect the demand in the high load period. Furthermore, this traffic demand converted to annual traffic is necessary for cost distribution over the different services. Therefore, a detailed description of the traffic generated by the different services is required for dimensioning the network elements. The attributes for defining the traffic for each service are explained in section 3.

The network reference architecture for providing an end-to-end Bitstream access service (BAS) is composed of four network segments, as shown in figure 2.1:

- Subscriber – DSLAM: Network segment implemented in star form without traffic concentration.
- DSLAM - Concentrator: The DSLAM constitutes the first aggregation point of user traffic. It is connected to the concentration level by a star topology
- Concentrator - Switch: This segment can be implemented in star form or an access ring topology.
- Switch - Point of interconnection with the Internet service provider: The last segment can be implemented in star form or a ring topology.

Hence in bitstream access the user traffic is routed from the DSLAM over the different network segments up to the point of interconnection of the Internet service provider.

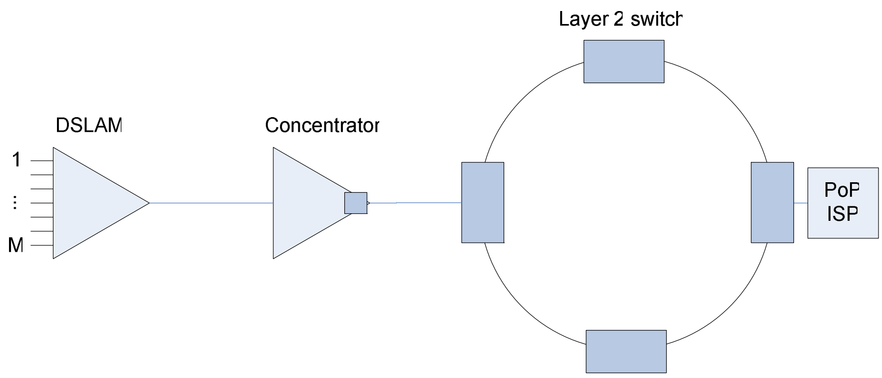

Figure 2.1: Reference Architecture

Most operators in Europe implemented the BAS reference architecture over their ATM broadband access networks and their ATM/IP backbones. Currently, access networks based on Carrier-Ethernet technology and backbone transport networks based on MPLS/IP are merging as part of next generation networks, but their penetration is still limited. Depending on the purpose of the cost study, the current architecture or the merging one should be considered. The TELRIC model developed in this paper is based on generic queuing models and so is valid for any network architecture fulfilling the requirement of “technological neutrality” for cost regulation studies.

3 Dimensioning by an approximation under Poisson arrival

As was indicated in section 2, the TELRIC model requires the calculation of the necessary capacities (e.g. the packet rate for switching or routing processors, or the bandwidth for transmission systems) by each network element of the long run target network structure. The packet stream generated by the different users and services to be transported by the network is described by two random variables, the packet rate and the packet length.

For calculating this packet stream we have to consider three layers:

- Connection layer, which describes whether a user connects to the Internet. The corresponding parameters are the connection calling rate and the duration of the connection.

- Service session layer, which describes the activity during a connection established by the user. Again two parameters describe the session layer: the session packet rate that a user generates during a service session and the length of the corresponding service protocol data unit (SPDU)

- Packet layer, which describes the packet stream generated from the SPDUs coming from the service level. The packet layer is described, similarly to the service session layer, by the resultant network packet rate and the corresponding packet length.

Note that for dimensioning purpose the packet stream must be estimated in a network element, where it is aggregated. As an example, the dimensioning and the cost model will be applied to the basic network element of a Bitstream service, the DSLAM, with its network node interface (NNI) and the corresponding transmission link to the next network element, mainly an Ethernet or ATM concentrator. This network element has been selected because it is the first one that provides traffic aggregation for the upstream network packet stream from the connected users, and traffic dis-aggregation of the arriving downstream packet stream and its distribution to the different users connected. Therefore, it is the most critical element in terms of cost parameters and QoS requirements of the different types of services.

We consider that the SMPO, as an ISP, offers retail-service to different user classes and, in its dimensioning rules, we assume that each user class generates a network packet stream mainly due to its use of Internet services, Table 3.1 shows an example.

User class nº	**1**	**2**	**3**	**4**
Name of user class	Business Premium	Business Standard	Residential High speed	Residential standard
Dominant service	VPN/VLAN service	VoIP, transaction, FTP	P2P, VoIP, streaming	www, P2P

Table 3.1: Typical user classes and dominant services

Hence, for network dimensioning purpose the values of parameters for the connection and service layers must be estimated, while the values of the parameters for the packet layer are calculated from the parameters value of the two layers above, see [Parkinson 02], [Garcia 07]. Table 3.2 shows the variables that will be used in the model.

Variable	**Explanation**
k	user class
M_k	number of users
$\alpha_C^{(k)}$	connection calling rate per user in the high load hour (1/h)
$t_C^{(k)}$	average connection duration (min.)
$\alpha_S^{(k)}$	session packet rate per user during an activated connection (1/s)
$L_S^{(k)}$	average length of a SPDU (oct.)
$\sigma(L_S^{(k)})$	standard deviation of the SPDU (oct.)
$\tau_S^{(k)}$	required average delay for the SPDU in the network element (for QoS purposes)
$\lambda_{IP}^{(k)}$	network packet rate resulting from all users of class k aggregated at a network element
$\bar{L}_{IP}^{(k)}$	average length of a network PDU (including overhead, in case of IP 10 octets)
$C(L_{IP}^{(k)})$	coefficient of variation for the network PDU length

Table 3.2: Description of the variables of the model

Under the assumption that the standard deviation of the packet layer PDU is the same as the one of the service layer PDU results for the packet layer:

$$\lambda_{IP}^{(k)} = \frac{M_k \cdot a_c^{(k)} \cdot \bar{L}_S^{(k)}}{\bar{L}_{IP}^{(k)} - 10} \quad \text{with} \quad a_c^{(k)} = \alpha_c^{(k)} \cdot \frac{t_c^{(k)}}{60} \tag{3.1}$$

$$\tau_{IP}^{(k)} = \tau_s^{(k)} \cdot \frac{L_{IP}^{(k)} - 10}{L_S^{(k)}} \tag{3.2}$$

$$C(L_{IP}^{(k)}) = C(L_S^{(k)}) \quad \text{with} \quad C(L_S^{(k)}) = \frac{\sigma(L_S^{(k)})}{\bar{L}_S^{(k)}} \tag{3.3}$$

General Data	
M	750
BW (neto) [Mbps]	50

Connection Layer				
User class nº	**1**	**2**	**3**	**4**
r_M	0.01	0.09	0.2	0.7
α_c [1/BH]	1	0.75	0.5	0.25
t_c [min]	60	60	60	30

Session Layer				
User class nº	**1**	**2**	**3**	**4**
α_s [p/s]	300	200	50	5
L_s [octs]	490	250	900	10000
$\sigma(L_s)$ [oct.]	980	6.25	900	20000
τ_s [ms]	25	5	25	250
Resulting mean BW/user [kbps]	1176	300	180	50
Resulting total mean BW [Mbps]	8.82	20.25	27	26.25

Network Layer				
User class nº	**1**	**2**	**3**	**4**
λ_{IP} [p/s]	2250	10125	7500	2296.87
Nº packets / service PDU	1	1	2	7
L_{IP} [oct]	500	260	460	1438
$C(L_{IP})$	2	2.5	1	2

Table 3.3: Example with traffic parameters and the resulting IP traffic stream

Given the user traffic parameters for each user class, for both the connection and session service layer as shown in Table 3.3, and under the application of relationships (3.1) to (3.3) the traffic values for the aggregated packet stream network traffic corresponding to each user class can be determined. Note that these parameter values $\lambda_{IP}^{(k)}$, $L_{IP}^{(k)}$, $C(L_{IP}^{(k)})$, $\tau_{IP}^{(k)}$ for k=1…K provide the basic input data for the dimensioning of the network elements used from the corresponding Bitstream Service[1]. Table 3.3 shows an example which will be used later for the application of the model to the dimensioning and cost calculation of a DSLAM based on the TELRIC model.

3.1 Models for dimensioning of the network layer

An operator which offers connections for different user classes, with the corresponding services under QoS requirements, can select among three main methods of traffic engineering, see [McDysan 00]. These are: traffic separation and routing over virtual tunnels (IntServ), traffic Integration and routing over common capacities (Over-engineering) and common capacity use but under separated queues with a corresponding priority scheme (DiffServ). Figure 3.1 shows the principles of these methods.

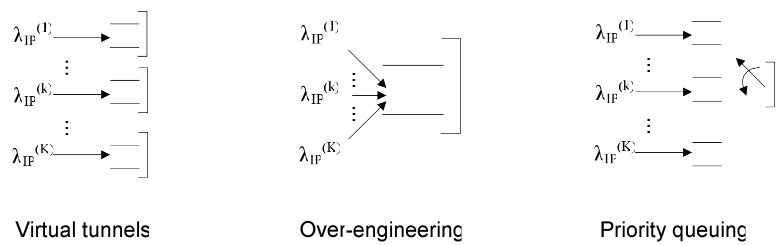

Figure 3.1: Schematic presentation of the different traffic engineering methods

Depending on the selected methods the packet stream resulting from each user class is routed over:

- Separate queues and virtually separated server capacities of the common server, also named *virtual tunnels* provided by corresponding capacity reservation (IntServ).

- A common queue and common server, named over-engineering because the capacity of the server must be dimensioned under the most restrictive QoS parameter values.

- Separate queues but common server, used under a policy of taking the packets from the queues by a priority scheme (DiffServ).

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[1] Note that this calculation must be provided for both upstream and downstream packet streams. Due to the symmetry in the bandwidth of the transmission systems and the network node interface cards (NNIC) of the different network elements, the maximum value of the two must be taken for dimensioning purpose.

Each of these methods has its advantages and disadvantages according to different criteria, which are summarised in Table 3.4. This paper mainly studies their influence on the results of the TELRIC model.

Characteristic	**IntServ**	**DiffServ**	**Over-Engineering**
Complexity of traffic Engineering	High	Middle	Low
Coordination in inter carrier connections	High	Middle	Low
Influence of the QoS parameters on the other services due to traffic increment in one service	None	Limited (upstairs) High (downstairs)	High
Scalability	Poor	Middle	High
Use of common capacity	Middle	High	Low
Fair service costing complexity	Low	High	Middle

Table 3.4: Characteristics of the different traffic engineering methods

3.1.1 Dimensioning under separate virtual tunnels

In this case the capacity of the server or the bandwidth of the transmission system is virtually divided and the packets resulting from each user class are stored in separate queues. Under the assumption of a Poisson arrival stream and the description of the packet length by the average value and the coefficient of variation, the mean queuing system occupation $n_s^{(k)}$ is calculated by the “Pollaczek Khintchine” equation, and the average delay $\tau_s^{(k)}$for a packet passing the system is calculated by the Little equation, see [Akimaru 99], resulting:

$$n_S^{(k)} = \rho_{IP}^{(k)} \cdot \left[1 - \frac{\rho_{IP}^{(k)}}{2} \cdot \left[1 - C^2(T_S^{(k)}) \right] \right] \qquad (3.4)$$

$$\text{with} \quad C(T_S^{(k)}) = C(L_{IP}^{(k)}) \;;\; \rho_{IP}^{(k)} = \lambda_{IP}^{(k)} \cdot t_S^{(k)} \quad \text{and } t_S^{(k)} = \frac{L_{IP}^{(k)} \cdot 8}{V_S^{(k)}}$$

$$\tau_S^{(k)} = \frac{n_S^{(k)}}{\lambda_{IP}^{(k)}} \qquad (3.5)$$

In the case of the dimensioning of a network element, the tunnel capacity $V_s^{(k)}$ is calculated by $\lambda_{IP}^{(k)}$, $L_{IP}^{\ (k)}$, $C(L_{IP}^{\ (k)})$ and $\tau_{IP}^{\ (k)}$. From equation (3.4) and (3.5) we obtain:

$$V_S^{(k)} = 4L \cdot \frac{\tau_S^{(k)} \cdot \lambda_{IP}^{(k)} + 1 \pm \sqrt{(\tau_{IP}^{(k)} \cdot \lambda_{IP}^{(k)} + 1)^2 - 2\tau_{IP}^{(k)} \cdot \lambda_{IP}^{(k)} \cdot (1 - C^2(T_S^{(k)})}}{\tau_{IP}^{(k)}} \qquad (3.6)$$

and hence the total required bandwidth results by:

$$V_S = \sum_{k=0}^{K} V_S^{(k)} \tag{3.7}$$

3.1.2 Over-engineering

Over-engineering is the simplest traffic engineering method and it was and is still currently widely applied for routing traffic in Internet Services, mainly when no special QoS parameters are required (best effort service). Applying this method to traffic engineering under average delay restrictions for different user classes implies that the dimensioning of the corresponding capacity must be provided under the most restrictive delay. For this purpose the packet streams produced by the different user classes are added in a common one. The statistical parameters for the resulting packet stream are calculated from the following equations:

$$\lambda_0 = \sum_{k=1}^{K} \lambda_{IP}^{(k)} \tag{3.8}$$

$$\bar{L}_0 = \sum_{k=1}^{K} \frac{\bar{L}_{IP}^{(k)} \cdot \lambda_{IP}^{(k)}}{\lambda_0} \tag{3.9}$$

$$C_0(L_0) = \frac{\sigma^2(L_0)}{\bar{L}_0} \quad \text{with} \quad \sigma^2(L_0) = \sum_{k=1}^{K} \frac{\sigma^2(L_{IP}^{(k)}) \cdot \lambda_{IP}^{(k)}}{\lambda_0} \tag{3.10}$$

$$n_0 = \frac{\rho_0}{1-\rho_0} \cdot \left[1 - \frac{\rho_0}{2} \cdot \left[1 - C_0^{\,2}(T_S)\right]\right] \quad \text{with } C(T_S) = C(L_0) \text{ and } \rho_0 = \lambda_0 \cdot \frac{\bar{L}_0 \cdot 8}{V_0}$$

$$\tau_0 = \frac{n_0}{\lambda_0} \tag{3.11}$$

Similarly to the case of virtual tunnels, the required bandwidth is calculated from:

$$V_0 = 4L \cdot \frac{\tau_0 \cdot \lambda_0 + 1 \pm \sqrt{(\tau_0 \cdot \lambda_0 + 1)^2 - 2\tau_0 \cdot \lambda_0 \cdot (1 - C^2(T_S)}}{\tau_0} \tag{3.12}$$

$$\text{with } \tau_0 = \min_k(\tau_{IP}^{(k)})$$

3.1.3 Common use of the bandwidth under DiffServ

In this case the packets produced by the different user classes are stored in different queues and the packets are served in a priority order where, in practice, the highest priority corresponds to the packets of the user with the most restrictive delay requirement, and the lowest one to the user with the least restrictive delay requirement[2]. Applying a non-pre-empty model, the following equation gives the average waiting time in each queue:

$$t_w^{(k)} = \frac{\sum_{k=1}^{K} \lambda_{IP}^{(k)} \cdot \left[V(T_{IP}^{(k)}) + (t_{IP}^{(k)})^2 \right]}{2 \cdot \left(1 - \sum_{i=1}^{K-1} \rho_{IP}^{(i)}\right) \cdot \left(1 - \sum_{i=1}^{K} \rho_{IP}^{(i)}\right)} \quad \text{with} \qquad (3.13)$$

$$V(T_{IP}^{(k)}) = C^2(T_{IP}^{(k)}) \cdot (t_{IP}^{(k)})^2 \quad ; \quad t_{IP}^{(k)} = \frac{\bar{L}_{IP}^{(k)} \cdot 8}{V_p} \quad ;$$

$$V(T_{IP}^{(k)}) = \frac{C^2(L_{IP}^{(k)}) \cdot (\bar{L}_{IP}^{(k)})^2 \cdot 64}{V_d^{\,2}}$$

The average delay is defined by:

$$\tau_{IP}^{(k)} = t_S^{(k)} + t_w^{(k)} \qquad (3.14)$$

Note that from (3.13) and (3.14) a closed formula cannot be deduced for calculating V_p under the given parameter values shown in Table 3.3, and hence an iterative procedure must be implemented to calculate the minimum bandwidth required for fulfilling the delay limits for all user classes.

3.2 Application to the dimensioning of the DSLAM

Applying the concepts to the dimensioning of a DSLAM we can solve two types of problems:

- calculating the minimal bandwidth of the DSLAM NNI when the number of users for each user class is given or

- calculating the maximum number of users that can be connected to a DSLAM under a given bandwidth V_T for the DSLAM NNI and the relative distribution of the users over the different user classes.

The first problem is solved easily for the case of virtual tunnels and over-engineering, applying formulas (3.6) and (3.7) for calculating the bandwidth in case of virtual tunnels, and formula (3.12) in case of over-engineering. Calculating the bandwidth in the case of priority queuing requires, as was previously indicated, solving the corresponding optimisation problem which minimises V_p under the condition that the resulting delay given by (3.14) is less than or equal to the required delay for each user class.

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[2] In general this might not always be the case; e.g. a user class with a less restrictive delay requirement but produced by services with a high variance in the packet length distribution and hence a value of C(Lk) >> 1 might be given a higher priority than a user class with a more restrictive delay requirement but a very small Variance giving C(Lk) <<1.

In the second problem, the bandwidth of the NNI and the relative distribution of the users over the different user classes are known, and the maximum number of users connected to a DSLAM is calculated under the condition, once again, that the required delay for each user class is fulfilled. Hence, a maximisation problem is produced by each traffic engineering method mentioned in section 3.1 considering the formulas (3.1) – (3.3) for calculating the parameter values of the IP traffic stream and the corresponding formulas for the traffic engineering model applied.

Hence the optimisation of the DSLAM (maximising the number of users to be connected and therefore minimizing the number of DSLAM to be installed) requires an iterative algorithm for each of the three traffic engineering models, which calculates the required bandwidth for a given total number of users and its distribution over the corresponding user classes.

For the values of the example shown in Table 3.2 considering a total bandwidth in Mbps[3] for the DSLAM NNI connection to the access concentrator, the results of the corresponding calculation are shown in Table 3.5 considering different types of NNIs.

Type of NNI	**Ethernet**	**SDH VC31**	**SONET VC32**	**Fast Ethernet**	**SDH/SONET STM-1**
BW neto	9	30.6	45	90	134
M svt	44	226	353	750	1142
M oe	48	233	360	760	1153
M pq	77	271	398	800	1193
max τ pq	27.6	30.7	26.7	32.52	28.79
min τ pq	0.6	0.17	0.12	0.06	0.04
ρ svt	0.548	0.828	0.877	0.934	0.955
ρ oe	0.603	0.856	0.899	0.948	0.964
ρ pq	0.959	0.989	0.991	0.997	0.997

Table 3.5: Results of optimal DSLAM utilisation for the different traffic engineering methods (svt: separated virtual tunnels, oe: over-engineering, pq: priority queuing) under different types of NNI

We can observe from these results that occupancy (use degree, ρ) of the DSLAM and its NNI is maximised under priority queuing nearly independently of the bandwidth provided. However, for the other two methods of traffic engineering the occupancy has worse values for DSLAM in rural areas with a small number of users and hence a low bandwidth requirement for the DSLAM and the NNI, but it improves under increasing user and traffic concentrations. For a high-speed NNI such as STM-N the occupancy and hence the user degree is nearly similar. We will show in the next section that this leads to unit costs for DSLAM nearly independent of the applied traffic engineering method and even of the required QoS.

[3] Note that we consider that the operator provides dimensioning with a 10% increase in capacity overhead for unpredicted traffic giving a reduced bandwidth e.g 90 Mbps for a Fast Ethernet NNI.

4 Cost model

This section develops the TELRIC cost model based on the cost of one network element considering the three traffic engineering methods evaluated in chapter 3. For this purpose the following notation is used:

- C_T : total cost of the network element
- $C^{(k)}$: cost part for the users of user class k
- $Cu^{(k)}$: cost part for one user of user class k
- M_{max} : maximum total number of users whose corresponding traffic requires a bandwidth less than or equal to that provided by the network element
- rM_k : relative number of users in class k corresponding to M_{max}

4.1 Cost calculation for the case of traffic separation in virtual tunnels

The TELRIC cost model for the bandwidth dependent cost[4] in case of separate virtual tunnels is simple because the total bandwidth of the network element is clearly divided among the user classes and hence the cost per user class is then distributed in relation to the bandwidth requirement of each tunnel. For this purpose, we have to calculate the maximum number of total users $M^{(s)}_{max}$ fulfilling the condition that the sum of the bandwidth over the different tunnels is less than or equal to the total bandwidth of the network element, V_s, (see relation 3.4 - 3.7). Hence results:

$$rV_S^{(k)} = \frac{V_s^{(k)}}{\sum V_s^{(k)}} \tag{4.1}$$

$$C_S^{(k)} = C_T \cdot rV_S^{(k)} \tag{4.2}$$

$$Cu_S^{(k)} = \frac{C_S^{(k)}}{M^{(s)}_{max} \cdot rM^{(k)}} \tag{4.3}$$

4.2 Cost calculation for the case of over-engineering

In this case, the TELRIC cost model has to distribute the common bandwidth V_o over the different user classes. For this purpose, we have to calculate the maximum number of users $M^{(o)}_{max}$ fulfilling the condition that the common average delay is less than or equal to the minimum value of the delay required from the different user classes. We propose for this distribution the relative bandwidth obtained from (4.1) which occurs when $M^{(o)}_{max}$ is applied for dimensioning the separate virtual tunnels. Hence, the cost calculation under over-engineering is:

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[4] The TERLIC model has to consider that a DSLAM contains two cost drivers one which depends on the required bandwidth for a user and a fixed cost component for providing the connection with the Subscriber Access line, see [Hackbarth 07]

$$C_O^{(k)} = C_T \cdot rV_S^{(k)} \tag{4.4}$$

$$Cu_O^{(k)} = \frac{C_O^{(k)}}{M^{(O)}_{max} \cdot rM^{(k)}} \tag{4.5}$$

It might be interesting to study the cost when the operator uses only the average network traffic resulting for each user class and hence does not provide any cost differentiation from the required delay and the standard deviation of the packet length. This is calculated by the following relationships:

$$A_O^{(k)} = \lambda_{IP}^{(k)} \cdot \frac{L_{IP}^{(k)} \cdot 8}{Vo} \quad \text{with } \lambda_{IP}^{(k)} \text{ calculated from (3.1)} \tag{4.6}$$

$$\tilde{C}_O^{(k)} = C_T \cdot \frac{A_O^{(k)}}{\sum A_O^{(k)}} \tag{4.7}$$

$$\tilde{C}u_O^{(k)} = \frac{\tilde{C}_O^{(k)}}{M^{(O)}_{max} \cdot rM^{(k)}} \tag{4.8}$$

4.3 Cost calculation under priority queuing

As in the case of over-engineering, the TELRIC cost model has to distribute the common bandwidth V_p over the different user classes. Again the maximum number of users $M^{(p)}_{max}$ is calculated under the condition that the resulting delay for each user class is less than or equal to the corresponding delay requirement. We propose for this distribution the same scheme as the one applied in the case of over-engineering, giving:

$$C_p^{(k)} = C_T \cdot rV_S^{(k)} \quad \text{with } V_s^{(k)} \text{ calculated from (4.1) applying } M^{(p)}_{max} \tag{4.9}$$

$$Cu_p^{(k)} = \frac{C_p^{(k)}}{M^{(p)}_{max} \cdot rM^{(k)}} \tag{4.10}$$

For the case that neither the delay requirement nor the standard deviation of the packet length is considered in the cost model it is:

$$A_p^{(k)} = \lambda_{IP}^{(k)} \cdot \frac{L_{IP}^{(k)} \cdot 8}{V_p} \tag{4.11}$$

$$\tilde{C}_p^{(k)} = C_T \cdot \frac{A_p^{(k)}}{\sum A_p^{(k)}} \tag{4.12}$$

$$\tilde{C}u_p^{(k)} = \frac{\tilde{C}_p^{(k)}}{M^{(p)}_{max} \cdot rM^{(k)}} \qquad (4.13)$$

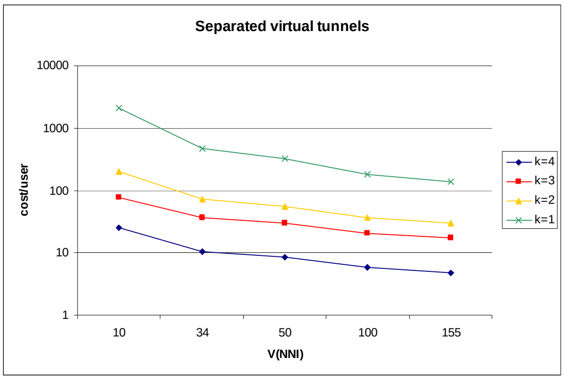
4.4 Application to the cost calculation for the DSLAM

In this section we consider the example for the DSLAM dimensioning shown in section 3.2 and calculate the cost figures resulting for one user under each user class and considering different NNIs. Note that in this example we consider only the bandwidth dependent cost of the DSLAM but not the fixed cost for each user, see [Hackbarth 07] for more details.

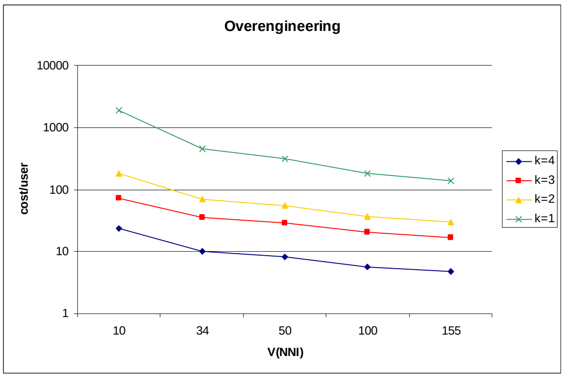
For this purpose, we assume for the traffic dependent cost part a cost function which was first formulated by [Ellis 75] and later on confirmed under real prices for corresponding cost studies.

$$C(V_{NNI}) = C_b \cdot \sqrt{V_{NNI}} \qquad (4.13)$$

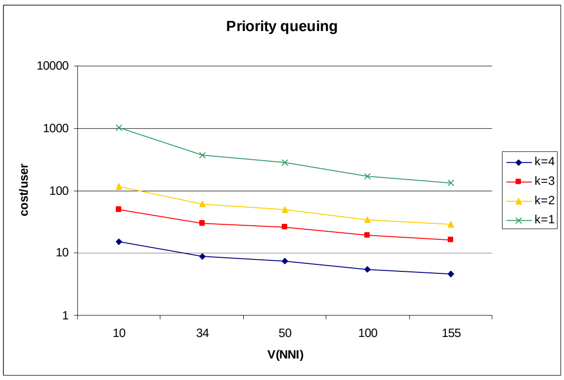
Under the assumption that the cost for a 1 Mbps bandwidth unit, c_b, is 1000 cost units, the cost development for the different type of user classes and traffic engineering methods is shown in figure 4.1.a - 4.1.c.



a) cost development in the case of separate tunnels



b) cost development in the case of over-engineering



c) cost development in the case of priority queuing

Figure 4.1: Development of the unit cost per user over the different user classes depending on the NNI bandwidth and different traffic engineering methods

The strong cost variation among the different types of user classes results from the strong differences in the required bandwidth for each user class; this relation between standard residential users (k=4) and the large business users (k=1) is nearly 1:20 (see Table 3.3), a result we find also in real application.

Anyway Fig 4.1 a) – c) demonstrates over all user classes a strong cost reduction under high-speed NNI interfaces caused by both the reduced unit cost resulting from (4.3) and the higher occupation of the bandwidth ρ, as shown in Table 3.4, resulting from the reduced service time which produces a reduced waiting time.

For studying the effect of QoS requirement and different statistical behavior of the packet streams among the user classes we calculate cost considering only the average traffic required from each user class but neither the QoS limitation nor different standard deviation in the SPDU length. For this purpose, we apply the relationship (4.7) - (4.8) for over-engineering and (4.11) – (4.12) for priority queuing.

We compare these values with the ones calculated under considering both QoS requirement and different statistical behavior shown in figure 4.1 a)-c).

From both, we calculate the cost quotient expressing the relative cost per user considering average traffic values in relation to the user cost, taking into account both QoS and the statistical behavior of the packets. The results show that the unit cost per user of user class 4 and 3 increases while the cost for the user classes 2 and 1 decreases, which is obviously because the bandwidth increase for stronger (lower) delay requirements is not considered. From this, it follows that a cost calculation without considering QoS aspects and the statistical behavior of the traffic might provide arbitration for the dominant operator in offering xDSL access to business clients. Anyway, as figure 4.2 shows, this effect is reduced under higher speed NNI interfaces. Hence, QoS differentiation is less important or even insignificant in core networks, partly due to the application of Terabit routers and corresponding NNIs at the level of OC48 (2.5 Gbps) or OC192 (10Gbps). This might happen even already in the Metro Network part due to the application of Gigabit Ethernet Metro Switches and corresponding NNIs of 1Gbps or 10 Gbps under NG-SDH, see [Kartalopoulos 04].

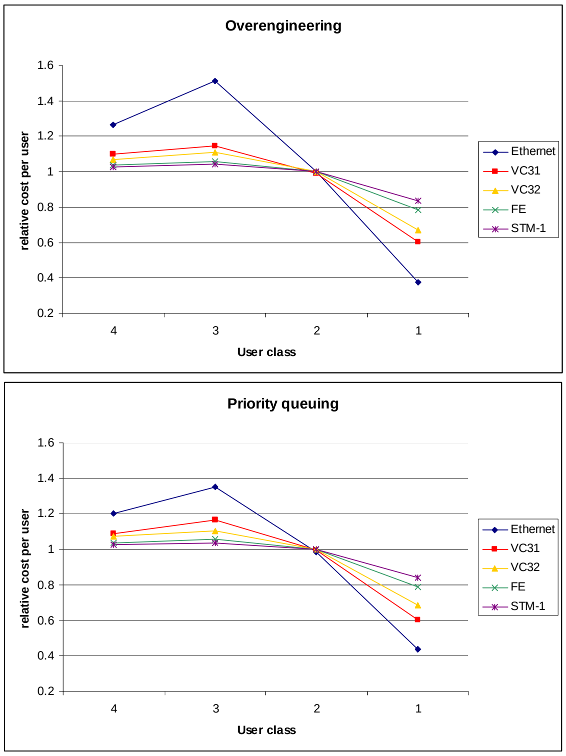


Figure 4.2: Cost development for the relative unit cost per user without considering QoS in relation to the cost under QoS consideration.

5 Extension to the case of burst arrivals

The cost model we proposed in chapter 4 is based on a Poisson approximation for the IP/Ethernet stream dealt with by the different network elements[5]. Additionally, we assumed that the coefficient of variation C_{IP} for the length of the IP/Ethernet unit L_{IP} is the same as the one for the service PDU L_s giving:

$$C_{L_S} = C_{L_{IP}} \tag{5.1}$$

Neither of these assumptions are true in fact because each service protocol data unit might produce a burst arrival of IP packets with shorter IP packets. In the case of a service PDU from FTP service, the length of the IP/Ethernet PDU will be not longer than 1500 octets and often the IP PDUs arriving from the Core Net are not longer than 500 octets. Hence the stochastical behaviour of the packet arrival and packet length will change between the service/application and the IP layers. Future work by simulation will check to what extent the approximation used in chapter 3 provides meaningful results for dimensioning from a practical point of view.

The simulation results will also be contrasted by an improved analytical approximation based on a Gi/Gi/1 model which might provide better results than the M/Gi/1 approach. The fundamental basis for the Gi/Gi/1 is an approximation formula proposed by Kingman, see [Gelenbe 98] which gives the mean system occupancy, E(N), as:

$$E(N) \approx \rho \left[1 + \rho \cdot \frac{{C_{Ta}}^2 + {C_{Ts}}^2}{2 \cdot (1-\rho)} \right] \tag{5.2}$$

Hence a corresponding model for the dimensioning must consider the same four parameters as in the case of the Poisson approximation applied in chapter 3 plus the variance of the IP/Ethernet packet inter-arrival time $Ta^{(k)}$. For each user class k the following five parameters: ${\lambda_{IP}}^{(k)}$, ${L_{IP}}^{(k)}$, $V({L_{IP}}^{(k)})$, $V({T_a}^{(k)})$, τ_k are given. Using the following relationships, the parameters required in the Kingman Formula of (5.2) are obtained:

$$C({L_{IP}}^{(k)}) = \frac{V({L_{IP}}^{(k)})}{E({L_{IP}}^{(k)})} = C({T_S}^{(k)})\,;$$

$$C({T_a}^{(k)}) = \frac{V({T_a}^{(k)})}{E({T_a}^{(k)})}\,;$$

$$E({T_a}^{(k)}) = \frac{1}{\lambda}\,;$$

$$\rho = \lambda \cdot E({T_S}^{(k)})\,;$$

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[5] We assume that the stochastic behavior between the third OSI layer IP and the second OSI layer Ethernet does not change, but the additional overhead of the second layer must be considered in determining the average length of the IP/Ethernet packet.

$$E(T_S^{(k)}) = \frac{E(L_{IP}^{(k)})\cdot 8}{V_S^{(k)}};$$

Under the Little formula the following expression is obtained:

$$\tau_{IP}^{(k)} = \frac{E(L_{IP}^{(k)}\cdot 8)}{V_S^{(k)}}\cdot\left[1+\frac{\frac{\lambda_{IP}^{(k)}\cdot E(L_{IP}^{(k)})\cdot 8}{V_S^{(k)}}\cdot\left(C(T_a^{(k)})+C(T_S^{(k)})\right)}{2\cdot\left(1-\frac{\lambda_{IP}^{(k)}\cdot E(L_{IP}^{(k)})\cdot 8}{V_S^{(k)}}\right)}\right] \quad (5.3)$$

This formula can then be formulated against $V_s^{(k)}$ as shown in chapter 3 for the M/Gi/1 case giving:

$$V_S^{(k)} = 4\cdot\frac{E(L_{IP}^{(k)})}{\tau_{IP}^{(k)}}\cdot\left(1+\tau_{IP}^{(k)}\cdot\lambda_{IP}^{(k)}\pm\sqrt{(1+\tau_{IP}^{(k)}\cdot\lambda_{IP}^{(k)})^2+2\tau_{IP}^{(k)}\cdot(C_{Ta}+C_{Ts}-2)}\right) \quad (5.4)$$

The relation expressed in (5.4) allows the application of the dimensioning for the over-engineering case and the dimensioning of separate tunnels, and hence the same cost model as applied before. With reference to the dimensioning under a non pre-empty queuing model we have to consider that the corresponding formula (3.12) is only valid for Poisson arrival streams and hence is strongly related to the M/Gi/1 approach. For applying the Gi/Gi/1 approach for the priority model, we propose transforming for each service the corresponding non Poisson IP packet arrival stream expressed by $\lambda_{IP}^{(k)}$, $V(T_a^{(k)})$ into an equivalent Poisson arrival stream expressed only by $\lambda e_{IP}^{(k)}$ considering the bandwidth $V_s(k)$ calculated by relationship (5.4) which gives:

$$\tau_{IP}^{(k)} = \frac{E(L_{IP}^{(k)}\cdot 8)}{V_S^{(k)}}\cdot\left[1+\frac{\lambda e_{IP}^{(k)}\cdot E(L_{IP}^{(k)})\cdot\left(1+C(T_S^{(k)})\right)}{2\cdot\left(1-\frac{\lambda e_{IP}^{(k)}\cdot E(L_{IP}^{(k)})\cdot 8}{V_S^{(k)}}\right)}\right] \quad (5.5)$$

The only unknown variable is $\lambda e_{IP}^{(k)}$ and so, expression (5.5) can be reformulated as:

$$\lambda e_{IP}^{(k)} = \frac{2\cdot(1-\tau_{IP}^{(k)}\cdot V_S^{(k)})}{E(L_{IP}^{(k)})\cdot\left(\frac{16}{V_S^{(k)}}+1+C(T_S^{(k)}-16\cdot\tau_{IP}^{(k)}\right)} \quad (5.6.)$$

Applying the values $\lambda e_{IP}^{(k)}$ for k=1…K to the non-pre-empty priority queuing model expressed in formula (3.13 -3.14) gives an approximation for the required bandwidth under priority queuing. Concerning the cost model, no change or extension is required.

6 Conclusions and future work

This paper develops a cost model for Bitstream Access under xDSL technology considering different user classes and traffic engineering methods. The work is stimulated from the open questions formulated by the European Regulator Groups which consider the wholesale BAS provided by a dominant network operator with a full national xDSL infrastructure to an Internet Service Provider with a reduced one as emergent. As a first result from the models and examples studied, we conclude that cost models for BAS should consider both the different statistic behaviour of the traffic parameter resulting from the different types of services and the QoS parameters, mainly a maximum value of the average delay required in a network element. This must be applied for retail services for individual costumers as also for wholesale services offered from a dominant operator to a smaller Internet Service Provider. In the contrary, the dominant operator can get an arbitrage which allows him to offer BAS to business costumers subsided by the residential one.

The study shows that the influence of QoS parameters must be considered mainly in the network elements which aggregate small traffic values, namely the DSLAM which is the first network element in the Bitstream access chain. In the contrary, the TELRIC cost model for network elements with high traffic concentration, mainly in the core part, could use simplified models without considering QoS requirements due to the high bandwidth of the corresponding systems as Giga or Terabit Router and very high speed DWDM transmission systems, see [Hardy 02].

This study is currently limited to the approximation considering a Poisson packet arrival stream at the network layer, but preliminary ideas to extend the model to Non-Poisson arrival are already explained. The influence of this extension will be studied in future work under both simulation studies and analytical models. A comparison of the results from simulation studies should show the validity of the analytical model proposed in section 5 of this paper.

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