Evaluation of the PBC Scheme in Integrated Services Networks

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1.- Introduction

This paper evaluates the PBC scheme in Integrated Services Networks. This evaluation confirms previous experiments published in 2000 [9].

2. Integrated Services

Aiming at multimedia transmission through Internet, the Internet Engineering Task Force (IETF) set-up an Integrated Services (Intserv) Working Group [4] which has defined several protocols and types of service. To guarantee a requested QoS, *IntServ* is based on setting up a real-time channel for each individual flow that guarantees some given network resources. Implementing this channel relies on resource reservation like RSVP. IETF has introduced different level of service like the guaranteed Quality of Service [6], based on a token bucket description of the flow.

The goal of this section is to evaluate the PBC scheme in Integrated Services networks. First, it will be shown that *IntServ* has an analytical expression to obtain the bandwidth reservation for a given end-to-end delay (the R(d) function). Then, an analytical and experimental evaluation of the three schemes is done. This evaluation is done with a test program called RTNOU (Real-Time Network Optimisations Utilities). This program can be freely downloaded from Internet[1]

Two sets of VBR traffic were used for these simulations and evaluations: the first one is the well-known MPEG-1 traces studied by O. Rose [29] from the University of *Wurzburg*. The second group is from the Technical University of Berlin [30] and contains MPEG-4, H.261, H.263 and H.263+ traces (with different quality codification levels). This variety of traffic traces proves the applicability of our new backup scheme.

2.1.- Obtaining Network Reservations

In Integrated Services the end-to-end delay bound is a function of the reserved bandwidth in the links and it is usually calculated using a model for the traffic specification and a network model. The model for traffic specification (T-SPEC) for IETF guaranteed

[1] From the following web site: `http://www.disca.upv.es/enheror/RTNOU.html`

Service is based on *token bucket*. T-SPEC is a 4-uple (p, M, b, r) where p is the peak rate, M the maximum packet size, b the burst tolerance and r the sustainable rate and implies that the number of bits that the source transmits is less than $min(M+pt, b+rt)$, for any interval of time t. The maximum end-to-end queuing delay bound can be calculated using this equation [6]:

$$D = \begin{cases} \dfrac{(b-M)(p-R)}{R(p-R)} + \dfrac{M+C_{tot}}{R} + D_{tot} & (p > R \geq r) \\ \dfrac{M+C_{tot}}{R} + D_{tot} & (R \geq p \geq r) \end{cases} \quad (1)$$

where C_{tot}, D_{tot} are the parameters defining the network, R is the bandwidth reservation in the network and D the end-to-end delay. The buffer size needed in the nodes is $b+C_{sum}+D_{sum}r$ where C_{sum} and D_{sum} are the sum of all the previous C_i and D_i parameters. It is important to remind that the network minimal latency must be added to the described equation (1) in order to obtain the complete delay. This latency is a fixed value and depends mainly on the physical transmission, which is usually negligible compared to the network delay.

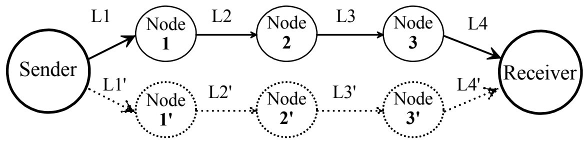
Solving out for R equation (1) we can obtain a simple expression for $R(d)$ that depends on delay, traffic specification and network model:

$$R = \begin{cases} \dfrac{(b-m)p + (M+C_{tot})(p-r)}{(d-D_{tot})(p-r)+b-M} & (p > R \geq r) \\ \dfrac{b+C_{tot}}{d-D_{tot}} & (R \geq p > r) \end{cases} = f(d, (b,r,p), (C_{tot}, D_{tot})) \quad (2)$$

The network parameters, C_{tot}, D_{tot} are obtained as the sum of the C_i and D_i parameters defining each node of the flow path. For instance, with a WFQ (*Weighted Fair Queuing*) scheduling algorithm C_i and D_i can be calculated as follows: D_i is equal to the *MTU* (Maximum Transmission Unit) of the link divided by the link bandwidth B_i, with the condition that M must be smaller than the minimal *MTU* of the path. The value C_i is assumed M in order to consider packet fragmentation.

In [8] the authors introduced a method for obtaining the traffic specification for a known traffic that minimises the bandwidth reservation for a given end-to-end delay for IETF guaranteed service. This method is extensible to leaky bucket traffic specifications as, for example, the end-to-end delay equations based on the seminal work by Parekh and Gallaguer [19][20]. Summing up, for a given traffic and network path we can obtain directly the minimal bandwidth reservation for a given end-to-end delay, that is, the function $R(d)$.

For example, using the sample network in Figure (1), with three nodes and the same networks parameters for primary and secondary channels, the network parameters are C_{tot}= 32,768 bits and D_{tot}= 0.00109s. For the MPEG1 Rose *Soccer* traffic trace, the minimal bandwidth reservation for a 0.1 seconds delay is 2,432,184b/s. The traffic specification is b= 207,793bits and r= 2,432,184 (p= 4,679,400 is constant and is obtained as the peak rate of the traffic). Figure (2) shows the minimal bandwidth reservation for the MPEG1 Rose traffic traces *Lambs*, *Soccer* and *News* as a function of the required delay ranging from 0s to 5s. As shown, the bandwidth reservation $R(d)$ is a decreasing function.



	Link	BW (bps)	MTU(bits)
	L1	50,000,000	10,000
	L2	35,000,000	12,000
	L3	100,000,000	15,000
M = 8192 bits	L4	50,000,000	20,000

Figure 1: Sample network

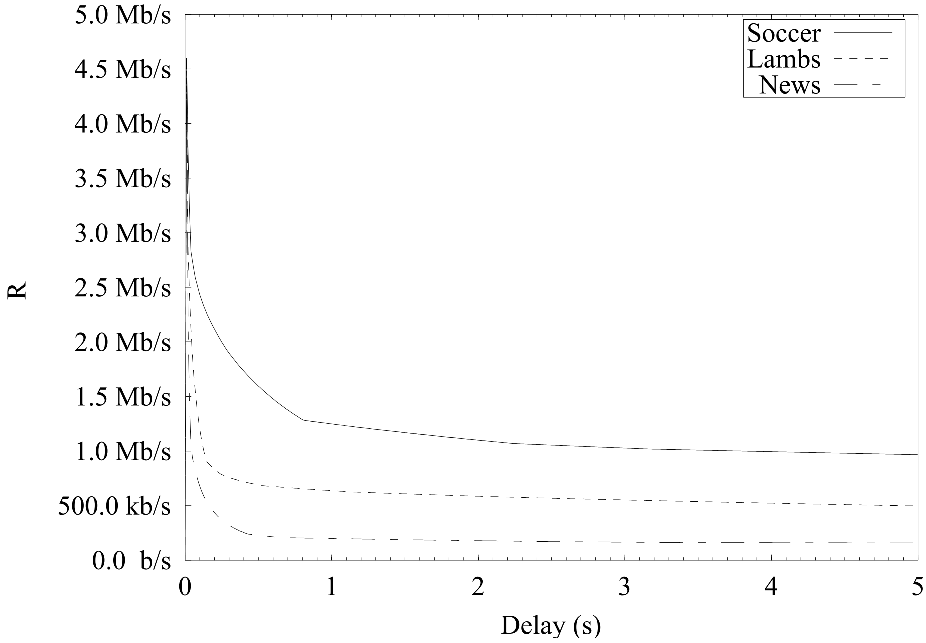


Figure 2: R(d) function for Lambs, Soccer and News traffics

2.2.- Analytical evaluation

The goal of this section is to compare the resource reservations of the PBC scheme with the other two schemes introduced in section 2. Given an end-to-end delay d_{total} is easy to obtain the total reservation using the $R(d)$ function, following the expressions of figure (2). First, we must split the total delay between both channels (d_A, d_B). For the RBC and PBC schemes it will depend on the failure detection time d_f. Without loss of applicability, in this analytical evaluation d_f will be $d_{total}/2$.

Using the sample network of the previous section and the Rose *Lambs* traffic, table (1) shows the results of total bandwidth reservation in a node for 2 end-to-end delays: 0.1s and 1s. In all the samples, the false failures rate (Φ) is assumed to be 0.001 following the delay distribution in Figure (1). The Reduction column shows the reduction of resources of the PBC new scheme versus the other schemes: Reduction=100*(1-R_{PBC}/R_X)[2] (assuming that the resources of the backup channel could be used by the router when the channel is not in use).

[2] R_x stands for R_{MC} or R_{RBC}

First of all, the new scheme PBC obtains a notable reduction versus the other schemes. The results show that for 0.1s the bandwidth reduction is very high and for 1s is a little less efficient. These results hold for every link in the path, so in the first example the total resource savings in the network (versus RBC) are (1.51-0.98)*3=1.59Mb/s.

	d_{total} = 0.1s			d_{total} = 1s	
Scheme	**Reservation calculus**	**Total**	**Reduction**	**Total**	**Reduction**
MC	2×*R*(0.1)	1.93Mb/s	49,74%	1.26Mb/s	49.9%
RBC	R(0.05)	1.51Mb/s	35,76%	0.68Mb/s	7.35%
PBC	*R*(0.1)+ 0.001×*R*(0.05)	0.97Mb/s	---	0.63Mb/s	---

Table 1: Bandwidth reduction for Lambs traffic.

It is easy to see that the bandwidth reduction versus the MC schemes is practically constant and near to 50%. Therefore, we will focus the study in the comparison of PCB and RBC schemes. In general, resource savings are more important as the total deadline becomes more restrictive. The resource gain depends mainly of the difference between the bandwidth reservation obtained for *d* and *d*/2.

Figure (3) shows graphically this difference for the *Lambs* traffic with deadlines between 0 and 1s (a usual range of deadlines). It shows that the peak of resource savings is for a deadline of 0.14s. From 0.14 to 0.25s the savings decay greatly to later decrease very slowly. Figure (4) shows the total gain for all *Lambs*, *Soccer* and *News* traffics in the Network. For the *Soccer* traffic the curve is very different. The gain is high for very low deadlines, but decreases very quickly until 0.07s to later increase lineally. The *News* traffic is very similar to the *Lambs* traffic with a peak gain of 42%. The results for other network configurations are very similar (see [9] for a detailed study).

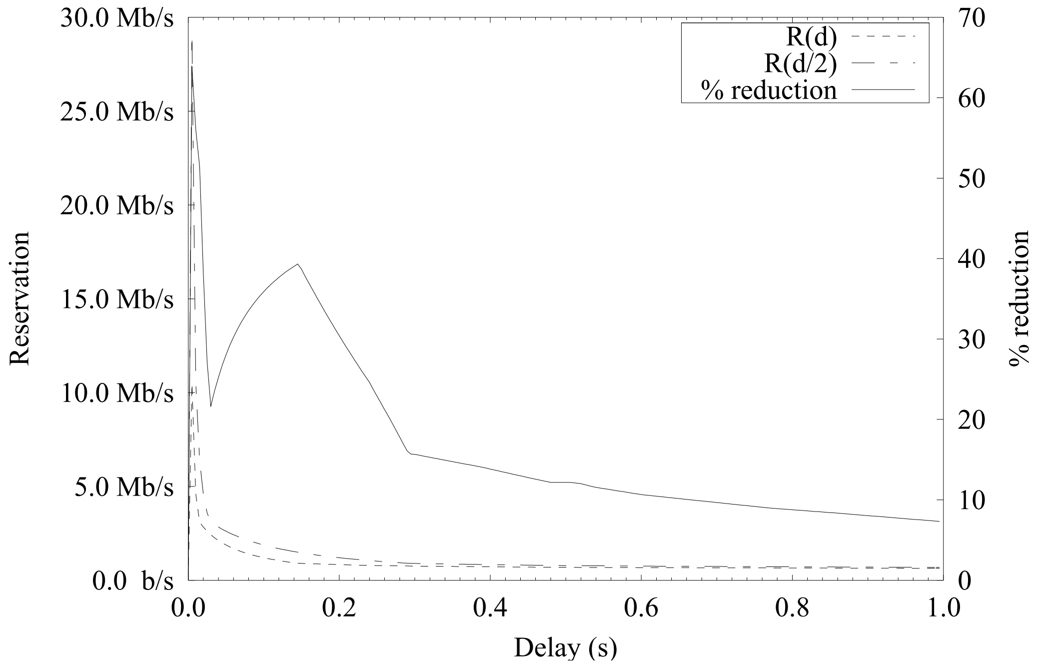


Figure 3: Difference between R(d) and R(d/2) for Lambs traffic

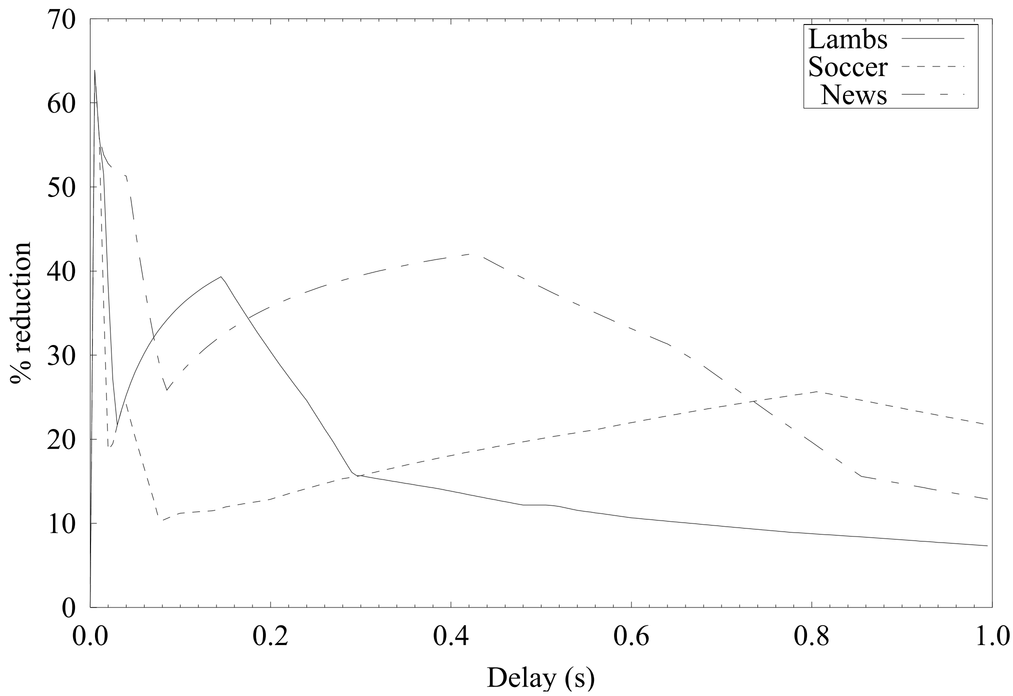


Figure 4: Bandwidth reduction for various traffics

In summary, the proposed PBC scheme reserves less resources that the other two schemes. The resource saving are between are between 10 to 50% over the RBC and MC protocols.

2.3.- Experimental evaluation

The efficiency of the scheme presented depends clearly on the PDF of the channel. This distribution will be used to obtain the Φ and d_f values. Moreover, for a given PDF, Φ is a function of the selected d_f . The results presented in this section shows that the PDF has a long tail so the false failure rate Φ is very low.

The first experiment simulated the network in Figure (1) using a WFQ scheduler in the nodes. As shown in Figure (5) the traffic generated *E(t)* is introduced in the network following the T-SPEC traffic specification. The network simulator provides also a high priority channel to send the NACK messages. The bandwidth reservation *R* in the nodes was obtained at channel establishment time as described in section 3.1. In order to introduce load in the network, 5 channels were created in each node with a load index that ranges from 0% (no load) to 100% (full load). The load index is the used percentage of the non-reserved bandwidth in the link.

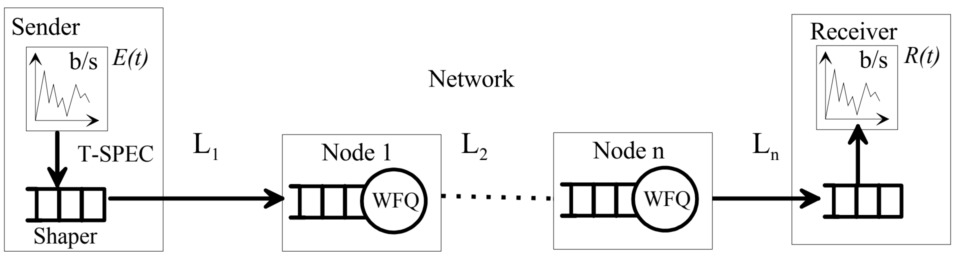


Figure 5: Network scenario simulation

Figure (6) represents the density functions for packet arrival in the simulations with *Soccer* traffic for various load indexes with a 0.02s end-to-end deadline. It is clearly shown that all packets arrive much sooner than their nominal deadlines and the more loaded the network is, the more the packets are delayed. For example, with full load the maximum delay is 0.0074s seconds, that is below of half the deadline (0.01s). Therefore, for this sample a value of *df*=0.01s would be a clear choice.

Table 2 shows the Φ values for different failure detection time d_f and end-to-end delays for the *Soccer*, *Lambs* and *News* traffic. The bandwidth reduction (the ℜ columns) is obtained for each d_f value taking into account the Φ value.

Several conclusions can be drawn from the results presented here. First, for a failure detection time of $d_{total}/2$ the Φ are zero (except for Soccer traffic and 0.01s deadline). Second, for high deadlines a reduced value of d_f can be used due to the fact that packets delays are far behind from their nominal deadline. Although in much cases the reduction for a d_f=d_{total}/2 is the better, this implies a reservation in the backup channel of d_{total}/2. In some cases it would better to reduce the reservation using a greater delay (for example if d_f=d_{total}/4 the backup channel delay is 3/4d_{total} and the reservation is reduced).

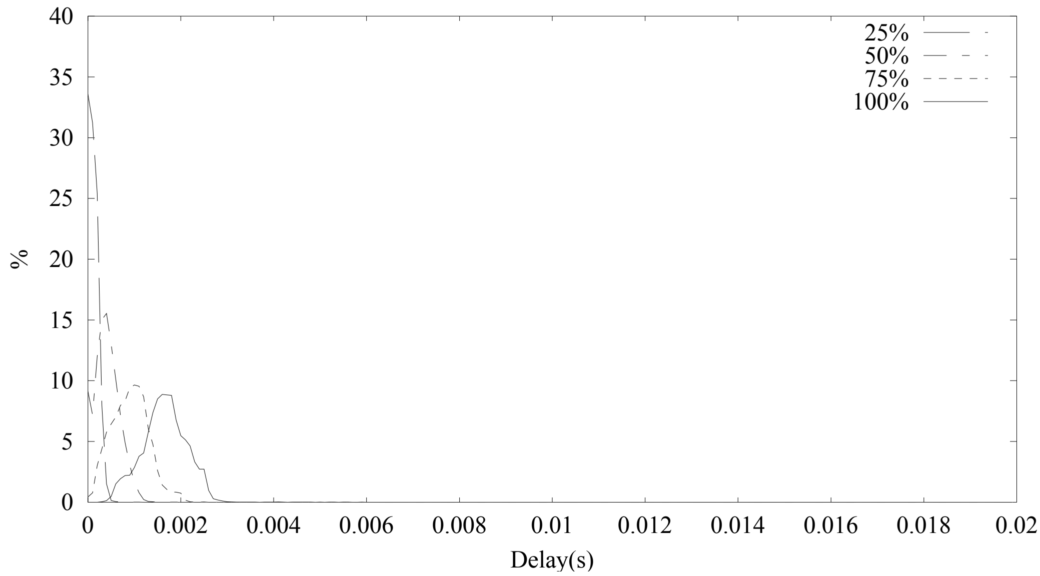


Figure 6: End-to-end packet delay distribution

Traffic	Delay	$\Phi_{d/2}$	$\Phi_{d/4}$	$\Phi_{d/8}$	$\Phi_{d/16}$	$\Re_{d/2}$	$\Re_{d/4}$	$\Re_{d/8}$	$\Re_{d/16}$
Soccer	*1s*	0	0	0	3.069	6.97	6.97	6.97	4.1
Soccer	*0.1s*	0	0	0.689	1.937	9.97	9.97	9.33	8.21
Soccer	*0.01s*	0.003	1.743	74,155	99.577	10.22	8.57	-	-
Lambs	*1s*	0	0	0	0.086	20.71	20.71	20.71	20.64
Lambs	*0.1s*	0	0	0	0.338	35.99	35.99	35.99	35.77
Lambs	*0.01s*	0	1.014	72.342	99.293	10.22	9.26	-	-
News	*1s*	0	0	0	0	6.027	6.027	6.027	6.027
News	*0.1s*	0	0	0	0.188	35.99	35.99	35.99	35.87
News	*0.01s*	0	0.952	72.659	99.342	10.22	9.32	-	-

Table 2: Φ values and bandwidth reduction for different traffics and delays.

One question that arises is why the packet delays are so much lower than their deadlines. There are two main reasons: first, is the bursty characteristics of the traffic and second, is that traffic characterisation and delay equations (as equation (1)) makes a very coarse approximation of the traffic dynamics so delay bound are very pessimistic.

Another result of the experiments is that the end-to-end delays of the first packets transmitted in a channel are minimal. This is logical because when the first packet is transmitted in a channel the node queues are empty. This implies that there is no queue delay and the end-to-end delay only depends on the bandwidth reservation and network parameters: $d'_B=(M+C_{tot})/R+D_{tot}$. This behaviour allows tightening the df value and therefore reducing the network resource reservation. Therefore, the delay for channel B can be d_{total} with the condition that $d'_B < d_f$. For example, for D_{total}=0.1s the bandwidth reservation for channel A and B is 1.93Mb/s. The delay of the first packet in channel B will be 0.022s so d_f can be 0.1-0.022= 0.078s.

3. Conclusions

The PBC scheme has been compared with the Multiple Copy (MC) and Reactive Backup Channel (RBC) approaches using Integrated and Differentiated Services Networks. The experiments in Integrated Services shows that the new scheme is very efficient and can provide savings about 50% of network resources.

Acknowledgements

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