

A FAIRNESS ANALYSIS OF LAN/WAN PROTOCOL RELAYS

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ABSTRACT

Functional standardization activities in ISO and in regional workshops are currently addressing network layer relays for the interconnection of several types of subnetworks. Relay systems are critical systems in the overall performance of the network because they are the points where network congestion can be build up or avoided. Particularly, when the interconnected subnetworks have very dissimilar bandwidths, congestion control becomes a very important issue in relay systems design. This paper addresses the problem of congestion control in relay systems for LAN/WAN interworking.

Congestion control deals with the avoidance of collapse situations in intermediate systems due to traffic overload. It deals also with the guarantee of fairness in resource utilization, considering user needs of communication services expressed in terms of Quality of Service (QoS) parameters.

To ensure congestion collapse avoidance and fairness, a channel service algorithm is proposed. Simulation results show that, in a situation of overload and for different traffic patterns with different QoS requirements, the relay's channel service and acknowledgment algorithms can guarantee justice in resource utilization and the expected QoS among the active channels.

1. INTRODUCTION

The issue of congestion control was raised in connectionless mode (CL) networks [Jain 87]. The absence of connections between end-systems and the nature of flow-control functions make these networks very sensitive to congestion. A considerable number of techniques have been proposed and studied for the congestion control in CL networks [Demers 89, Gerla 88, Jacobson 88, Jain 87, Jain 90, Keshav 91, Mankin 90 and Mishra 92] and a lot of work is going on in this field.

More recently, ATM networks brought new challenges to congestion control. The need to support real-time traffic (such as video and voice) together with traditional asynchronous data services, in high speed links, makes the issue of congestion control a very complex one. The references [Boyer 92, Eckberg 92, Jain 92, Lea 92, Trajkovic 92, Turner 92 and Wernik 92] are only examples of recent work on the field.

In connection mode (CO) networks the issue of congestion control is not as urgent as in ATM or in CL networks. The main reasons are the existence of the connection establishment phase that enables resource reservation for the data transfer phase, (preventing congestion due to resource starvation), and the fact that connection mode protocols (such as X.25) have more built-in functions for congestion control than CL protocols (such as IP) do. There are however some important issues, related to congestion control in CO networks, that need to be studied, such as those brought up by network interconnection.

Network interconnection became a very important field in past few years. At the present moment, several functional standardization activities address network layer relaying, covering CLNS relaying, CONS relaying and X.25 Packet Level Protocol relaying [Stallings 93]. These functional specifications, or profiles, are being developed by regional workshops (EWOS¹, NIST OIW² and AOW³) and are at different development stages (e.g., development in progress within organization, harmonization between regional workshops in progress, submitted to JTC1/SGFS for ISP processing). Current profile work addresses the interconnection of different types of subnetworks, e.g., CSMA/CD, Token Ring, PSDN, and FDDI, in various combinations.

This paper addresses the problem of congestion control in relay systems for LAN/WAN interworking. The study is focused on CSMA/CD LANs and X.25 PSDNs but its results can be easily extended to other subnetwork types.

¹ European Workshop for Open Systems

² National Institute for Standards and Technology - OSI Implementors Workshop

³ Asian and Oceanic Workshop

Some may argue that the study of RC relays is no longer important because X.25 and CONS belongs to the past and now is time for CLNS or IP over high speed subnetworks such as ATM or Frame Relay. This is not true. X.25 and CONS are going to be included in the (almost ready to appear) 4.4 BSD Unix release, side-by-side with the CLNS and TCP/IP [Husemann 92]. X.25 networks have a strong implantation in Europe, with a continuous growth over the last years, and can operate at high speeds [Holleczec 92] providing a communication infrastructure for LAN interconnection, directly supporting the CONS, and also the CLNS and IP.

For the particular interworking scenario of the CSMA/CD LANs and X.25 PSDNs two different relay approaches are possible: *service relays* and the *protocol relays*, classified, according to the ISO taxonomy, as RB51.1xxx and RC51.1xxx, respectively [ISO 1991, EWOS 1990].

The RB51.1xxx profile family specifies *connection-mode network service relays* (RB) for the interconnection of a CSMA/CD LAN (subnetwork identifier 51) and PSDNs. The access to the PSDN can be permanent or switched, and can be over leased line, digital data circuit or ISDN B-channel (1xxx stands for subnetwork identifiers from 1111 to 1231). The RC51.1xxx profile family specify an *X.25 protocol relay* (RC), for the interconnection of the above mentioned subnetwork types.

Although the RB51.1xxx relay family represents a more orthodox approach to network layer relaying, because their operation is based on a standardized layer, the RC51.1xxx family have, in despite of their non orthodoxy, some interesting characteristics and functionality. They support both kinds of Network layer services (with appropriate convergence sublayers) and they are capable of relaying non-OSI traffic, namely X.29 (triple X) PAD traffic or traffic from proprietary communication architectures.

This paper addresses the congestion control issues in RC51.1xxx relays, focusing mechanisms that act in the relaying module and in the X.25 protocol built-in functions.

2. RC51.1xxx RELAYS

The internal architecture of an RC51.1xxx relay is shown in figure 2.1. In the PSDN side the relay has a pure X.25 [ISO 1990] stack: X.21, X.21 bis or ISDN-B channel in the Physical Layer (depending of the PSDN access method), LAP B in the Link Layer and X.25 PLP as the SNAcP (Subnetwork Access Protocol) of the Network Layer.

In the CSMA/CD LAN side, the X.25 PLP (also playing the SNAcP role) is used above the CSMA/CD MAC (Physical Layer). The LLC Type 2 is used in-between to provide the X.25 PLP a link service with the error free characteristics needed by the X.25 and not provided by the MAC protocol or the LLC type 1. This protocol stack is proposed in the ISO standard IS8881-2 (Use of the X.25 packet level protocol in local area networks - Part 2: Use with LLC Type 2 procedures) [ISO 1987].

The relaying functions between the X.25 PSDN and the CSMA/CD LAN (with X.25 on top) are accomplished on the basis of the X.25 PDUs (X.25 packets).

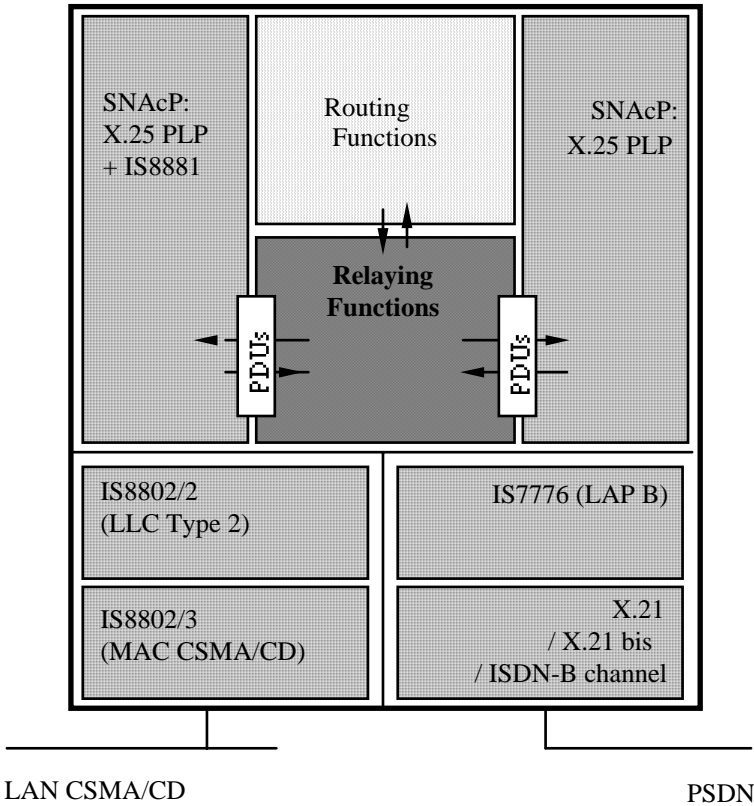


Fig. 2.1 - An RC 51.1xxx relay

Because this relay operates at the SNAcP sublayer of the Network Layer, it is possible, with appropriate convergence functions, (SNDCCP sublayer) to use it to support the two different types of Network Layer Services (even at the same time), and non-OSI traffic like PAD traffic or traffic from non-OSI architecture (TCP/IP, SNA, DNA, etc.) implanted over X.25 subnetworks.

Some functions of the relaying module are covered by the ISO Technical Report 10029 [ISO 1989]. This Technical Report describes, in a rather superficial way, the functions of an X.25

IWU (Interworking Unit) which is a module that provides the way for the interconnection of X.25 PLP based subnetworks. TR 10029 does not regard subnetwork the lower layers and thus, refers to all RCxx.yyyy relays.

3. CONGESTION CONTROL IN RC51.1xxx RELAYS

Performance issues are very important in intermediate system design. In RC51.1xxx relays the issue is of great importance because of the bandwidth difference between the interconnected subnetworks (typically 2 to 3 orders of magnitude).

Several factors affect performance. They can be split into two major groups according to their origin: *processing factors* and *communication factors*. Processing factors deal with the hardware that supports the intermediate system, like its architecture, processing speed, amount of memory, etc. Communication factors deal with the communication itself. They include link speed and error characteristics, communication protocol performance, and issues related to the performance of the intermediate system routing and relaying modules.

The relaying module is responsible for the forwarding of the information between the interconnected subnetworks. Thence its performance has a major influence in the overall intermediate system performance.

When the amount of traffic arriving at the relay exceeds its relaying capacity (due to processing speed limitation, to buffer limitations or to bandwidth limitations) it is said that the relay is *congested*. A severe congestion state is characterized by *throughput* approaching to zero and *transit delay* approaching to infinite (this state is also known as the *congestion collapse* state [Jain 87]).

To avoid performance degradation due to congestion, special functions need to be added to the communication systems (end systems and intermediate systems). These functionalities are known as *congestion control* or *congestion management* [Jain 87] functions.

In relay systems, congestion control must avoid performance degradation due to overload and guarantee *fairness* in resource utilization among active users. Fairness is not a clear concept. It can have many definitions and measurement criteria.

In this work, fairness is evaluated against the user *Quality of Service* (QoS) parameters. If QoS parameters are respected the system is said to be *fair*, otherwise it's *unfair*.

Congestion control functions can be accomplished acting at several levels: using mechanisms built in protocol layers (e.g., window flow control), acting upon the relaying module and acting upon the routing module.

Some routing functions can be used by congestion control. For example, new paths can be selected according to their load or to the delay they introduce. Routing functions must be used in conjunction with other congestion control mechanisms because, by themselves, they are not capable of resolving congestion due to a load larger than the total available bandwidth (in all the available links).

Routing functions are more efficient in connectionless networks than in connection mode ones. In CL networks, routes can be selected in a per packet basis, reflecting load dynamics. In CO networks, routing functions act only during the connection establishment phase and, thence, can't usually be adjusted to load variations during the information transfer phase.

The most sensitive module concerning congestion control is the *relaying module*. It is the only point where congestion control functions can ensure fairness in resource utilization among users. This work is focused in congestion control mechanisms acting in the relaying module and in the X.25 protocol built in functions.

In order to analyze the congestion control mechanisms, a relay model was developed. The model includes all the relaying and X.25 protocol functions needed for congestion control as well as all the end system and subnetwork aspects that have influence in throughput and transit delay.

In the relaying module two levels of congestion control policies must be applied: buffer allocation policies and channel service policies.

Buffer allocation policies have great impact in transit delay. In connection mode networks, with window flow control, it's possible to predict the buffer need for each channel, during call setup phase. To avoid packet loss due to buffer starvation, the buffer space allocated to each active channel is determined by the product of the window size by the packet length:

$$NeedBuffer_{channel} = WindowSize_{channel} \times PacketSize_{channel} \quad (3.1)$$

Channel service policies must guarantee fairness in bandwidth utilization among users, according to their QoS parameter set.

In [Nag 87] and later, in [Demers 89] a channel service algorithm called "*fair queuing*" is proposed and analyzed for gateways in connectionless mode networks. This algorithm ensures that available bandwidth is *equally* shared among source-destination pairs, and ensures

protection from ill-behaved users. The fair queuing algorithm doesn't distinguish between users and considers all them equally.

In connection mode networks each channel has its own QoS parameter set to be respected. To ensure that the negotiated QoS minimum throughput is guaranteed by relay intermediate systems a more sophisticated algorithm is needed. Let us define the *Sharing Index* of a channel for the instant t_i , $SI(t_i)$, as:

$$SI(t_i)_{channel} = \frac{EffectiveThroughput}{QoSThroughput} = \frac{\frac{1}{t_i} \sum SizePacketsTransmitted}{QoSThroughput} \quad (3.2)$$

The next channel to be served at instant t_i is scheduled by ascending order of the channels $SI(t_i)$. This algorithm guarantees that QoS throughput parameters are respected. The evaluation of $SI(t_i)$ doesn't require much calculation and can be made in parallel with packet transmission to avoid transmission delays. When the k packet is transmitted by the relay, the packet finishing transmission time, t_k , is calculated and the SI vector is updated for the instant t_k , using the following expressions:

$$SI(t_0) = 1 \quad (3.3)$$

$$SI(t_k) = \frac{t_{k-1}}{t_k} SI(t_{k-1}) \quad (3.4)$$

$$SI(t_k) = \frac{1}{t_k} \left(t_{k-1} SI(t_{k-1}) + \frac{PacketSize_k}{QoSThroughput} \right) \quad (3.5)$$

Expression (3.3) defines the initial conditions for $SI(t_i)$ evaluation, (3.4) is the $SI(t_i)$ update expression for the idle channels (with or without packets pending) and (3.5) is the update expression for the channel currently busy with the transmission of packet k .

QoS transit delay parameters aren't explicitly controlled by the relay. Once QoS throughput is satisfied QoS maximum delay is automatically bounded by expression (3.6) below. This value can be imposed during the QoS negotiation phase.

$$QoSMaxDelay = \frac{W \times MaxPacketSize}{QoSThroughput} \quad (3.6)$$

Table 3.1 summarizes the relaying module, X25 protocol, CSMA/CD subnetwork, PSDN subnetwork and end system characteristics that are to be included in the model.

| module | characteristics |
|-----------------------------------|---|
| Relaying | <ul style="list-style-type: none"> - Static buffer allocation policy: buffers are allocated according to window size and packet length - Dynamic QoS channel service policy - Segmentation and reassembling capabilities, to match different window and packet sizes |
| X.25 protocol | <ul style="list-style-type: none"> - Negotiable window size - Negotiable packet size - Acknowledgment policy: ACKs are sent as soon as buffers are available to receive a new packet |
| CSMA/CD subnetwork lower layers | <ul style="list-style-type: none"> - Bit rate of 10 M bps - Error free (the effect of error control is neglected) - Bit stuffing (to guarantee minimum frame size) - Half-duplex medium - Effect of traffic not destined (originated) to (in) the relay in bandwidth consumption - Propagation time of ACKs |
| PSDN subnetwork lower layers | <ul style="list-style-type: none"> - Variable bit rate (set to 64 K bps) - Error free (the effect of error control is neglected) - Full-duplex medium - Propagation time of ACKs |
| End system (or next relay system) | <ul style="list-style-type: none"> - Generated data block size (e.g., size of the N-Data primitives in the case of network service users) - Data block interarrival time - Number of data blocks generated - QoS parameters: <ul style="list-style-type: none"> - throughput - transit delay |

Tab. 3.1. Summary of characteristics included in the model.

Based on the aspects summarized on table 3.1 a simulation model was built up using Activity Cycle Diagrams (ACDs) [Clementson 82]. In ACDs two kinds of elements exist: *entities* and *activity cycles*. Entities represent real elements such as packets, buffers or available window. The dynamic behavior of entities is represented by activity cycles. Activity cycles are closed sequences (cycles) of alternating activities and waiting states through which entities circulate. ACDs are supported by the ECSL (Extended Control and Simulation Language) simulation language, to which the description can be easily rewritten into [Clementson 82].

4. SIMULATION RESULTS

Without congestion control mechanisms, communication systems exhibit the behavior illustrated in figure 4.1 [Jain 87].

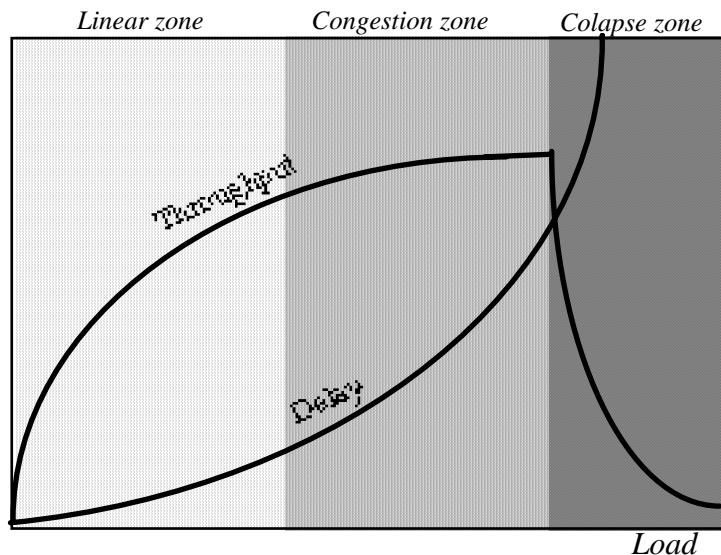


Fig. 4.1 Communication systems congestion behavior

In the *linear zone* transit delays are low and throughput increases with load. If the load continues to increase the communication system approaches its limit capacity, queues start to build up and transit delay increases rapidly -- the system is said to be in the *congestion zone*. Due to the overflow of internal queues and retransmissions when the communication system is overloaded, throughput decreases exponentially and transit delay increases also exponentially; this region is known as the *congestion collapse zone*.

Ideally, congestion control functions should keep the communication system within the linear zone and they must recover if, by any reason, the system enters the congestion or, furthermore, the collapse region.

In order to evaluate the congestion collapse avoidance and the fairness guarantee behavior of RC51.1xxx relays, two different situations have been simulated (Situation A and Situation B).

In both situations six active channels were considered in the simulation setup (this number was imposed by the simulation hardware environment, but it was found to be enough for the analysis made). The load is considered to be balanced in the two traffic flow directions (LAN -> RELAY -> PSDN and PSDN -> RELAY -> LAN). Data for channels is generated in blocks of variable size with a Weibull probability distribution (corresponding to the generation of *N-DATA.request* primitives by the Network service users) and are then split (if necessary) into PSDN or LAN packets. The data interarrival time is ruled by a Poisson distribution. As said before the Relay performs segmentation/reassembling functions to fit different packet sizes in the PSDN and LAN sides.

In order to obtain load/throughput and load/delay charts the total load is continuously increased from a small value (corresponding to a large interarrival time) to a high value (small interarrival time). There are two kinds of channel users: “*well-behaved*” users that don’t increase their demand above their QoS throughput; “*ill-behaved*” ones that don’t respect this limit. The goal is to see if the ill-behaved channel users get more than their fair share of bandwidth and if they harm the well-behaved channels with their misconduct.

In situation A all the channel users are ill-behaved. The QoS throughput and delay are asymmetrically distributed among channels (see table 1). To evaluate the bandwidth redistribution capabilities of the Relay, channel 1 stops transmitting for some time and then restarts his activity.

In situation B, interactive, well-behaved traffic is mixed with ill-behaved file-transfer-like-traffic. Two channels (2 and 5) carry terminal generated traffic with small data blocks and medium interarrival times. The demand of these channels is constant and small (2% of the available bandwidth each). Ill-behaved channels (1, 3, 4 and 6) use 96% of available bandwidth (24 % each) but they don’t respect this limit and their demand is continuously increased.

In both situations the *QoS Max. Delay* parameter is calculated by expression (3.6) using LAN window and packet sizes. This is because the most relevant relay delays are those introduced in the LAN -> PSDN traffic.

Tables 4.1 and 4.2 show a summary of the most relevant parameters of the simulations made in Situation A and Situation B respectively.

| Parameter | Channel 1 | Channel 2 | Channel 3 | Channel 4 | Channel 5 | Channel 6 |
|-------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| QoS Throughput [bps] | 26800 | 19200 | 9600 | 4800 | 2400 | 1200 |
| QoS Max Delay [ms] | 305 | 425 | 850 | 1700 | 3410 | 6820 |
| PSDN Window [packets] | 4 | 4 | 4 | 4 | 4 | 4 |
| PSDN Max Packet Size [bytes] | 128 | 128 | 128 | 128 | 128 | 128 |
| PSDN N-DATA med. size [bytes] | 512 | 512 | 512 | 512 | 512 | 512 |
| PSDN N-DATA interarrival [ms] | 8000-200 | 8000-250 | 8000-300 | 8000-400 | 8000-500 | 8000-600 |
| LAN Window [packets] | 2 | 2 | 2 | 2 | 2 | 2 |
| LAN Max. Packet Size [bytes] | 1024 | 1024 | 1024 | 1024 | 1024 | 1024 |
| LAN N-DATA med. size [bytes] | 512 | 512 | 512 | 512 | 512 | 512 |
| LAN N-DATA interarrival [ms] | 8000-200 | 8000-250 | 8000-300 | 8000-400 | 8000-500 | 8000-600 |

| | | | | | | |
|-----------------------|-----|-----|-----|-----|-----|-----|
| Channel user behavior | ill | ill | ill | ill | ill | ill |
|-----------------------|-----|-----|-----|-----|-----|-----|

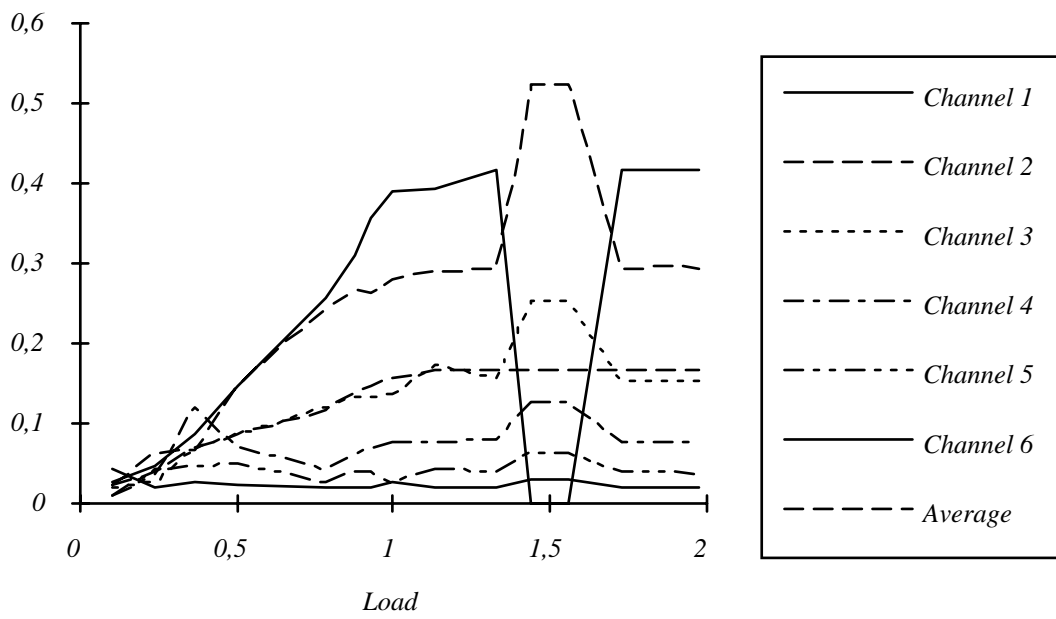
Tab. 4.1 Summary of the simulation parameters for Situation A

| Parameter | Channel 1 | Channel 2 | Channel 3 | Channel 4 | Channel 5 | Channel 6 |
|-------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| QoS Throughput [bps] | 15400 | 1200 | 15400 | 15400 | 1200 | 15400 |
| QoS Max. Delay [ms] | 532 | 533 | 532 | 532 | 533 | 532 |
| PSDN Window [packets] | 4 | 4 | 4 | 4 | 4 | 4 |
| PSDN Max. Packet Size [bytes] | 128 | 128 | 128 | 128 | 128 | 128 |
| PSDN N-DATA med. size [bytes] | 1024 | 40 | 1024 | 1024 | 40 | 1024 |
| PSDN N-DATA interarrival [ms] | 8000-150 | 500 | 8000-150 | 8000-150 | 500 | 8000-150 |
| LAN Window [packets] | 2 | 2 | 2 | 2 | 2 | 2 |
| LAN Max. Packet Size [bytes] | 1518 | 1518 | 1518 | 1518 | 1518 | 1518 |
| LAN N-DATA med. size [bytes] | 512 | 40 | 512 | 512 | 40 | 512 |
| LAN N-DATA interarrival [ms] | 8000-150 | 500 | 8000-150 | 8000-150 | 500 | 8000-150 |
| Channel user behavior | ill | well | ill | ill | well | ill |

Tab. 4.2 Summary of the simulation parameters for Situation B

Figures 4.2 and 4.3 show the simulation results relative to RELAY -> PSDN throughput and RELAY queues delay respectively. Throughputs are plotted normalized to the communication system bottleneck (PSDN link speed of 64000 bps). PSDN -> LAN traffic is not analyzed in detail because it doesn't congest the relay. For this traffic direction, queues never build up in the relay, and the delay introduced by it is neglectable, compared to the total delay.

Situation A



Situation B

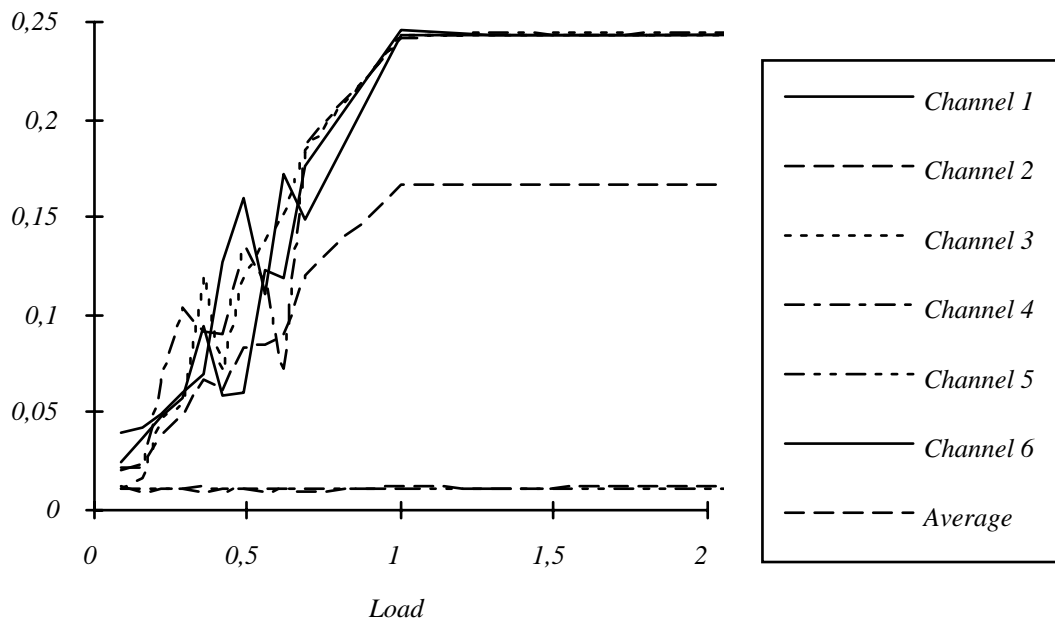
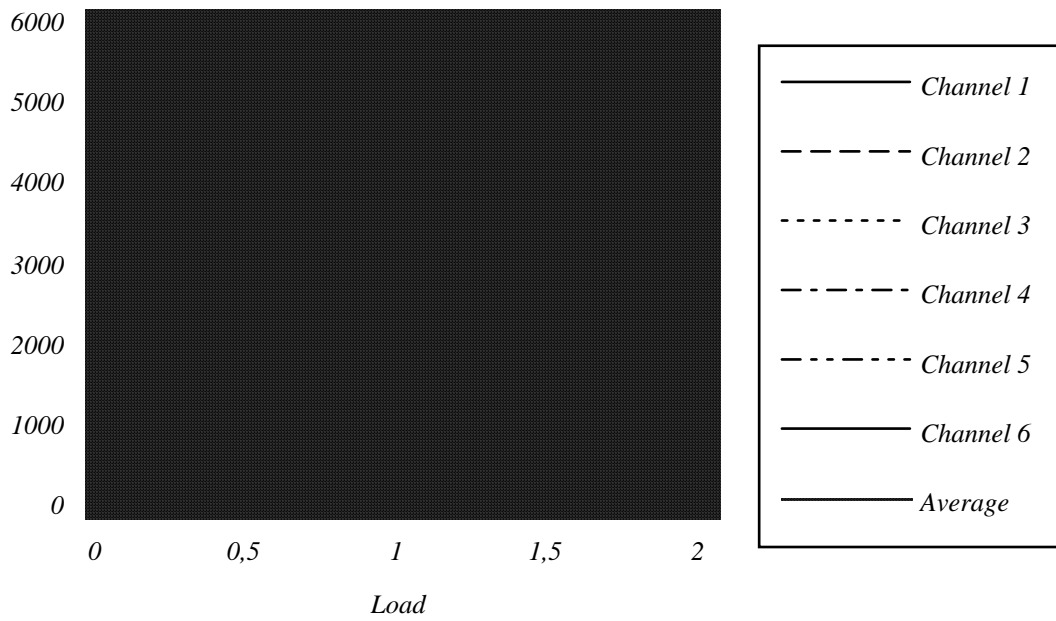


Fig. 4.2 RELAY -> PSDN throughput

Situation A



Situation B

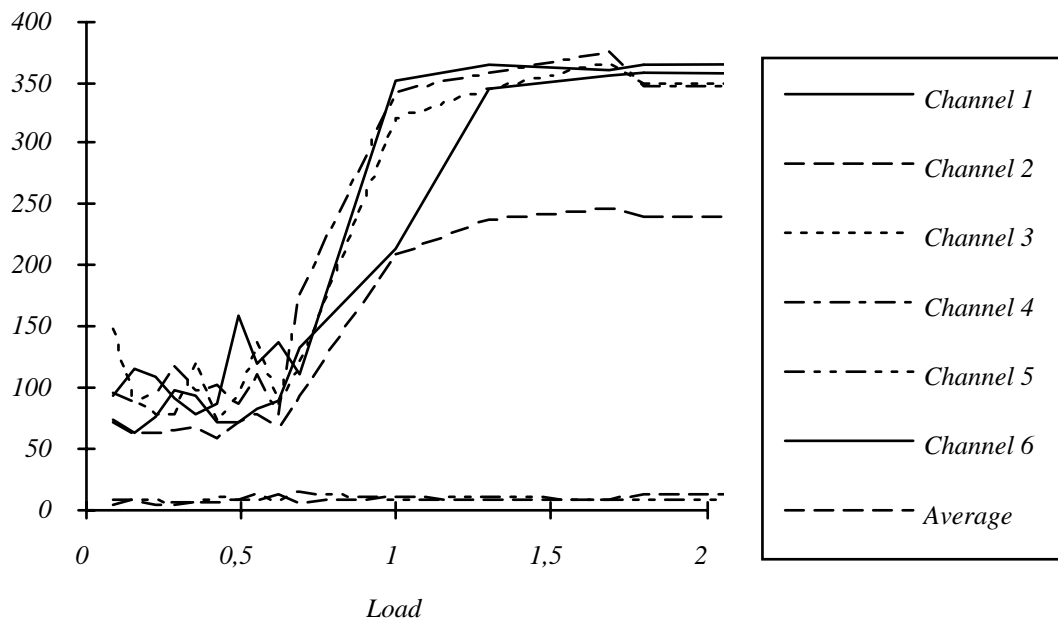


Fig. 4.3 RELAY queues delay

As can be observed from the average plots the congestion collapse zone is never reached, even under severe load situations (2 times the bottleneck capacity). For load under around 80 % of the bottleneck capacity (PSDN link speed), the relay operates in the linear zone with low transit delay and throughput proportional to load. As load increases above this point, the relay moves from the linear zone into the congestion zone. Queues built up in the relay and transit delays increases exponentially with load. When the load reaches the bottleneck capacity, the relay queues saturate. Flow control avoids queue overflow and thence avoids the entrance of the relay in the congestion collapse zone.

Looking at the throughput/load plots it can be seen that, when overload arises, bandwidth is shared according to QoS throughput parameters.

In situation A throughput increases with load and, when the bottleneck is reached, channel throughput is regulated by QoS throughput values. Also in situation A, when channel 1 becomes idle its bandwidth is split between the active channels, proportionally to QoS throughput values. When it becomes busy again its bandwidth is recovered from the other channels.

Situation B shows that “well-behaved” users are protected from “ill-behaved” ones. Ill-behaved file-transfer-like channels (1, 3, 4, 6) have a share of 24 % of the bandwidth each, but their demand is continuously increasing in spite of this limit; well-behaved channels have a share of 2% and a constant demand of 1% each. When the system reaches the congestion zone the channel service algorithm ensures protection to the well-behaved channels.

Looking now at the transit delay QoS parameters Figure 4.3 shows that, in both situations A and B, QoS Max. Delay is always respected. Another interesting observation is that for demands below 80% of the QoS throughput class, delays are very small compared to QoS delay parameter. When the demand exceeds QoS throughput (ill-behavior) channel users are penalized with delays near de QoS Max. Delay parameter.

5. CONCLUSION

The simulation study of the X.25 protocol relay for the interconnection of CSMA/CD LANs and X.25 PSDNs highlighted some important aspects of the relay congestion control behavior.

A channel service algorithm was proposed to avoid unfairness in respect to bandwidth and to internal resources utilization. Fairness is measured against the QoS throughput and delay parameters.

The simulations made revealed that the proposed channel service algorithm in conjunction with X.25 built-in flow control mechanisms, can avoid the congestion collapse in X.25 protocol relays, even under severe load situations.

Simulation also showed that fairness can be achieved. User throughput and transit delay QoS parameters are respected even when the demand increases above the system bottleneck capacity (PSDN link). The proposed algorithm creates “fire-walls” between well and ill behaved channel users protecting the first ones from the misbehavior of the seconds.

The queuing delay analysis revealed that the optimal operating point for channels is around 80% of channel’s QoS throughput. Below this point, delays are low compared to the QoS delay parameter. When the load exceeds that point queues build-up exponentially and the delay reaches the QoS delay. This effect acts like a punishment to ill-behaved users.

These simulation results are being substantiated by experiments with a prototype implementation of an RC51.1111 relay, in order to effectively evaluate the feasibility and usefulness of the proposed algorithms.

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