LAN/WAN Interconnection:
Congestion Control in X.25 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. This paper addresses the problem of congestion control in relay systems for LAN/WAN interworking.

Particularly, the congestion behavior of the X.25 protocol relay is analyzed from simulations. The load/throughput and load/transit delay curves for the relay are evaluated for different load situations, and for different traffic patterns such as interactive and batch traffic.

The results show that, although the relay can always stay away from the congestion collapse situation due to the flow control mechanisms embedded in the X.25 protocol, it can not guarantee fairness in the sharing of the relay internal resources and bandwidth among the active connections.

The conclusion of the paper points to some possible solutions to this problem.

KEY WORDS

Congestion control, interworking, X.25 protocol relay, network-layer relays

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. 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 build up or be avoided. Particularly, when the interconnected subnetworks have very different bandwidths, congestion control becomes a very important issue in relay system design.

Congestion control deals with the avoidance of collapse situations in intermediate systems due to traffic overload. The collapse situation is characterized by high transit delay and low throughput in the network. Congestion control deals also with the guarantee of fairness in resource utilization among users considering their needs of communication services expressed in terms of Quality of Service (QoS) parameters.

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. For this particular interworking scenario two different relay approaches are possible: the service relays and the protocol relays, classified, according to the ISO taxonomy, as RB51.1xxx and RC51.1xxx, respectively (the xxx stands for the identifier of the X.25 PSDN access method, as will be explained later). This paper addresses the congestion control issues in RC51.1xxx relays, focusing upon mechanisms that act in the relaying module and in the X.25 protocol built-in functions.

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.

In Section 2, some basic concepts regarding Network Layer and Network Layer Relays are presented. A functional model for RC51.1xxx relays is proposed. The main functional modules of the relay are presented characterized and the relations between them clarified.

In Section 3, the relaying module of the relay is further detailed to include all the relevant aspects to the study of congestion issues. This module is then modeled by interacting concurrent processes that are described by Activity Cycle Diagrams (ACD), a semi-graphical description technique particularly suited for direct simulation and thence performance analysis. ACDs are supported by the ECSL simulation language to which the description can be easily rewritten into.

In Section 4, the congestion behavior of RC51.1xxx relays is then analyzed from simulations. The load/throughput and load/transit delay curves for the relay are evaluated for different load situations (from very light to very heavy loads), and for different traffic patterns such as bursty (terminal-like) and batch (file-transfer-like) traffic.

The results show that, although the relay can always stay away from the congestion collapse situation due to the flow control mechanisms embedded in the X.25 protocol, it can not guarantee fairness in the sharing of the relay internal resources and bandwidth among the active connections. Congestion avoidance can't also be guaranteed because throughput and transit delay QoS parameters are not respected when demand reaches the system bottleneck capacity.

The analysis of the results shows that to ensure fairness against QoS parameters some dynamic evaluation of the needed resources and bandwidth for each connection is necessary. The conclusion of the paper points to some possible solutions to this problem.

2. THE X.25 PROTOCOL RELAYS

2.1 The OSI Network Layer

According to the principles of the OSI Basic Reference Model [ISO 84], the Network Layer provides the transparent transfer of data between transport entities, in such a way that the characteristics of different transmission and subnetwork technologies are masked and a consistent network service is offered.

In order to do so, the Network Layer is organized in three sublayers (Fig. 2.1) that may or may not be present in a system [ISO 88a], depending on the interconnected subnetworks:

- the SubNetwork Access Protocol (SNAcP) Sublayer, a subnetwork specific sublayer;
- the SubNetwork Independent Convergence Protocol (SNICP) sublayer, that presents an uniform service to the Transport Layer;
- the SubNetwork Dependent Convergence Protocol (SNDCP) sublayer, that is responsible for the necessary adaptations between the SNAcP and the SNICP sublayers.

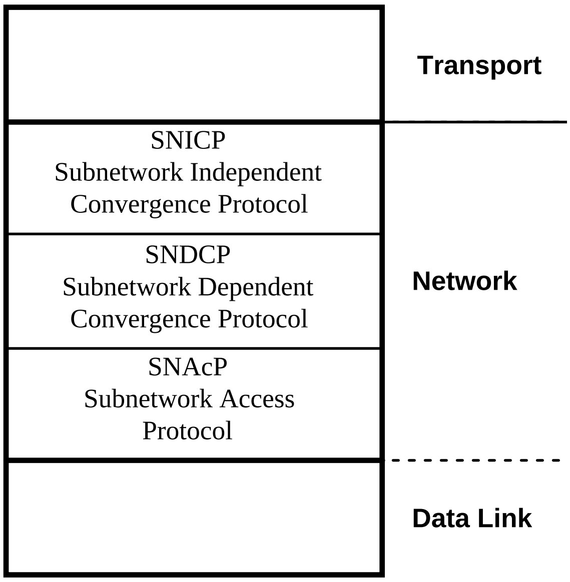

Fig. 2.1 - Internal Organization of the Network Layer.

In spite of this organization, the OSI environment supports two incompatible types of network services: the connection-mode network service (CONS), supported by the X.25 Packet Level Protocol [ISO 90], and the connectionless-mode network service (CLNS), supported by the connectionless-mode network protocol [ISO 88b]. In the OSI environment, the interconnection of end-systems attached to the same or different subnetworks is only possible if the end-systems use the same type of network service. This CO/CL Interworking Problem has several possible solutions [EWOS 90; Schepers 92], all of them outside the context of OSI.

When the subnetwork interconnection is carried out by network layer intermediate systems, those intermediate systems, or *relays*, must perform *routing* as well as *relaying* functions. In addition, they harmonize differences between the interconnected subnetworks, and assure that the semantics of relayed information is preserved.

2.2 Types of relays

Depending on the way in which the information relaying is performed, relays may be grouped in two different types [EWOS 90]:

- *protocol relays*, that relay the information on the basis of the semantics of protocol data units (PDUs) of a given layer, establishing a correspondence between the PDUs of one subnetwork to the PDUs of other subnetworks (Fig. 2.2);
- *service relays*, that relay the information on the basis of the semantics of the service supported by the protocols of the layer in which the relay operates. This approach requires the definition and use of an (N)-*Internal Layer Service* ((N)-ILS), that results from the addition of the necessary relaying functionality to the normal layer service (Fig. 2.3).

These types of relays can be used for the interconnection of different types of subnetworks, operating at one of several layers, and relaying one of the two service modes (connection-mode or connectionless-mode service). ISO/IEC Technical Report 10000-2 [ISO 91] defines a taxonomy for relay system classification.

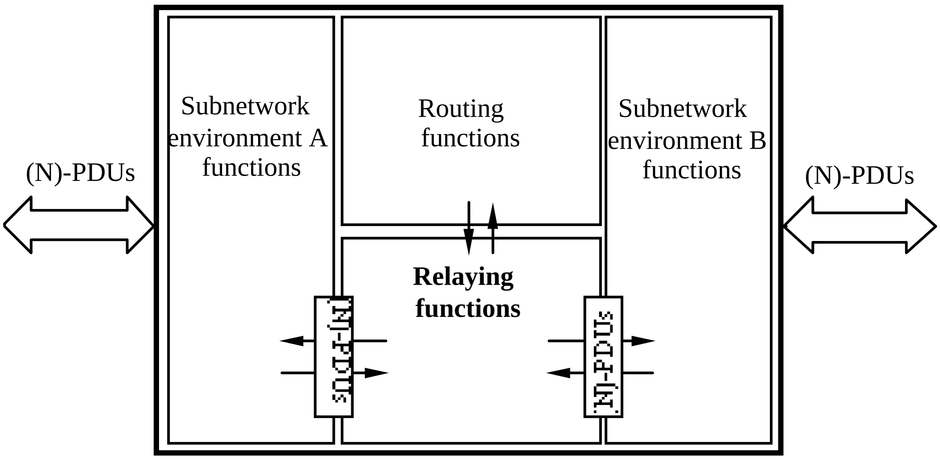

Fig. 2.2 - Protocol Relay

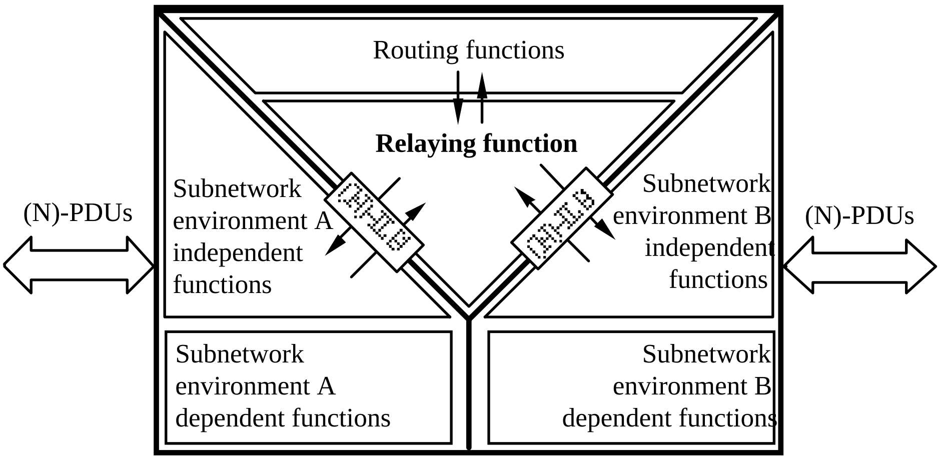

Fig. 2.3 - Service Relay

From TR 10000-2, relays are classified according to the form:

RXp.q where
R = stands for Relay
X = relay type identifier, covering the layer at which the relay operates, the service mode being supported and the type of relay
p, q = subnetwork numerical identifiers

That is, RXp.q represents a relay of type X, between subnetwork type p and subnetwork type q.

At the present moment, several functional standardization activities address network layer relaying, covering CLNS relaying (RAp.q profiles), CONS relaying (RBp.q profiles) and X.25 Packet Level Protocol relaying (RCp.q profiles). These functional specifications, or profiles, are being developed by regional workshops (EWOS[1], NIST OIW[2] and AOW[3]) 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.

Examples of relay profiles regarding which there is a recognized interest are the RB51.1xxx and RC51.1xxx profile families.

The RB51.1xxx profile family specifies *connection-mode network service relays* for the interconnection of a CSMA/CD LAN (subnetwork identifier 51) and a PSDN. 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*s, 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 XXX) PAD traffic or traffic from proprietary communication architectures.

2.3 RC51.1xxx Relays

The internal architecture of an RC51.1xxx relay is shown in figure 2.4. In the PSDN side the relay has a pure X.25 [ISO 90] 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 87].

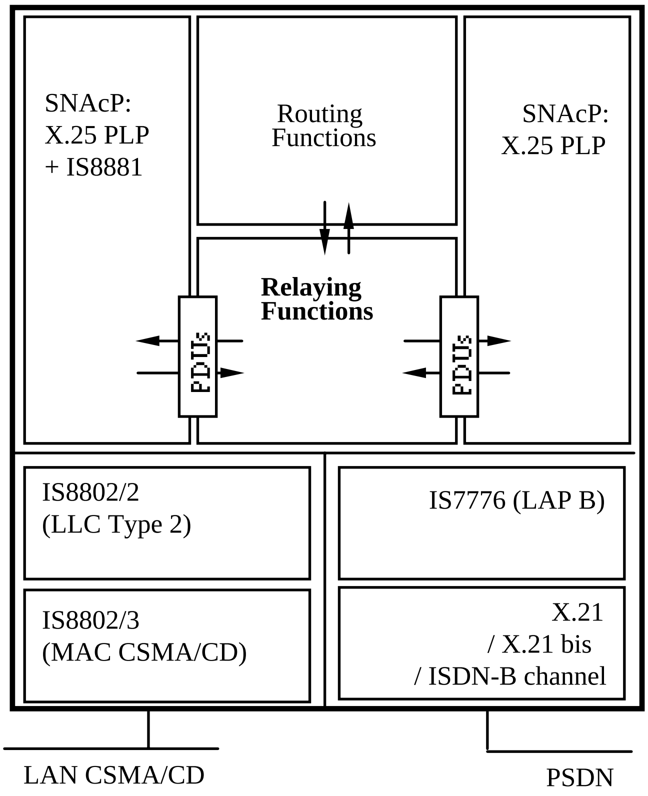

Fig. 2.4 - An RC 51.1xxx relay

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).

Because this relay operates at the SNAcP sublayer of the Network Layer, it is possible, with

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[1] European Workshop for Open Systems

[2] National Institute for Standards and Technology - OSI Implementors Workshop

[3] Asian and Oceanic Workshop

appropriate convergence functions, (SNDCP 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 89a]. This Technical Report describes the functions of an X.25 IWU (Interworking Unit) which is a module that provides the way to the interconnection of X.25 PLP based subnetworks. TR 10029 does not regard subnetworks lower layers and thus, refers to all RCxx.yyyy relays.

In TR 10029 the operation of the X.25 IWU is defined in a rather superficial way. It includes procedures for reset, setup and clearing of virtual calls, data transfer, flow control and for the use of optional user facilities. The X.25 IWU must match the packet and window sizes of the interconnected subnetworks. For that purpose the need of segmentation and reassembling functions is also identified in TR 10029.

Figure 2.4 shows also a routing module, operating above the relaying module. Routing functions deal with the problem of finding the best route between two end systems who want to communicate. Routing and relaying modules exchange information about the state of intermediate systems and links in the neighbor of the relay.

ISO Technical Report 9575 (OSI routing framework) [ISO 89b] identifies four distinct aspects of routing: *routing information base*, *routing information collection*, *routing information distribution* and, *path calculation and maintenance*. The routing information base contains information necessary to path calculation. This information is updated by routing protocols from remote systems and from local system by management functions, directory services and by the relaying module. When the relaying module needs routing information to setup a new connection to a remote system, path calculation functions provide this information. On the other side, the relaying module provides the routing module with information about dynamic path characteristics (congestion state, delay introduced, available bandwidth, etc.). This information is stored in the information base and used in subsequent path calculations.

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 it’s 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 the 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 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;
- acting upon the routing module.

For RC51.1xxx relays several mechanisms have been identified [EWOS 90] in the X.25 protocol that can be used for the purpose of congestion control. Table 3.2 summarizes the available mechanisms.

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 then 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 be adjusted to load variations during the information transfer phase.

The most sensitive module in respect to congestion control is the *relaying module*. It is the only point where congestion control functions can ensure fairness in resource utilization among users. In the relaying module two levels of congestion control policies must be studied:

- buffer allocation policies;
- channel service policies.

Congestion Control related mechanisms	**Correspondent mechanisms in the X.25 PLP**
Flow control	Sliding window flow control in Virtual Calls (VCs) and in Permanent Virtual Circuits (PVCs).
Adaptive routing	In some circumstances X.25 packets may be routed in an adaptive way by RC relays.
Block new connections	New X.25 VCs can be rejected by RC relays.
QoS negotiation	QoS parameters, present in call setup packets, can be changed by RC relays, according to available resources.
QoS re negotiation in active connections	The minimum throughput class negotiation facility allows QoS changes during data transfer phase.
Connection release	It is possible to release VCs, using CLEAR REQUEST packets
Connection reset	It is possible to reset VCs, using RESET REQUEST packets
Throttle message generation	RR and RNR packets
Discard of Data Units	Mechanism not necessary in RC relays. Flow control can be used instead.

Tab. 3.1 Congestion Control mechanisms in RC relays [EWOS 90]

Buffer allocation policies have great impact in throughput as well as in transit delay. Channel service policies must guarantee fairness in bandwidth utilization among users.

This work is focused on 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.

Table 3.2 summarizes the relaying module, X25 protocol, CSMA/CD subnetwork, PSDN subnetwork and end system characteristics that are included in the model.

Based on the aspects summarized on table 3.2 a simulation model was built up using Activity Cycle Diagrams (ACDs) [Clementson 82].

module	**characteristics**
Relaying	- Static buffer allocation policy: buffers are allocated according to window size and packet length - Round-robin channel service policy - Segmentation and reassembling capabilities, to match different window and packet sizes
X.25 protocol	- 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	- 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	- 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)	- 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: - throughput - transit delay

Tab. 3.2. Summary of characteristics included in the model.

3.1 Model of the RC Relay for Simulation

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].

In figure 3.1 the ACD model for the relay is presented. Taking, for example, the *PSDN packet* cycle (represented by ··········), the figure shows a three-activity cycle: *outside queue* -> *Arrival to PSDN end-system activity* -> *PSDN end-system channel queues* -> *Reception Relay activity* -> *RELAY channel queue* -> *Transmission LAN activity* -> *outside queue.* This activity cycle is going to described in detail as example.

First, PSDN packets are *outside* the system and must *Arrive to PSDN end-system*. The arrival is controlled by a *door* entity that is responsible for the interarrival distribution (Poisson arrivals). The arrival activity models data generation by users (human or machine) in the PSDN end-systems. Each user is attached to a channel (X.25 virtual call) from the end-system to the relay. Data for

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Figure 3.1 ACD model for the relay

channels is generated in blocks of variable size with a probability distribution (corresponding to the generation of N-Data primitives by the Network service users). Data blocks are then split (if necessary) into PSDN packets, taken from the *outside queue* and transferred into the *PSDN end-system channel queue* (one for each channel).

PSDN packets in *PSDN end-system channel queue* wait to be transmitted to (received by) the relay. This is done by the *Reception Relay activity* that takes one *PSDN packet* from one channel queue (selected randomly), one *window* free from *window PSDN free queue* of the window PSDN activity cycle, and the number of *buffers* necessary to store the packet from *buffer free queue*. The *PSDN receiver* entity ensures that only one reception can occur at a time.

Once received, PSDN packets stay in relay queues waiting to be transmitted into the LAN. When the LAN medium is free (LAN transmitter and receiver idle) a channel with packets pending is selected in a round-robin way and a packet is transmitted. Segmentation or reassembling can occur to match different packet sizes in the PSDN and LAN subnetworks. Transmitted packets free relay buffers and go into the *outside queue* where they wait to be reused in subsequent cycles.

LAN packet entities follow a cycle similar to PSDN packets. In fact the model is very symmetrical for the two traffic directions, crossing the relay, the exception is the difference between LAN and PSDN lower layers and physical mediums: the PSDN physical medium is slow (not necessarily) and duplex, LAN medium is fast, half-duplex and not for exclusive use of the relay and end-systems using it - other LAN stations also contribute to load. These differences are reflected in the *PSDN receiver, PSDN transmitter, LAN receiver/transmitter and LAN physical medium* entity cycles.

From the model illustrated in Fig. 3.1, and briefly described above, a simulation program in ECSL was driven with the help of CAPS (Computer Aided Programming System) [Clementson 82], a tool to help the generation of ESCL program from ACDs.

4. SIMULATION RESULTS

Two different aspects of congestion control identified in previous chapters - *congestion collapse avoidance* and *fairness guarantee* - have been analyzed by simulation of the RC51.1xxx relay family.

4.1. Congestion Collapse Avoidance

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

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 know as the *congestion collapse zone*.

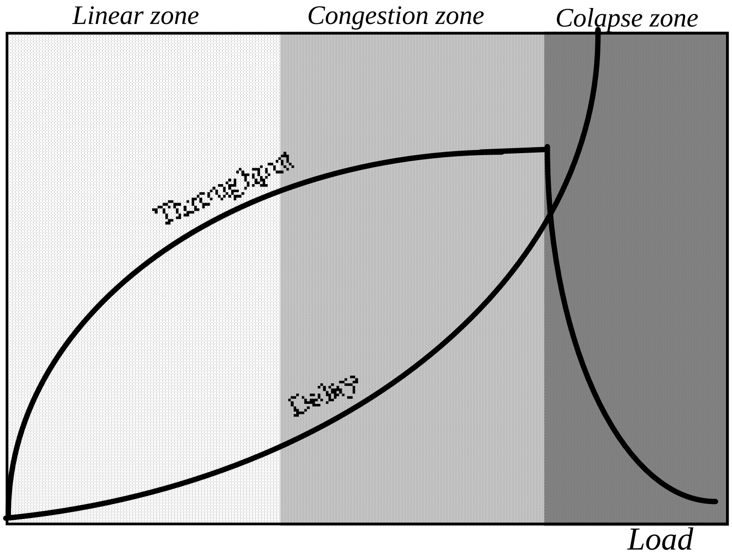


Fig. 4.1 Communication systems congestion behavior

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, further more, the collapse region.

In order to evaluate the congestion collapse avoidance behavior of RC51.1xxx relays, several simulations have been made. Six, equal demand, active channels were considered in the simulation setup (this number was imposed by the simulation hardware environment, but it was found to be enough to the analysis made). The demand in the channels was progressively increased in order to obtain total load values from 10% (small load) to 1000% (strong overload) of the relay capacity. All the other parameters remained equal. Table 4.1 shows a summary of the most relevant parameters of the simulations made.

Figures 4.2 and 4.3 show the simulation results relative to LAN originated traffic and PSDN originated traffic respectively.

Plotted values are the average of channel values. Throughput values are plotted normalized to link speed capacity (PSDN link speed for the *‘Relay <-> Psdn’* traffic, and LAN transmission rate for the *‘Relay <-> LAN’* traffic). Transit delays are measured in seconds and queue lengths are plotted normalized to maximum queue size. Load values are relative to communication system bottleneck, which was the PSDN link speed.

As can be observed from the plots the congestion collapse zone is never reached, even under severe load situations (10 times the bottleneck capacity).

The PSDN -> LAN traffic (Fig. 4.3) doesn’t congest the relay because load increase has only effects on end systems. For this traffic direction, queues never build up in the relay, and the delay introduced by it is neglectable, compared to the total delay. When the total load (the sum of the loads in the PSDN -> Relay active channels) reaches the PSDN link capacity, end-system queues built up and saturate, disabling new data from being generated *(backpressure effect).*

As could be predicted LAN -> PSDN traffic (Fig. 4.2) is the responsible for congestion on the relay system. For load under 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 the relay moves from the linear zone into the congestion zone. Queues built up in the relay and in end-systems, and transit delays increases exponentially with load. When the load reaches the bottleneck capacity, the relay queues saturate causing the saturation of source end-system queues. This effect prevents new data from being generated and stabilizes transit delay.

Flow control avoids queue overflow and thence avoids the entrance of the relay in the congestion collapse zone. From the analysis made it can be concluded that built in X.25 flow control procedures, acting together with input buffer limit in end-systems and a static buffer allocation policy with round-robin service discipline in the relaying module can ensure congestion collapse avoidance.

Unlike collapse avoidance, congestion avoidance can not be guaranteed by built in X.25 flow control procedures. When the load approaches the system bottleneck capacity queues built up, transit delay grows exponentially with load and the relay becomes congested.

Parameter	Value
Number of active channels	6
Relay buffer size	128 bytes
LAN channel window size	4 packets
LAN maximum packet size	1518 bytes (ethernet maximum)
LAN N-DATA primitives medium size	1024 bytes
LAN N-DATA primitives interarrival time	10.000 to 100 ms (Poisson)
PSDN channel window size	4 packets
PSDN maximum packet size	128 bytes (X.25 default)
PSDN N-DATA primitives medium size	1024 bytes
PSDN N-DATA primitives interarrival time	10.000 to 100 ms (Poisson)

Tab. 4.1 Summary of the simulation parameters

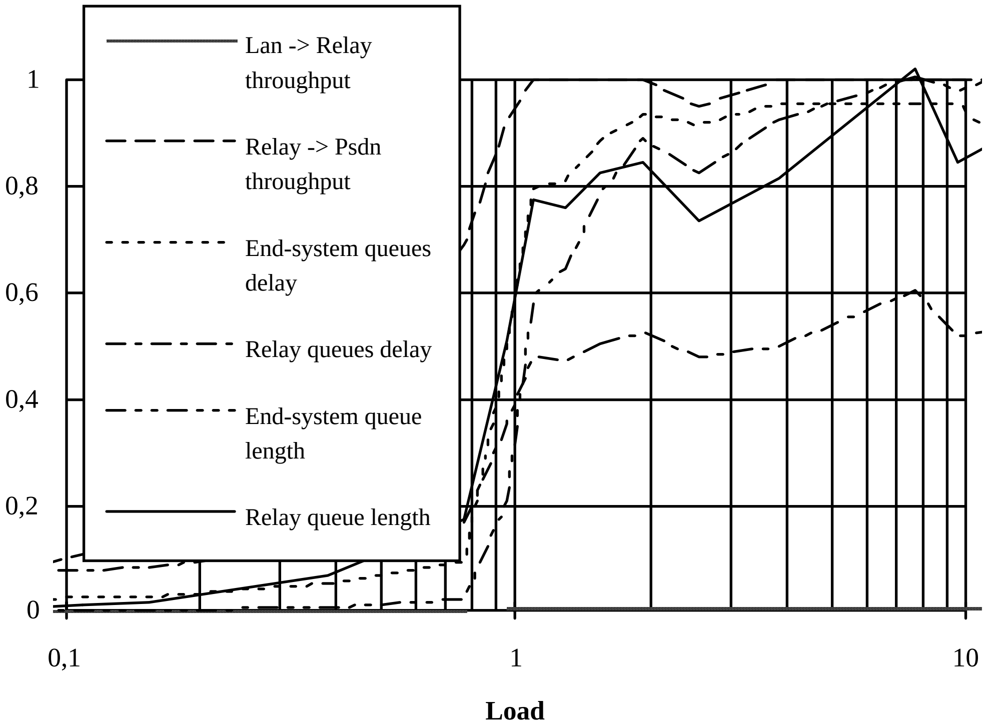


Fig. 4.2 Simulation results relative to LAN originated traffic

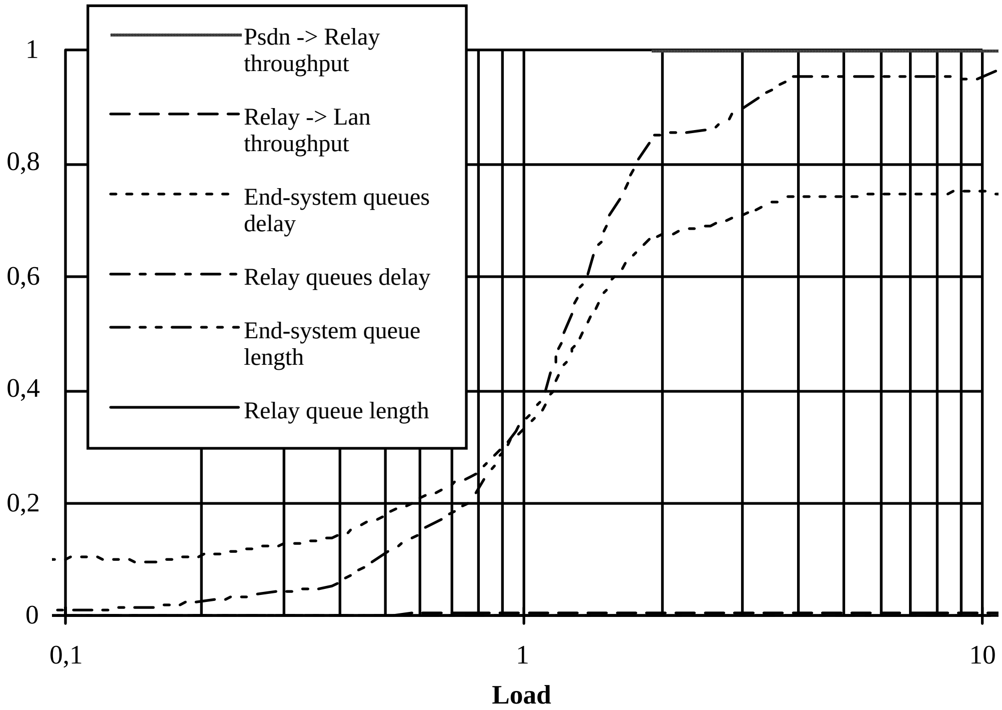


Fig. 4.3 Simulation results relative to PSDN originated traffic

Looking now at channel level, figures 4.4 and 4.5 show channel throughput and transit delay, respectively, for LAN -> PSDN traffic (critical traffic). From these plots it can be observed that a reasonable degree of fairness is achieved between channels. The channel values follow relatively close the average value, even when the load is fairly above the bottleneck capacity. This result is not surprising because the channels have all equal demand and all other simulation parameters are also equal. A more careful analysis of the relay fairness characteristics will be made in the next section.

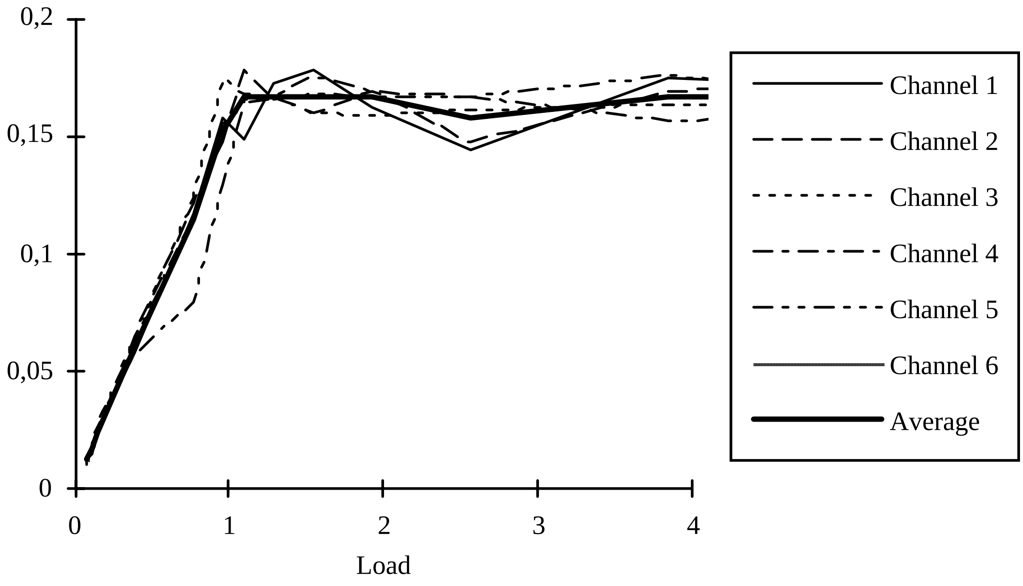


Fig. 4.4 Channel throughput of LAN -> PSDN traffic

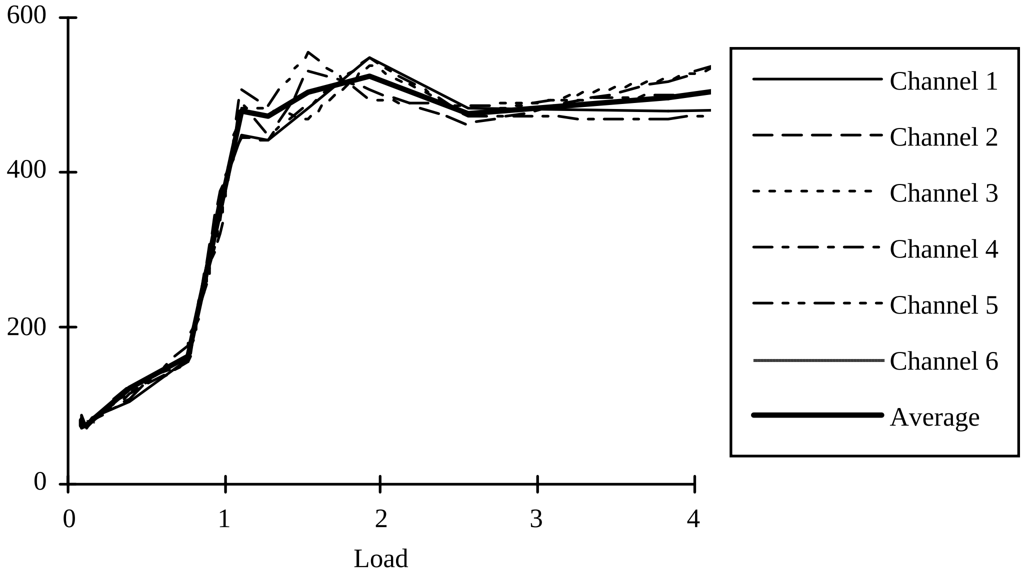


Fig. 4.5 Channel transit delay of LAN -> PSDN traffic

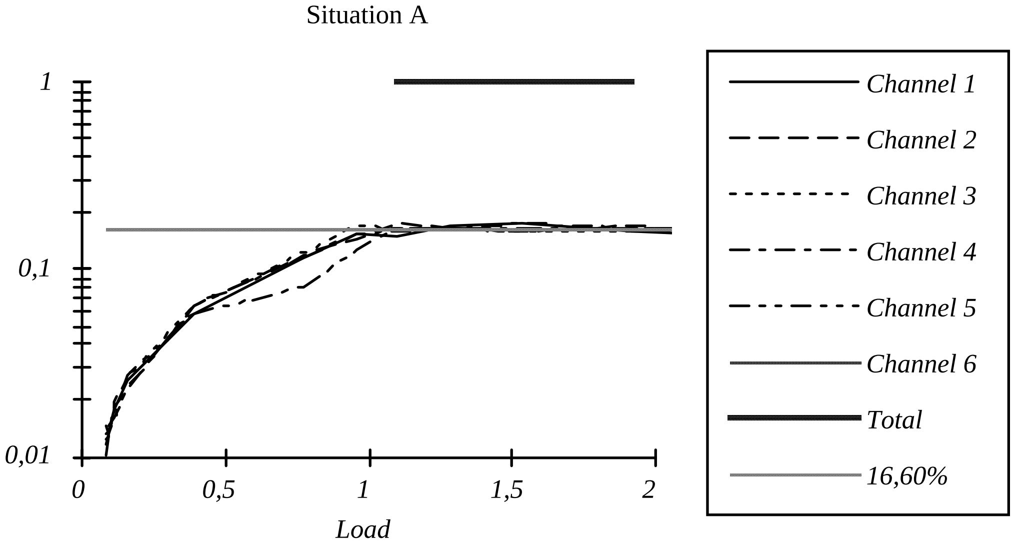
4.2. Fairness Analysis

To evaluate fairness it’s necessary to look at the channel level with detail. For that propose tree different situations where considered.

In situation A all six active channels are equal *“ill behaved”*. This means that they don’t respect their share of available resources and they increase demand beyond it.

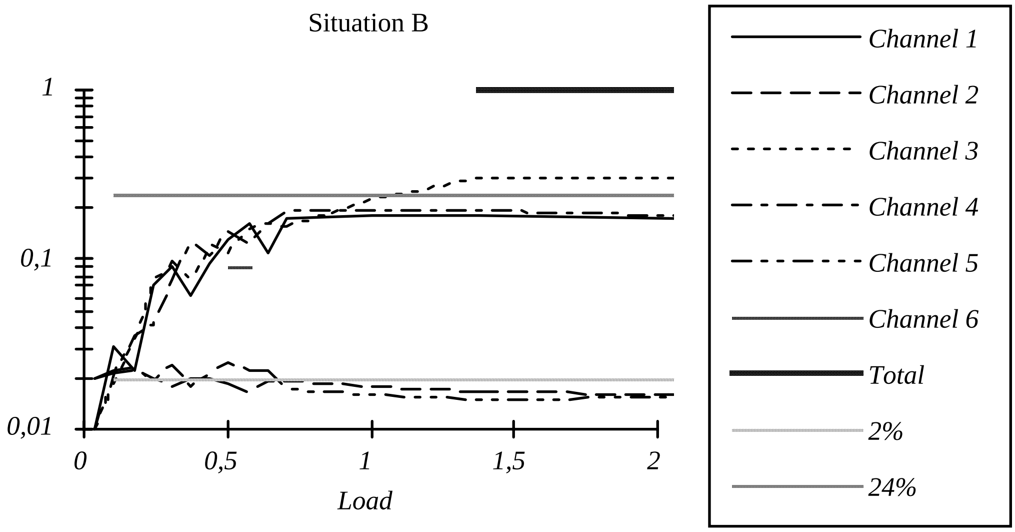
In situation B interactive, *“well behaved”*, traffic is mixed with ill behaved “file-transfer-like-traffic”. Two channels (2 and 5) carry terminal generated traffic with small data blocks and medium interarrival times. The demand of these channels is constant and small (2% of the available bandwidth 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.

Finally, in situation C four well behaved (1, 2, 3 and 4) and two ill behaved (5 and 6) channels are considered. The well behaved ones stop increasing the demand when they reach their share of bandwidth, specified by the throughput class QoS parameter. The ill behaved ones don't respect this limit and they continue increasing the demand. All six channels have "file-transfer-like" traffic patterns - data is generated in large blocks with small interarrival times. Table 4.2 summarizes the main parameters of situations A, B and C.



Parameter	Situation A	Situation B	Situation C
Number of active channels	6	6	6
Ill behaved channels	6	4	2
Well behaved channels	0	2	4
Ill behaved channel N-DATA med. size	1024 bytes	1024 bytes	1024 bytes
Well behaved channel N-DATA med. size	-	40 bytes	1024 bytes
Ill behaved channel N-DATA interarrival	8000 - 100 ms	8000 - 100 ms	8000 - 100 ms
Well behaved channel N-DATA interarrival	-	500 ms	8000 - 800 ms
Ill behaved channel bandwidth	16,6 %	24%	16,6%
Well behaved channel bandwidth	-	2%	16,6%
Relay buffer size	128 bytes	128 bytes	128 bytes
LAN channel window size	4 packets	4 packets	4 packets
PSDN channel window size	4 packets	4 packets	4 packets
LAN maximum packet size	1518 bytes	1518 bytes	1518 bytes
PSDN maximum packet size	128 bytes	128 bytes	128 bytes

Table 4.2 Summary of the simulation parameters



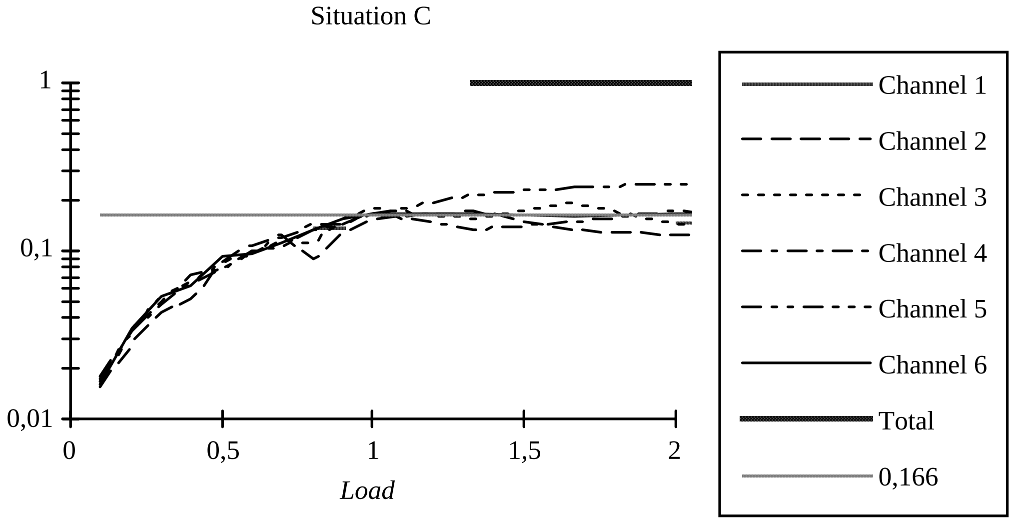
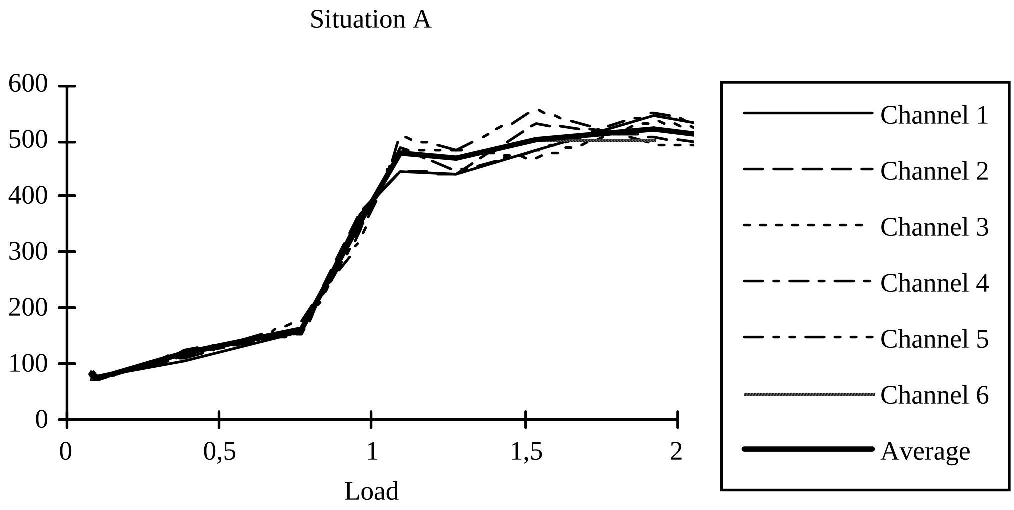
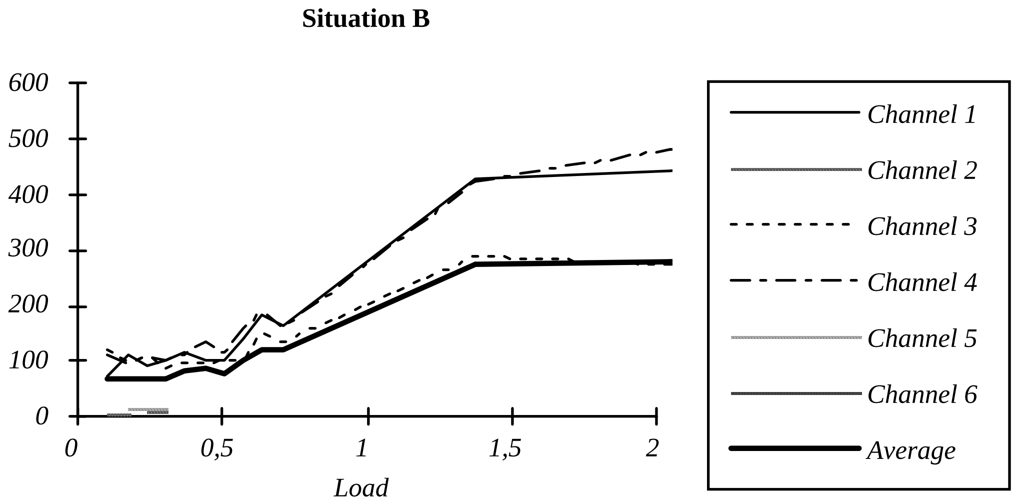


Figure 4.6 PSDN bandwidth utilization





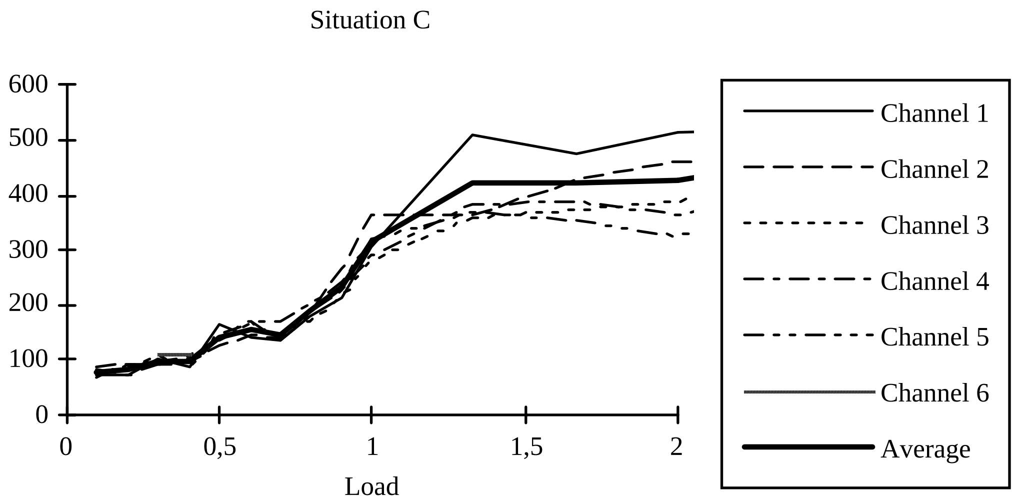


Figure 4.7 Delay in Relay queues

Figure 4.6 shows the PSDN bandwidth utilization by active channels in the three described situations. Given the large range of plotted values, throughput is represented in a logarithmic scale in order to reduce de size of the plots.

In situation A all the ill behaved channels get their fair share of the bandwidth available in the PSDN link, even when demand exceeds capacity. Flow control procedures prevent de relay from entering the congestion collapse zone, and round-robin service discipline ensures fairness among equally demanding ill behaved channels.

In situation B 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 is spite of this limit. Well behaved channels have a constant demand of 2% each. When the system reaches the congestion zone bandwidth begins to be unfairly shared among active channels. Well behaved channels and ill behaved channels 1 and 4 get less than they demand. Ill behaved channels 3 and 6 get more. This is due to the round-robin channel service discipline: channels 3 and 6 are served just after the low demanding 2 and 5 channels.

In situation C, when demand exceeds capacity, the first ill behaved channel (in the round-robin sequence) gets more bandwidth then its fair share, stealing it from all the others.

From the three situations described and, as far as throughput QoS parameter is concerned, it can be concluded that fairness is not guaranteed by the relay. Only situation A exhibits a fair share of bandwidth, and this is because all channels have equal throughput QoS parameter. In situations B and C fairness couldn’t be achieved when the demand exceeded the available capacity.

Looking now at the transit delay QoS parameters (Fig. 4.7) for situations A, B and C, the same conclusion is reached: fairness can only be guaranteed if all channels have equal QoS transit delay parameters (situation A).

In situation B, when congestion arrives, channels 3 and 6 (the ones served after well behaved channels 2 and 5) get a relatively lower transit delay compared to channels 1 and 4 (200 ms less). Transit delay of the well behaved low demanding channels is also affected by congestion, increasing more than 400 % (from around 20 ms to 100 ms).

In situation C unfairness is also present in the congestion zone. The first (in the round-robin channel service order) ill behaved channel (channel 5) gets a transit delay 100 ms lower than average and, in turn, channels 6 and 1 have transit delays around 100 ms higher than average.

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.

Activity Cycle Diagrams - the modeling technique used in the study - revealed a very good descriptive power for communications systems and can be used as formal description technique. ACDs have good characteristics for performance studies and are directly supported by a the simulation language ESCL.

The simulations made revealed that round-robin service discipline and static buffer allocation algorithms in conjunction with X.25 built-in flow control mechanisms, are enough to avoid the congestion collapse in X.25 protocol relays, even under severe load situations.

On the contrary, congestion avoidance and fairness can not be achieved. Throughput and transit delay user QoS parameters are not respected when the demand increases above 80% of the system bottleneck capacity (PSDN link). To avoid congestion, the load should not exceed this limit. The study showed that X.25 built in flow control mechanisms are not capable of such job.

To ensure fairness against QoS parameters a dynamic evaluation of the resources and bandwidth needed by each connection is necessary. The relay channel service, buffer allocation and acknowledgment algorithms must also be modified in order to receive input from the dynamic evaluation algorithm and, all together, guarantee fairness in resource utilization and the QoS expected by relay users. This is the subject of further on-going work.

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