MODELLING PROCEDURE TO INCREASE THE EFFICIENCY IN FIBER BROADBAND ACCESS NETWORKS

Aggregating traffic streams in a cable network

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Abstract: This paper provides a strategy to create accurate and complete models of cable networks for voice and data transmission. Also, a model of the traffic generated in a fiber broadband access network is implemented, representing the use that network subscribers make of the system. Traffic models are essential for the performance evaluation of telecommunications networks. Broadband access networks need an accurate estimation to guarantee an acceptable Quality of Service (QoS) level to the subscribers. Therefore, traffic models need to be accurate and able to represent the statistical characteristics of the real traffic. The simulation of great networks with high traffic volumes requires the establishment of an analysis methodology to increase the efficiency in the simulator resources consumption, in order to minimize the simulation run time and the memory consumption without loss of precision in the results. The model developed uses the number of subscribers assigned to each return channel. The traffic in each return channel is obtained from the aggregation of the separated traffic streams originated by the user's applications executed. The results obtained in these processes can be validated using the real data provided by a fiber cable operator. For the accomplishment of the model, the OPNET simulation language has been used. The results have been exported to MATLAB, which permits the execution of all types of statistical analyses, with the aim of both making the verification of the results and the validation of the developed model.

1 INTRODUCTION

The great growth experienced in recent years by information technologies, mainly due to the expansion of the Internet, has also meant a considerable increase in the volume of traffic and number of users and in types of applications. New telecommunications networks must be able to provide the integration of TV services, voice services and data services. This fact has motivated the study of the statistical characteristics of the traffic generated in the network, which is determined by the users behaviour and the actions of the necessary protocols for the communications between the different elements in the networks (García et al, 2003) (Kleijnen, 1999) (Floyd and Paxson, 2001).

The recent appearance of new network services has supposed a considerable increase in the consumption of resources from the networks and the involved computers. A continuous growth in the consumption of these resources may lead to unexpected performance degradations in systems that were working proficiently in the past. The accomplishment of previous analyses could help to determine the impact that new services will have in the future, to take the necessary precautions in order to avoid problems that may arise and the consequent displeasure of the users of the network, and to avoid elevated deployment costs.

To gain access to wider bandwidths with low costs, a network access technology is needed in order to connect broadband transmission lines, throug optical fiber, with the end users, guaranteeing QoS for all the applications (Madav et al, 2001). Historically, the telecommunication providers have used HFC (Hybrid Coaxial Fiber) technologies, where the optical fiber is used in the backbone of the network and the coaxial cable connects the backbone with the individual users. More recently, the telecommunication operators have begun to replace the coaxial cable with optical fiber. These circumstances have led to the appearance of FTTX technologies, where the optical fiber directly takes broadband services to the home (FTTH: Fiber To The Home), to the curb (FTTC: Fiber To The Curb),

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to the building (FTTB: Fiber To The Building) or to the service area (FTSA: Fiber To Service Area).

Rigorous studies made of high quality samples from data networks, have demonstrated that traffic processes present the statistical property of self-similarity, which cannot be obtained from the traditional models of Poisson (Leland et al, 1994) (Paxson and Floyd, 1995). The characteristic of these self-similar processes is that they present a long-range-dependence (LRD), defined as a slow decrease in the autocorrelation function, of the form:

$$r(k) \propto c_r k^{-(2-2H)}, \quad k \to \infty$$

where $c_r > 0$ and $0.5 < H < 1$. The fundamental parameter that describes LRD property is the Hurst coefficient, when $0.5 < H < 1$, LRD appears and the process exhibits self-similarity.

Simulation models are increasingly being used in problem solving and in decision making processes. The developers of these models and the decision makers use the information derived from the results of the models. They would have to know when a model and its results are correct. This concern is addressed through model verification and validation (Sargent, 2000). To simulate systems with great volumes of differentiated traffic, traditionally analytical techniques or discrete events methods are used, depending on the precision of the results and the simulation run time. To implement the complete network model, a hybrid simulation technique has been used (OPNET, 2001), facilitating model systems that present high volumes of traffic in relatively short execution times. Using the hybrid simulation, OPNET has developed a new technique called “micro-simulation” (OPNET, 2002) that combines analytical techniques and discrete events to provide control over the precision of the results and the execution time in a simulation.

A general survey of traffic models in telecommunications networks is carried out in (Adas, 1997). (Klemm et al, 2001) present a synthetic traffic model based on measured trace data. Furthermore, they introduce an aggregated traffic model for UMTS networks that is analytically tractable. Anagnostou et al, propose a traffic model for multi-service IP networks taking into account individual user descriptions (Anagnostou et al,1996).

Our contribution has been to develop a modelling procedure capable of managing high volumes of differentiated traffic with short execution times. This procedure makes possible an accurate analysis of network and services, including QoS configuration and SLA accomplishment. We also develop a model based on the real behaviour of the users of a cable network, taking into account the number of subscribers assigned to the return channel as well as the use that each subscriber makes of the network. Furthermore, the medium access protocol has been considered and the responses to users’ requests have been modelled. The aggregated traffic generation model developed has been integrated in the TCP/IP protocols architecture to facilitate the construction of a complete network model. Finally, the obtained results have been validated using the real data provided by the network operator.

This paper is organized as follows. In section 2, we describe the simulation methodology designed and the real system to be modelled. In section 3 we perform a model of aggregated traffic generation in an HFC or a FTSA network, indicating the obtained results. Sections 4 and 5 present our conclusions and future work.

2 SIMULATION METHODOLOGY

In order to simulate great networks with high traffic volumes it is important to define an analysis methodology. It will also be used as a prior study to QoS implementation and SLA definition. The purpose is to analyze the effects produced in the network and in the applications by different QoS solutions. The process is reflected in figure1.

2.1 Real System Description

The first step is to define the network to be analyzed. The Cable Telecommunications Network is able to support integrated services of TV, voice and data, as shown in figure 2. The HFC network infrastructure permits the optical fiber to reach each secondary node giving service to 250 homes (FTSA).

Figure 2 shows the network topology of the operator, where each subscriber is connected from his home or office through a cable-modem. Nowadays, there are simultaneously implemented IP access networks and ATM access networks. Through a fiber network, the requests are sent to the CMTS (Cable Modem Termination System) or to the HCX (Headend-Context Switch), where the communication with the IP router or ATM switches is established. Routers and ATM switches transfer the traffic to the optical fiber backbone that links the different branches of the network, addressing the traffic depending on the destination of the request.

The traffic can have as a destination the branch where the subscriber is connected (internal traffic), another branch owned by the operator network (local traffic) or the traffic can go to the outside through the routers (external traffic).

Communication between the subscribers and the local head-end is bidirectional, the downstream channel being shared by all the subscribers

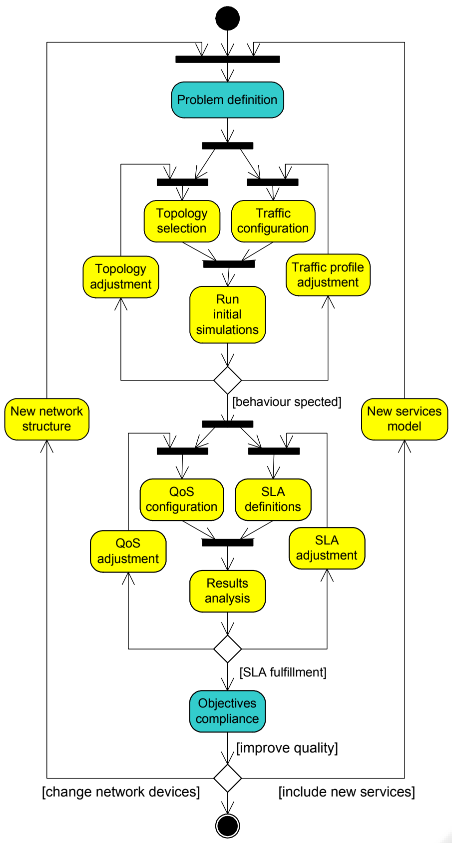

Figure 1: Analysis procedure

connected to each CMTS / HCX. In the upstream channel the subscribers are assigned to the six existing return channels. The transmission is not symmetrical, the downstream channel having a transference rate of 24Mbps and each upstream channel 1.5Mbps. Both cablemodem and CMTS are based on the EURODOCSIS 1.1 (European Data Over Cable Service Interface Specifications) standard.

2.2 Topology Selection

In this section we establish the network topology selection phase. Figure 3 illustrates this process.

In order to determine the network scheme it is necessary to know some aspects of the real network to be modelled, such as Network Device Identification, Physical Disposition in the Real System, Function in the Network, Implemented Protocols and Flows and Traffic Profiles.

To build the topology it is important to determine if we need to aggregate portions of the network. In the cable network aggregation will be carried out in the following portions of the network, when detailed analysis is not necessary: *HFC Networks of CMTS* (or HCX controllers), *Internet*

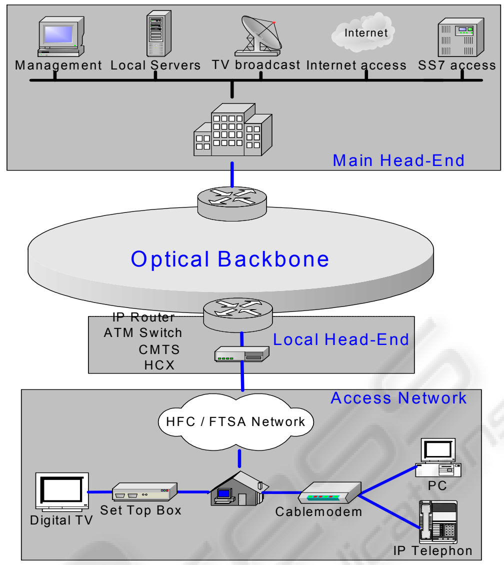

Figure 2: Network topology

Network, since this one is outside the corporative control. It will be represented like a simple "cloud" where we will model the traffic latency inside it as well as the packet losses that can cause the transit through it.

The network topology is constructed manually, following the real network structure.

Finally, we use three network topologies: complete, partial and single path. The complete topology includes all the connections and devices in the network. A partial topology shows a section of the network in detail. A single path topology contains only the infrastucture supporting the traffic between the final devices.

The complete topology studies aspects such as the link usage, routers behaviour and time delays of the application traffic in the complete network. In this topology all the traffic sources and destinations are represented. (OPNET, 2001)

When we need to represent in detail portions of the network, we use a partial topology. For example, if the objective is to study the utilization of a backbone, the backbone portion must be completely represented. Other sections of the network may be abstracted. However their effects should be captured when traffic information is entered. Also, we use a partial topology to model an HFC network in detail, aggregating the other sections of the network.

To study the behaviour of the network between two devices of interest we use a single path topology. The effect of the remaining portions of the network will be taken into account by representing the traffic that crosses, and therefore affects, the path of interest. This topology focuses on the interesting devices. Since other devices are not explicitly

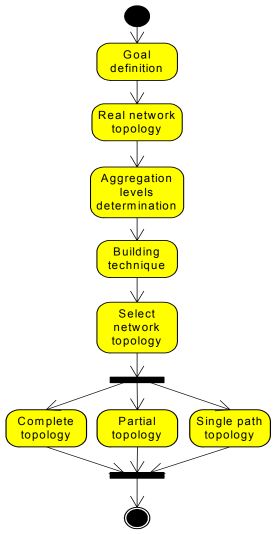

Figure 3: Building network topology

modeled, the simulation is very efficient. There is no loss of accuracy since the effect of the remaining network on the desired traffic is taken into account. This topology is used to model aspects such as the effect of the traffic generated by the users connected to a branch of the network, the response times of the application considering QoS, the delays in the network, the behaviour of protocols, etc. Also, it is employed to evaluate the benefits of VoIP.

2.3 Traffic Configuration

Traffic information is included manually, taking into account two types of traffic:

Background Traffic captured in the network. This traffic provided by the network operator from the real data will be included manually.

Background Traffic from previous simulations. This traffic is imported from simulations of the users behaviour and upstreams channels made to model the branches of the cable network.

Explicit Traffic, included to analyze the behaviour of an application in detail, and to study the influence of the access protocol used (DOCSIS). Combining explicit traffic with background traffic we make simulations with acceptable run times where the influence of QoS including applications like VoIP, VoD, etc, is shown.

Once the traffic specifications have been completed, we need to capture the simulations results, selecting the adequate statistics that allow us to verify if the generated traffic fulfills the demands. The statistics vary depending on the event to be simulated, including links throughput, queuing delays in the routers interfaces, packets losses, applications response times, end to end latency of the applications, etc.

Once the topology, traffic and statistics have been selected we execute the initial simulations to adjust the different structures within the model and to determine if the behaviour of the model is as spected. The results obtained in this step permits the verification and validation of the traffic profiles simulated with the real network traffic, as well as the selected routing protocols.

Now, the network will be populated with the real traffic (or statistically similar traffic) and we proceed to analyze the behaviour of protocols and applications of interest with differentiated traffic flows having different QoS to match the Service Level Agreements proposed.

3 TRAFFIC GENERATION

In this section, we develop a model of traffic generation to represent the use that the network subscribers make of the system. A partial topology of an HFC branch is used, aggregating the rest of the operator network and the Internet.

Figure 4 displays the model for one network branch, where it is shown that users are connected through the six upstream channels to the HCX controller, which sends requests to the rest of the network. The exterior network is modelled as an aggregate element that generates response traffic to users' requests.

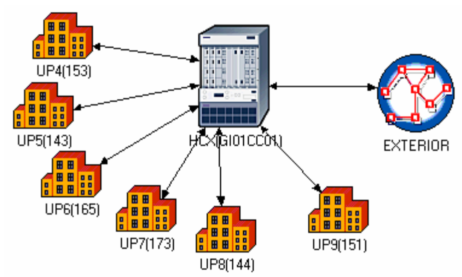

Figure 4: Network model

3.1 Traffic Modelling Process

(Sargent, 2000) describes the processes of verification and validation of simulated models. Following this methodology, with the suitable adaptations for the current problem, the process utilized to model the data network is illustrated in figure 5. The *Real network* is the physical network that is going to be modelled. The *conceptual model* indicates the mathematical, logical or verbal representation of the system, and the *OPNET model* is the conceptual model implemented on a computer. The *conceptual model* is obtained through an *analysis and modelling phase*, and the *conceptual model validity* determines if the theoretical arguments are valid and represent the nature of the problem. The computerized model is obtained in the *programming and implementation phase*, and the *OPNET model verification* ensures that both programming and implementation of the conceptual model are correct. Inferences about the real system are obtained by conducting computer experiments on the OPNET model in the *experimentation phase*. Finally, *data validation* ensures that the data necessary for model building, model evaluation and testing, is adequate and correct (Schlesinger, 1979).

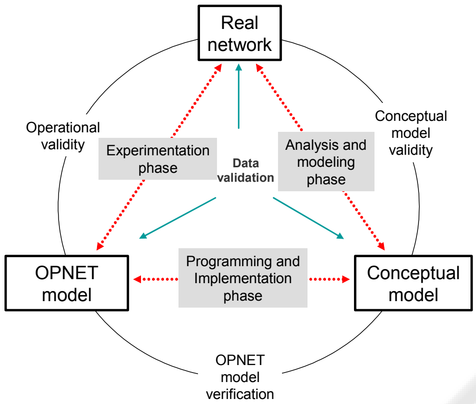

Figure 5: Modelling process of FTTX network

3.2 Analysis and Modelling Phase

In order to model the size of the requests and the inter-arrival time for the different types of traffic, the accomplishment of a prior study of the real data provided by the network operator is necessary. An exhaustive analysis appears in (García et al, 2003), where a complete and deep analysis has been carried out, and has permitted the accomplishment of this model within the OPNET simulator. Table 1 shows the data analysis process undertaken for each one of the traffic profiles.

Table 1: Data analysis

Basic representations	Time representation Frequency response Mean value analysis Peak value analysis
Underlying statistics	Variance analysis Autocorrelation analysis
Self-similarity analysis	Self-similarity study Hurst coeff. representation Self-similarity validation

The temporary representation exhibits the traffic evolution throughout the day, reaching the maximum values between 20:00 and 24:00 and the minimum values during the early hours of the morning. In addition, the periodogram of traffic profiles shows the cyclical evolution within a period of 24 hours. Another significant aspect of the analysis process is the graphical representation of the average and peak values of the traffic. Using these values we can obtain the regression lines indicated below, with the determination coefficients showing the precision of the regression:

$average=0.1119*subscribers-0.4076,\ R^2=0.551$

$peak=0.2201*subscribers+11.811,\ \ R^2=0.6540$

$minimum=44.579*(subscribers)^{-3.312},\ \ R^2=0.5063$

Examining the traffic evolution per subscriber, zones are observed where the traffic is constant, indicating that each subscriber contributes, approximately, the same to the global traffic. This traffic depends on the number of subscribers connected to the return channel, and is called interactive traffic. The interactive traffic corresponding to each application is the following: 27.87% HTTP, 29.06% MP3, 2.58% SMTP, 1.45% FTP and 39.02% *others* type of traffic, including real-time applications and UDP transferences. In other periods of the day (between midnight and dawn), the subscriber traffic begins to increase, indicating that few subscribers are generating high volumes of traffic. This traffic is originated by peer to peer applications and will be modelled specifically, its volume not depending on the users' behaviour.

In order to determine the number of users using the system, we can use the DHCP server data, which reflects the evolution of the number of assigned addresses. This temporary evolution is modelled using the Discrete Cosine Transform (DCT), where a small number of coefficients represent most of the sequence energy. Once calculated, the DCT coefficients y(k), IDCT (Inverse Discrete Cosine Transform) compute the inverse transformed, allowing the original signal reconstruction from few coefficients. Mathematically:

$$x(n)=w(n)\cdot\sum_{k=1}^{N}y(k)\cos\frac{\pi(2n-1)(k-1)}{2N} \qquad n=1,\dots,N$$

Using the information provided by the cable operator, the DCT coefficients are calculated and only those more significant are selected (with an absolute value greater than 20). We have used 13 coefficients, obtaining in the reconstructed signal 98,586% of energy from the original.

We compute the sizes of the generated packets and the inter-arrival time between requests. Peer-to-peer traffic is modelled using a Pareto distribution for the packet size, since this traffic comes from filetransference applications (Crovella and Bestavros,1997). Inter-arrival time is modelled by following an exponential distribution. For the interactive traffic, we compute the traffic generated by each connected user that is using a certain application. Inter-arrival time uses an exponential distribution, the one that best represents the human behaviour. In (Kelmm et al, 2001) a traffic characterization per application appears. The packet size distributions for HTTP, MP3, e-mail, and FTP follow a large extended discrete distribution. Table 2 shows that packets of sizes 40 bytes, 576 bytes, and 1500 bytes constitute the largest amount of the overall packet sizes. This phenomenon relies on the maximum transfer units (MTU) of Ethernet and SLIP (serial line IP) networks. The authors observe further, that the remaining packet sizes are distributed uniformly between 40 bytes and 1500 bytes. The traffic *others,* have been modelled using an exponential distribution for the inter-arrival time, and a normal distribution to model the packet size.

Table 2: Packet size fractions by application

Size	**40 byte**	**576 byte**	**1500 byte**	**Other**
HTTP	46.77%	27.96%	8.10%	17.17%
MP3	34.98%	45.54%	4.18%	15.30%
SMTP	38.25%	25.98%	9.51%	26.26%
FTP	40.43%	18.08%	9.33%	32.16%

This table permits the calculation of the inter-arrival time by subscriber for each application:

$$mean = \sum_{size} P(size) \frac{mean(size) \cdot 8}{interarrival\_time}$$

where size={40, 576, 1500, other} and P(40), P(576), P(1500) and P(other) are the packet size probabilities shown in table 2.

Conceptual model validity is carried out using the face validation technique, by means of the documentation revised on traffic characterization. The numerical calculations and the used distributions are adequate for the real problem.

3.3 Programming and Implementation Phase

The programming and implementation phase has been established using OPNET Modeler as the simulation language.

The different types of traffic are configured by ON/OFF models, presenting time intervals in which requests are sent (ON) and time intervals where there is no information transference (OFF), as indicated in figure 6 (Klemm et al, 2001).

A user can run applications such as HTTP, MP3, e-mail, and various other applications that may be concurrently enabled. Each application has alternating ON and OFF periods. The packet inter-arrival times within each connection and the

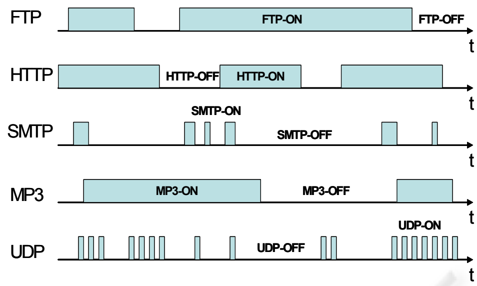

Figure 6: Application ON-OFF states

corresponding packet sizes are drawn according to an application dependent distribution. The overall traffic stream of one user is constituted by the superposition of the packet arrival processes for all application connections within the user's session. New users enter the considered system environment according to DCT equation and leave the system after passing the specified connection time.

According to these previous considerations, the UML activities diagram that represents the traffic model generation in the upstream channels is indicated in figure 7, where the traffic aggregation is appraised. We have implemented a mechanism for dynamic creation and destruction of processes, where each process represents the behaviour of a single-user carrying out requests according to the selected application.

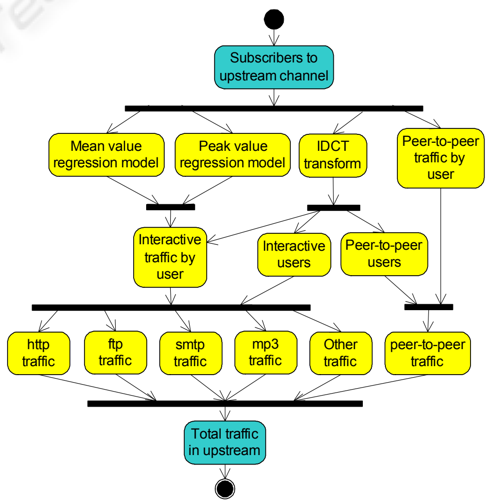

Figure 7: Traffic generation diagram

Users' requests reach the HCX controller through the six upstream channels. These packets can be sent to the outer network or can be internal traffic directed to a user of the network. In this case, the information is delivered by the downstream channel to the corresponding user. The information coming from the exterior network will receive the same treatment as the data coming from the return channels. Once it has been processed at a rate of 50000 pps, modelled by a FIFO queue, it will be sent to the destiny address. The *HCX Node Model* in figure 4 implements these functions.

The *Exterior network* models the behaviour of the rest of the network, the accesses to the operator servers and to the Internet. It returns responses to users' requests according to the size and the delay distributions obtained in the data analysis phase, depending on the traffic requests.

OPNET model verification is carried out by using techniques such as object-oriented design, structured programming and programme modularity, determining that the simulations are satisfactory and the computer model has been programmed and implemented correctly.

3.4 Experimentation phase

To obtain simulation results the temporary data distributions provided by the network operator have been considered. Thus, the provided data consists of 600 samples at intervals of 5 minutes, obtaining a total of 50 hours of simulation. We have simulated the 17 scenes corresponding to all branches of the cable network, with different numbers of users in upstream channels. We present only four scenarios to simplify the results. The simulated scenes presented, correspond to the users' allocations indicated in Table 3:

Table 3: Subscribers allocations to the upstream channels

HCX	Subs	UP4	UP5	UP6	UP7	UP8	UP9
GI01CC01	929	153	143	165	173	144	151
GI01CC02	1252	220	197	170	246	188	231
GI02CC01	1365	238	224	232	271	190	210
GI03CC01	1047	169	182	193	165	156	182

Operational validity is undertaken demonstrating that the model's output behaviour has the accuracy required for the model's intended purposes.

3.5 Data Validation

In figure 10, the traffic in upstream channels 5 and 7 from the GI01CC01 controller are shown. They have been scaled in bps, indicating the total generated traffic, and the traffic obtained per application. In figure 11.a the percentage of use in the downstream channels for each controller is observed. Figure 11.b displays the packet size of application requests in upstream 7 of GI01CC01.

The beginning of the simulation corresponds to 08:00 hours, according to the provided real data. The maximum traffic occurs from 18:00h to 24:00h, corresponding with the greatest number of

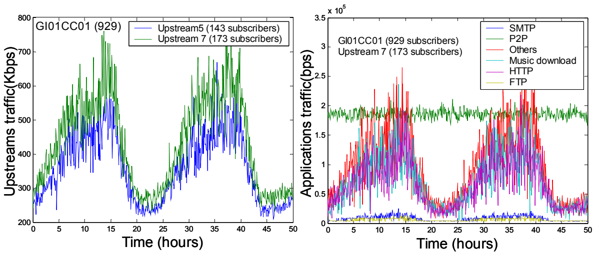

Figure 10: Traffic in upstream channels

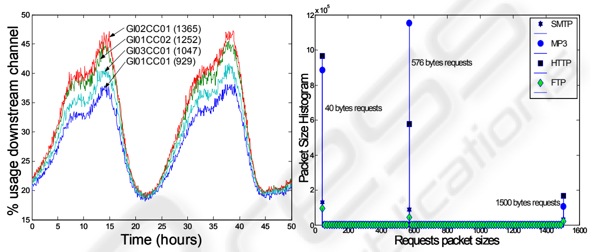

Figure 11: a)Traffic in downstream channels
b) Histogram of SMTP/MP3/HTTP/FTP requests

connected users. Also, a minimum between 5:00h and 6:00h is observed, where most of the generated traffic corresponds to peer-to-peer traffic that does not require the presence of the user to make the information transference.

Figure 10.a and 11.a show how more subscribers generate a greater amount of traffic. These traffic profiles have been compared to real traces. In figure 10.b we show how traffic per application agrees with that indicated in section 3.2. On the other hand, the histogram displayed in figure 11.b verifies the packet size fractions described in Table 2.

Furthermore, we have calculated the autocorrelation function to demonstrate the long range dependency (LRD) property. Another significant characteristic of the current traffic is its self-similarity property, determined by the Hurst coefficient. The obtained traffic will present the self-similarity property if $0.5<H<1$, the self-similarity being more intense when the Hurst value is near to the unit. If H □ 0.5, we will have a Poisson process. In order to calculate the Hurst coefficient we have used the methods indicated in table 4.

Table 4: Hurst coefficients in downstream channels

HCX Controller	REAL DATA	SIMULATION RESULTS		
		Variance-time plot	R/S plot	Period
GI01CC01	0.9218	0.9451	0.9384	0.8807
GI01CC02	0.9026	0.9458	0.9233	0.9636
GI02CC01	0.8835	0.9458	0.9274	0.9310
GI03CC01	0.9338	0.9457	0.9266	0.9368

4 CONCLUSIONS

The expounded work has allowed the specification of an analysis procedure of broadband access networks, reducing greatly the execution run times of the simulated models, using hybrid simulation techniques. This procedure also allows QoS analysis with differentiated traffic flows.

On the other hand, the model of the FTTX network that appears in this paper allows the generation of statistically comparable traffic profiles with the real data provided by the network operator. The configuration of the different upstream channels has been made possible, and it includes an HCX controller to which the subscribers are connected, the assigned upstream channel, as well as the number of subscribers in the upstream channel.

We also considered the different types of existing traffic in the network, providing a differentiated treatment for each kind in the distributions used for their generation as well as in the treatment of their requests to the system servers. All the developed process has been verified and validated from real data traffic captured in the network.

5 FUTURE WORK

Future work will be undertaken to define models of services and applications, such as VoIP, Video On Demand, peer-to-peer applications, in order to evaluate its behaviour in the network.

Another significant aspect is to perform a deep analysis of the access protocol (DOCSIS) and the routing algorithms used in the network.

The explicit traffic of the interested applications will compete for the network resources, with the traffic of the rest of applications. It will also be possible to analyze the effect of using QoS, being able to evaluate the performance of the network with differentiated traffic. We also need to define the SLA for each application, verifying their fulfillment from the obtained results.

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