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Delay and Throughput Analysis on a Cable Network for Video Streaming Services

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Abstract

Cable networks are spread all over the world as a solution to support television services. In order to take advantage of these deployed networks, the DOCSIS Data Over Cable Service Interface Specification standard that allow data transfers and provide internet access has been incorporated. With this in mind, this paper analyzes the parameters of quality-of-service delay and throughput in cable networks given the increase in the number of users who consume video streaming services. The knowledge of these parameters allows to estimate the access networks capable of supporting the high traffic demands generated by the multimedia content offered by the different social networks and the over-the-top (OTT) content distribution companies. Finally, the impact of video streaming consumption services on the QoS parameters on other types of applications is presented.

Keywords: Delay, DOCSIS, Throughput, video streaming.

I. INTRODUCTION

In Colombia, according to the ICT statistics portal, more than 90% of internet access for internet subscribers is supported by two technologies: Cable technology with 65.84% and XDSL technology with 27.19%. Therefore, this paper is focused on the study of the behavior of the Data Over Cable Service Interface Specification DOCSIS, which defines the requirements of the communications and operations interface to add data transfer over cable networks [1]. Consequently, cable operators can use DOCSIS to provide Internet over an existing hybrid fiber-optic-coaxial cable (HFC) network [2].

Then, this research provides information on the parameters of quality of service (QoS), delay, and throughput in cable networks. The knowledge of these parameters allows to adapt and generate solutions for the dimensioning and performance evaluation of the network elements and their interconnection as an access network capable of supporting the high traffic demands generated by the current killer applications as the multimedia content offered by different social networks and the over the top (OTT) content from distribution companies. In this respect, as relevant attributes for this research on cable networks there are: delay, throughput, and the access protocol to the shared means that they use.

The network delay specifies how long it takes for a bit of data to travel through the network from a source node to a final node; it is unidirectional, and its measurement unit is the second. This parameter is also known in telecommunications as latency [3], [4]. Delay has always been a particular problem for data network designers, and it is one of the determining parameters of the QoS. It is possible that this delay does not affect the bulk data transfer applications, but it does affect applications that involve interactivity such as the ones that are supported under the transport protocol TCP (Transmission Control Protocol) [5].

Throughput is one of the parameters established by the International Telecommunication Union (ITU), and it is used to measure QoS. This parameter can be defined as the average success rate for the delivery of information without including packet headers, acknowledgment (ACK), or retransmissions; in other words, only user data [6]. In this sense, it can be said that throughput is associated with the capacity of a channel to transport useful information; therefore, it establishes the amount of valid information that can be transmitted per time unit [6].

After several proposals by the ITU, cable operators have opted for the DOCSIS protocol [7], which defines the radio frequency specifications for high-speed systems over cable networks [8]. DOCSIS includes QoS features to support real-time traffic requirements [9], [10]. In a broader sense, DOCSIS is the set of standards, approved by CableLabs, that guarantee the interoperability of cable modem technology, with the aim of providing switched data access in CATV (Community Antenna Television) infrastructures over HFC networks initially designed for television signal transport, hence its strong asymmetry [11], [12]. In an HFC network, the fiber optic cables run from the CMTS Cable Modem Termination System and the fiber nodes while these are connected to the Cable Modem (CM) by means of copper cables; hence their name, optic fiber cable and copper cable hybrid networks [13]. The CMTS is the equipment that manages the CMs, the latter being the one that provide the users with the access point to the network [11], [12].

This research uses the OPNET Modeler research tool that allows to build scenarios with the DOCSIS protocol, the CMTS, and the CM. This is for the behavior analysis of the delay and throughput parameters generated by video streaming services supported on the TCP protocol, according to the protocols trend for video streaming services HAS (HTTP Adaptive Streaming). For this reason, the other QoS parameter, such as packet loss, is not relevant in this study. Thus, the contribution of this paper is demonstrating the potential of the OPNET Modeler tool in the study, designing, and planning of cable networks and its DOCSIS protocol, knowing the behavior of the QoS delay and throughput parameters in the face of the increase in users consuming video streaming services encoded with different qualities, and showing how the traffic generated by these applications influences typical internet applications such as light browsing through HTTP.

The rest of the article is organized as follows: section two presents the materials and methods where the scenarios and their configuration are described. Section three presents the results and their discussion where the cable network behavior is shown through the parameters used and the user number increase. Finally, section four presents the conclusions and future work derived from this research.

II. MATERIALS AND METHODS

The first step is the building of the simulation scenarios. They are made up of a streaming server where the multimedia content is hosted. The server is connected to a CMTS where a bus topology is generated from a single interface; each node is made up by a CM and a host. The different scenarios make it possible to analyze the network behavior with the increase in users and traffic generated by the video streaming service with different encoding qualities.

Regarding the server and according to the OPNET Modeler tool, the profiles, applications, task specification, and the phases that represent the video streaming applications behavior are configured. Profiles is a collection of applications that describe the activity patterns of an individual user or a group of users in such a way that for this investigation a single video streaming profile was defined. The applications specify the parameters of requests and responses, as well as grouping tasks. Among the applications are the Custom Applications that allow making custom models, in which the traffic pattern generated by the simulated application can be configured with specific attributes such as time between requests, packet size in bytes, packets per request, time between packets, etc. [14], [15].

In the task specification, the number of tasks to be created are entered in a way that 6 tasks were created for this model corresponding to each one of the characterized samples of video streaming services. Each task has phases on which the mathematical parameters that characterize the behavior of the video streaming flows are chosen. For this research, 6 videos were characterized whose probability density functions that describe their behavior are presented in tables 1 and 2. These are, then, the traffic input parameters necessary to carry out the simulation using the OPNET Modeler tool. For the size of the bursts measured in number of packets, the analysis shows different distribution functions according to the coding qualities. However, during the process of the Kolmogorov-Smirnov goodness-of-fit tests, it is observed that all samples can be characterized by a Laplace probability density function, whose parameters are those presented in Table 1. The time between bursts can be characterized by a normal probability density function, whose parameters are presented in Table 2.

Table 1. Characterization of the size of video streaming flow bursts using Laplace distribution.

video streaming flow	**1** (AA32V144)	**2** (AA32V528)	**3** (AA32V528)	**4** (AA64V528)	**5** (AA64V528)	**6** (AA64V528)
Bitrate (Audio & Video) (Kbps)	32 & 144	32 & 528	32 & 1008	64 & 144	64 & 528	64 & 1008
Mean	15	24,5	43,0	18	24,5	46,5
Escale	0,1722	0,115	0,081	0,151	0,152	0,087

Table 2. Characterization of time between video streaming flow bursts using Normal distribution.

video streaming flow	**1**	**2**	**3**	**4**	**5**	**6**
Mean	0,967021	0,948749	0,921313	0,956326	0,943724	0,93095
Typical deviation	0,0184262	0,023054	0,0274772	0,0168749	0,018591	0,0223895

Table 3. Scenario configuration.

<table>
<tr><th colspan="5">Scenarios 1 and 2</th><th>Total users</th></tr>
<tr><td colspan="2">Audio (Kbps)</td><td>Video (Kbps)</td><td>Label: video streaming flow</td><td>User</td><td rowspan="4">3</td></tr>
<tr><td rowspan="3">32
Scenario 1</td><td rowspan="3">64
Scenario 2</td><td>144</td><td>AA(32 /64)V144</td><td>node_0</td></tr>
<tr><td>528</td><td>AA(32/64)V528</td><td>node_1</td></tr>
<tr><td>1008</td><td>AA(32/64)V1008</td><td>node_2</td></tr>
<tr><td colspan="5">Scenario 3</td><td rowspan="2">6</td></tr>
<tr><td colspan="2">Scenario 1 + 2</td><td colspan="3">video streaming flow: 1, 2, 3, 4, 5 and 6
node_(0, 1, 2, 3, 4, 5, 6)</td></tr>
<tr><td colspan="5">Scenario 4</td><td rowspan="3">14</td></tr>
<tr><td colspan="3">Video streaming flow: 1, 4, 5 and 6.</td><td colspan="2">Two users each.</td></tr>
<tr><td colspan="3">Video streaming flow: 2 and 3</td><td colspan="2">Three users each.</td></tr>
</table>

Table 4. DOCSIS basic configuration.

DOCSIS configuration	Descending Channel	Ascending Channel
Modulation	256-QAM	QPSK
Data rate	55 Mbps	2.56 Mbps
Channel bandwidth	8 MHz	800 KHz
Central frequency	550 MHz	12 MHz
Fragmentation Option	Enabled	

Four scenarios were defined where a client is configured for each one of the video streaming flows on the respective nodes (see Table 3). All the proposed scenarios have the configuration at the DOCSIS protocol level specified in Table 4.

The simulation times were 10 minutes each since the IP address assignment was configured through the DHCP protocol. The addressing process takes time to be carried out because of the large number of users, which makes it necessary to assign enough time to the profiles for the execution of the applications, their respective tasks, and phases.

III. RESULTS AND DISCUSSION

In this section, the analysis of the delay and throughput parameters is performed by simulating the behavior of a cable network under the DOCSIS protocol when the flow generated by multiple clients is transported simultaneously consuming video streaming services.

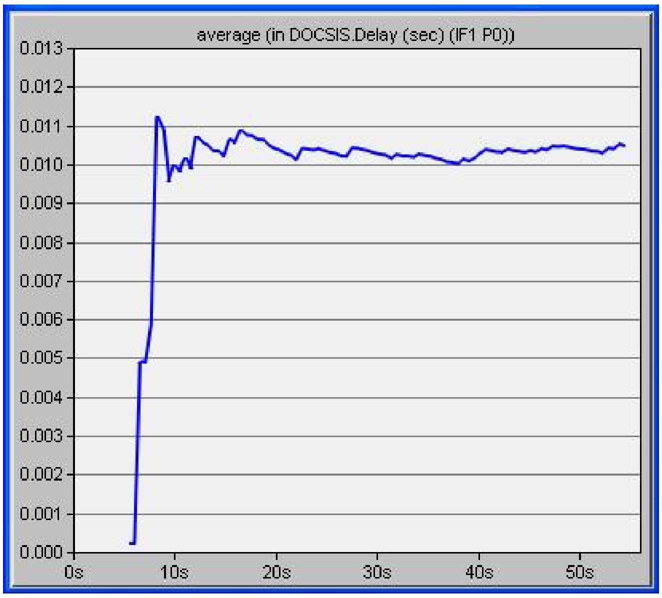
III.I Delay on different scenarios

The behavior analysis of the delay parameter for each scenario is presented next.

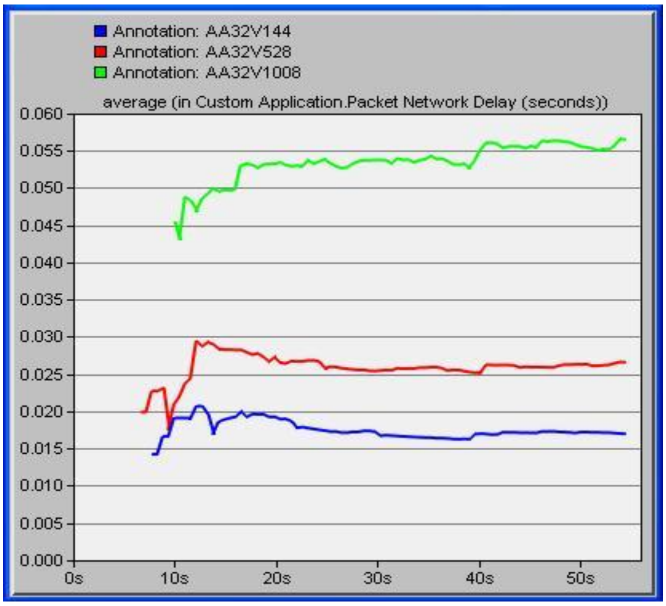
III.I.I Scenario 1 delay

The DOCSIS delay is measured from the moment a frame is queued for transmission at the DOCSIS MAC layer on the transmitter side (either CM or CMTS) to the moment it is delivered to the receiver. The application delay represents the time it takes for video streaming packets to reach their destination.

In Fig. 1a the DOCSIS delay is observed at the layer two level of the OSI tower (Open Systems Interconnection), which is between 10 and 11 ms average. At the application level, at the layer seven level of the OSI tower, there is the delay of each one of the video streaming flows, whose highest value is presented for video 3 since it is the video with the highest coding values (see Fig. 1b). It is observed that the network is capable of supporting video streaming flows 1, 2, and 3 simultaneously, with a delay value lower than the established limit of 150 ms [16].



a. DOCSIS

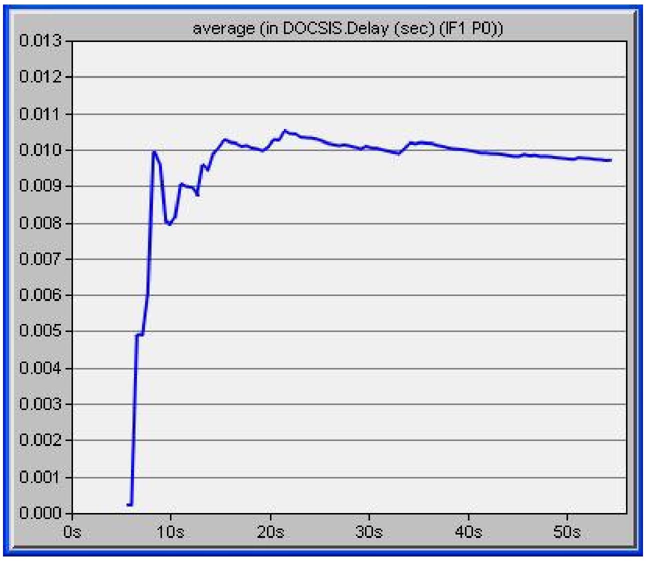


b. Applications

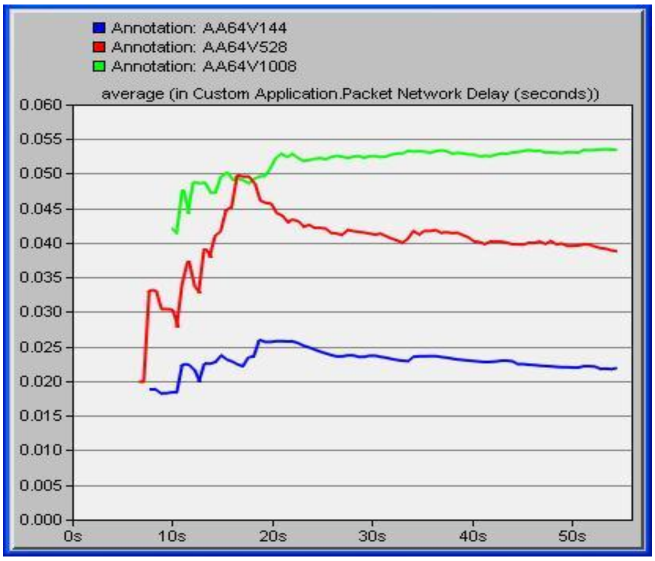
Fig. 1. Delay over video streaming flows 1, 2 and 3.

III.I.II Scenario 2 delay

Fig. 2 shows the delay both at the DOCSIS protocol level and at the application level for video streaming flows 4, 5, and 6. The behavior is similar to the one described for scenario 1. Therefore, the network is capable of supporting layer seven applications of the OSI tower; that means the corresponding video streaming flows present a value lower than the established limit of 150 ms for the delay [16].



a. DOCSIS

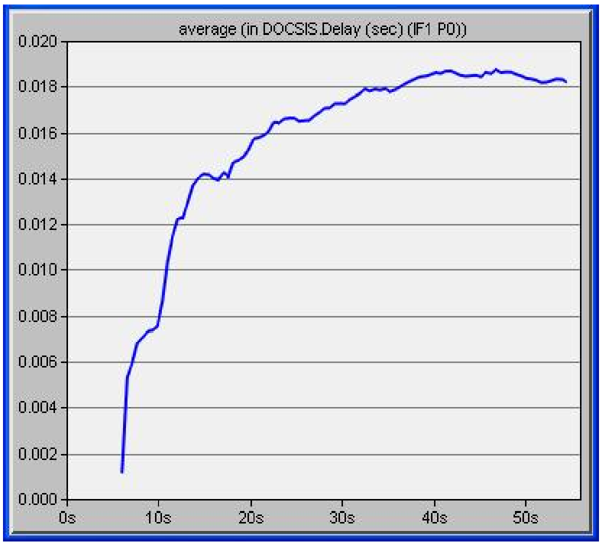


b. Applications

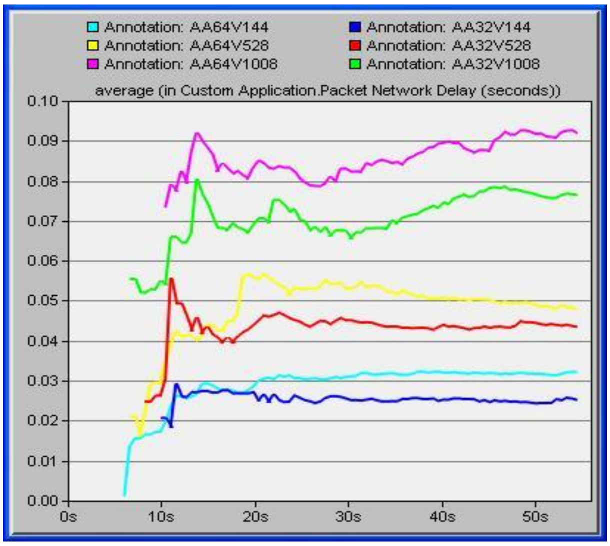
Fig. 2. Delay over video streaming flows 4, 5 and 6.

III.I.III Scenario 3 delay

Fig 3a shows the DOCSIS delay for all flows. Its value has increased to 19 ms as a consequence of the greater number of users compared to scenarios 1 and 2. At the application level, there is the delay of each of the video streaming flows whose highest value is presented for flow 6. This has increased by 45 ms in regards to the value presented in scenario 2, reaching a delay value of 95 ms (see Fig 3b); also due to the fact that the network must support a greater number of clients simultaneously. Despite these circumstances, it can be stated that the cable network can support the corresponding video streaming flows with a value lower than the established limit of 150 ms for the delay [16].



a. DOCSIS



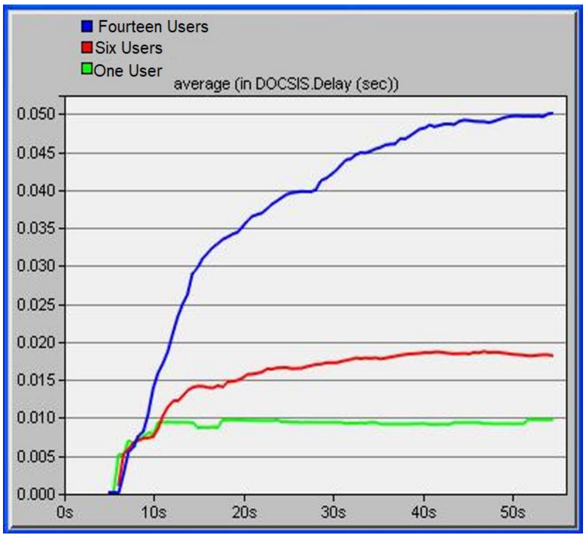
b. Applications

Fig. 3. Delay over video streaming flows 1, 2, 3, 4, 5 and 6.

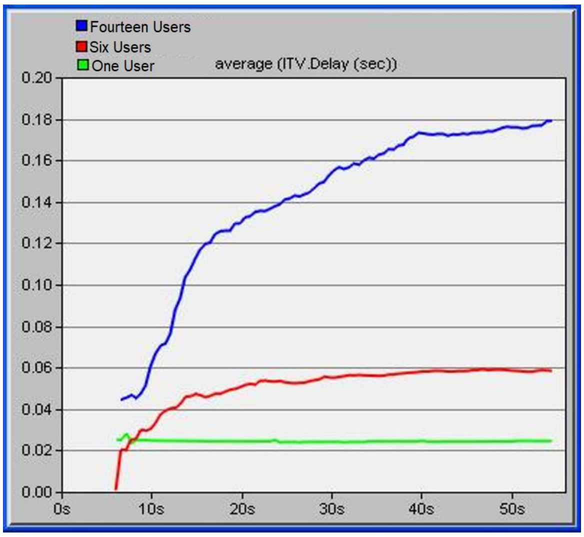
III.I.IV Scenario 4 delay

For this scenario, an HTTP application is configured with the help of the custom application according to [17]. The delay and throughput for the application are affected by the number of users who consume the video streaming service.

The average DOCSIS delays with 14 users and the HTTP application averaged 50 ms, see Fig. 4a. However, if the delay is observed at the level of the custom applications; that is, at layer 7 of the OSI tower, it reaches the value of 180 ms for 14 users transmitting simultaneously (see Fig. 4.b). It should be clarified that this value is for the custom application. Despite it corresponds to an HTTP light traffic, it is strongly influenced by the traffic of the 14 video streams consumed simultaneously. Therefore, it can be inferred that if that application were a videoconference service, which generates higher throughput than that of the configured custom application, it would not comply with the maximum delay parameter suggested in [16]. For this case, this is a basic web page as it is HTTP light traffic. This type of delay of 180 ms is not a problem for an end user.



a. Delay DOCSIS



b. Delay Custom applications

Fig. 4. Custom application delay with 14 users.

III.II Throughput on different scenarios

The behavior analysis of the throughput parameter for each scenario is presented below.

III.II.I Throughput scenario 1

In Fig. 5, the throughput for the upstream and downstream channels of scenario 1 is observed. As expected, the throughput of the downstream channel is much higher, reaching a maximum value of 1100 Kbps, which refers to all the video streaming flows sent to each user. The upstream channel throughput reaches an average value of 40 Kbps that corresponds to ACK messages.

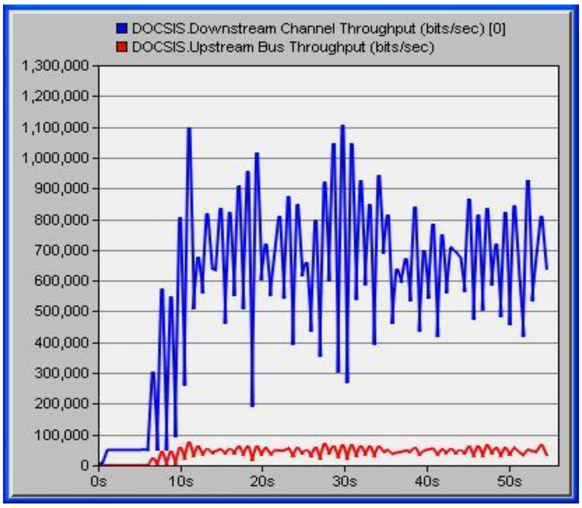


Fig. 5. Throughput video streaming flows 1, 2 and 3.

Then in scenario 1, the video streaming flow 3 is the one that shows the highest throughput by presenting the highest encoding characteristics (Audio 32 Kbps and Video 1008 Kbps). On the other hand, video streaming flow 1, presenting the lowest encoding characteristics (Audio 32 Kbps and Video 144 Kbps), is the one that shows the lowest throughput.

III.II.II Throughput scenario 2

Fig. 6 shows the throughput for the upstream and downstream channels. A behavior similar to the one described in scenario 1 is presented. The difference is that the values reached by the throughput in the upstream and downstream channel (1365 Kbps and 84 Kbps respectively) are higher compared to the previous scenario, since the encoding qualities of the video streaming flows in this scenario are higher.

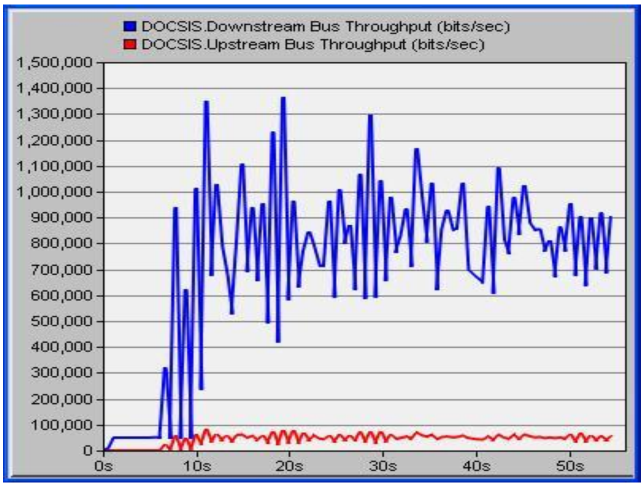


Fig. 6. Throughput video streaming flows 4, 5 and 6.

III.II.III Throughput scenario 3

Fig. 7 shows the throughput for the upstream and downstream channels. The behavior is similar to that described in scenario 2. The downstream throughput reaches maximum values of 1700 Kbps, and the upstream channel throughput reaches maximum values of 135 Kbps.

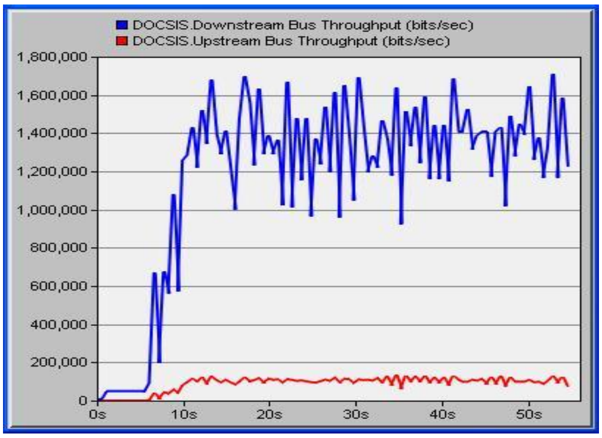
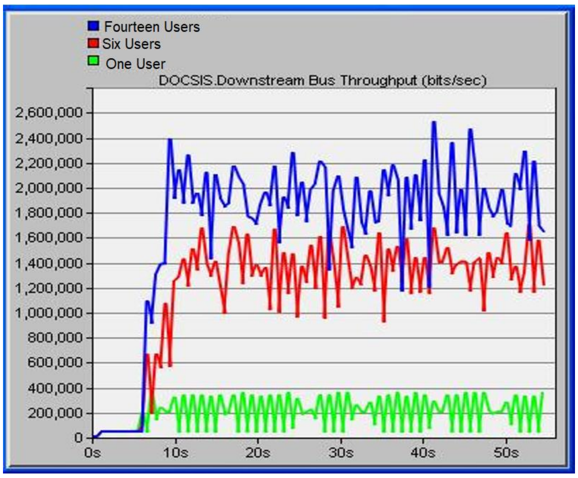


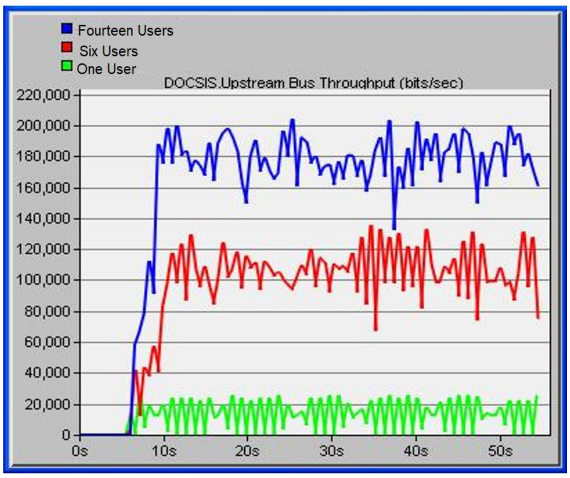
Fig. 7. Throughput video streaming flows 1, 2, 3, 4, 5 and 6.

III.II.IV Throughput scenario 4

There are peak values of 2.5 Mbps in the downstream channel and peak values around 200 Kbps in the upstream channel in this scenario with 14 users and the custom application. Fig. 8.a shows the comparison for DOCSIS throughput for 1, 6, and 14 users. For the upstream channel, the differences for DOCSIS throughput for 1, 6, and 14 users are more noticeable reaching values of 200 Kbps, see Fig. 8b.



a. Downstream



b. Upstream

Fig. 8. Throughput for 14 users.

According to the different behaviors in each of the throughput scenarios and to the data rate of Table 4, the DOCSIS cable network offers sufficient throughput capacity; that is, this parameter is not a limitation for QoS in cable networks unlike the delay parameter, which is critical with the increase in users and directly impacts those real-time and/or interactive applications.

IV. CONCLUSIONS

This research shows the flexibility of the OPNET Modeler tool in configuring DOCSIS protocol parameters and services characterized by probability density functions. Likewise, the tool offers the possibility of configuring applications commonly used in data networks through custom applications, such as those based on the consumption of basic HTTP traffic. Thus, this work aims to serve as a reference for the design and planning of networks that support the implementation and consumption of video streaming services on cable networks.

The delay is presented both at the DOCSIS and the application level of the network facing the constant increase of clients through simulations that respond to the operation of the real system. This way, obtaining a limit of 14 users generating traffic simultaneously before exceeding the limits of the delay parameters established for real-time and/or interactive applications whose value is around 150 ms.

The throughput at the DOCSIS level is shown for the upstream and downstream channels, which showed a sufficient throughput capacity. Then, this parameter is not a limitation for QoS in cable networks. The results showed that according to the modulations and the coding characteristics, it is possible to find the maximum number of clients that the network can support simultaneously. Then, its throughput can be known.

As future work, the proposal is to vary the different parameters provided by the DOCSIS protocol to get to know the impact of each one of them on the QoS parameters; and also, what the best configuration would be in order to support video streaming services.

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