Distribution of Video-on-Demand Service over Cable Television Networks

Lidia T. JORDANOVA, Jordan I. NENKOV

Faculty of Telecommunications, Technical University, Kliment Ohridski 8, 1756 Sofia, Bulgaria

jordanova@tu-sofia.bg, jordan_n2002@yahoo.com

Abstract. *The paper deals with investigations carried out to increase the effectiveness of video-on-demand (VoD) systems when cable television networks are used. A comparative analysis of the existing VoD architectures is made with respect to the equipment cost and the traffic load over the central transport network. Through statistical studies the main characteristics of a particular hybrid VoD are determined (such as twenty-four-hour distribution of the video traffic, average inter-arrival time of the VoD requests, average duration of video streams demanded, movies distribution according to the subscribers' preferences). An algorithm for the video-content flexible distribution among the distribution hubs is suggested. Thus a higher effectiveness of the system is achieved without significantly increasing the equipment cost.*

Keywords

HFC CATV, DVB-C, VoD architecture, SD and HD video streams, DHUB, CMTS, STB.

1. Introduction

Contemporary CATV systems give their subscribers the opportunity to access wide range of both common access services (TV and wireless broadcast) and additional ones. According to the DOCSIS standard there are five main types of additional services: UGS (Unsolicited Grant Service – VoIP), UGS-AD (Unsolicited Grant Service with Activity Detection – VoIP with silence suppression), RTPS (Real-Time Polling Service – video-on-demand and video-conference), NRTPS (Non-Real-Time Polling Service – high-speed file transfer with FTP protocol) and BES (Best Effort Service – Internet surfing, mail and chat).

The Video-on-Demand Service (VoD) provides the subscribers with the possibility to continuously access any desired video program and to manage the received video stream (pause, random access, fast forward, fast reverse, etc.). When compared to other services the VoD service appears to be rather sensitive to interruptions and temporary drops in the transmission bit rate, yet it requires a considerably high bit rate.

The VoD system consists of video servers, transport network, service gateway and subscribers' set top box (STB) devices. The paper deals with a VoD system implementing a hybrid fiber-coax (HFC) television network. Such a network is usually realized on the hierarchical principle. The highest hierarchical level includes a primary optical ring which consists of one primary and several secondary head-ends. The primary optical ring transports digital information using SDH or SONET standards. The second hierarchical level consists of secondary optical rings that are connected to the primary ring. Distribution hubs are connected to the secondary optical rings. Through optical lines the signals are transported from the hubs to the optical nodes that feed the coaxial network segments forming the lowest hierarchical level of the system [1], [2], [3], [4], [5].

The transmission of the additional services signals is based on the DVB-C standard which involves a quadrature amplitude modulation (generally 64QAM or 256QAM) of the radiofrequency (RF) carriers to transmit signals over the downstream channel, the RF band being 450 MHz to 862 MHz. Information coming from the subscribers is transmitted over the upstream channels within the band 5 MHz to 65 MHz, noise-immunity methods (mostly QPSK and 16QAM) being used to this end. The downstream channel's width is 7 or 8 MHz (European standard) while the upstream channel's width varies from 200 kHz to 6.4 MHz according to the requested channel capacity. The digital signals' bit rate over the downstream channel is up to 50 Mbps, if both the implementation of additional information processing methods (compression and coding) and the use of 256QAM are taken into consideration. For upstream channels with 16QAM the bit rate is about 9 Mbps.

The VoD systems design aims to find out the optimum video traffic distribution over the network so that maximum effectiveness and minimum price are obtained. This fact imposes preliminary research to be done in order to determine the distribution laws of a set of random events that requires long-term observations and statistical processing of the data collected. In results, algorithms can

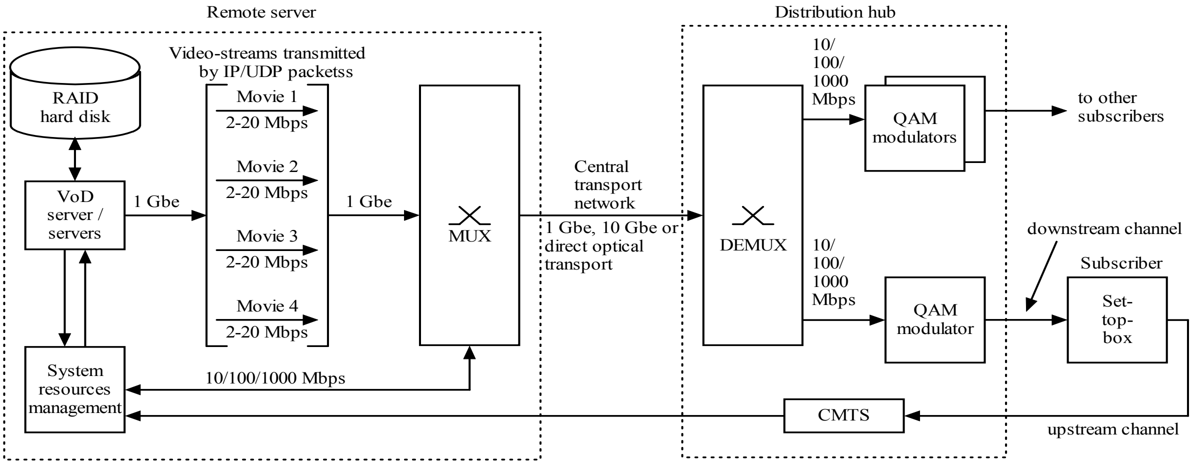

Fig. 1. Distribution of the video streams to the cable television network subscribers.

be developed for the VoD resources' distribution among the QAM modulators whose disposition at either the head-end or the distribution hubs depends on the architecture chosen [3], [4], [5].

The aim of this work is to comparatively analyze different architectures of VoD systems and, given the conditions, to suggest the appropriate solution and algorithm for the video-traffic distribution in the network. To that purpose the distribution laws of the random events must be defined (such as 24-hour distribution of the video traffic, VoD requests inter-arrival time in peak hours, requested video streams time duration and movies distribution according to the subscribers' preferences).

2. VoD System Design over Cable Television Network

In Fig. 1 a simplified block-diagram is shown that illustrates the way video streams from a server at a regional or a local head-end are transmitted to CATV network subscribers through a distribution hub.

The subscriber sends a VoD request to the cable modem termination system (CMTS). The CMTS receives the request and transmits it to the system resources' management block. After processing the request and verifying whether an access to a certain movie is available the system transmits a command to the multiplexer in the remote server to redirect the selected video stream towards the distribution hub at a bit rate of 2 to 20 Mbps [1]. Normally RAID hard disks in the remote server are used in order to provide higher video information reliability. The movie selected by the subscriber is transmitted over the central network to the distribution hub, where a de-multiplexer is located that redirects the requested video stream to a QAM modulator and to the respective sub-scriber.

Though IP is the perfect choice for VoD output streams and network transport the IP headers must be removed from the MPEG-2 TS packets prior to QAM/RF modulation in order to make the digital video signal compatible with the millions of residential STBs deployed. Each MPEG-2 TS packet is 188 bytes long, 4 bytes being reserved for the header. Standard QAMs only provide a DVB-ASI input, so IP to ASI gateway is used at the distribution hubs (DHUB) to remove the IP headers from the VoD streams prior to QAM/RF modulation as shown in Fig. 2. New GbE QAMs are introduced to provide standard IP/Ethernet interfaces and to remove the IP headers internally prior to QAM/RF modulation.

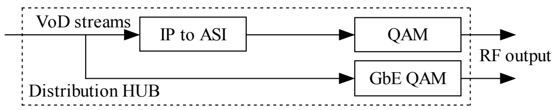

Fig. 2. Data processing in the distribution hub.

3. VoD Systems Architectures

Three types of VoD system architectures are used: centralized, distributed and hybrid [3], [4], [5].

The centralized VoD architecture solution suggests a single, large VoD system at the head-end with VoD streams transmitted over the network to multiple DHUBs. Since only one VoD system is required, this approach tends to reduce the VoD hardware and software costs. The centralized architecture turns out to be inappropriate if the movie content and the subscribers' number considerably increase. This causes the higher bit rate network segment (between the head-end and the distribution hubs) to be overloaded with video traffic to a great extent. Hence, this architecture is recommended when the number of subscribers to use the VoD service and the video content capacities are not great.

With distributed VoD architecture the VoD servers are situated at the DHUBs, each of them serving its own small area. This approach reduces the video traffic and the transport costs across the core network but requires too many VoD servers and hard disks which dramatically rise the VoD equipment cost. Yet the hardware improvement of contemporary servers and the ever increasing capacity of hard disks seem to bring about both decreasing the realization cost of this architecture and increasing the transmitted video information quality. Hence, this architecture is recommended when the number of subscribers to use the VoD service and the video content capacities are great enough.

The hybrid VoD architecture combines the centralized model and the distributed one. The smaller VoD servers are located at the DHUBs and are limited in both size and storage only for the most popular movie selections. The biggest VoD platform that is supplied with a large library of movies and program content is installed at the head-end. If compared with the distributed model the hybrid approach results in lower VoD equipment costs but is still more expensive than the centralized one. With the hybrid approach the video information is transmitted over the core transport network at a lower bit rate, besides a flexible system periodically refreshing the video information in the DHUBs can be built up. With appropriate planning this approach can be optimal from point of view of both the DHUB equipment cost and the video traffic across the central transport network.

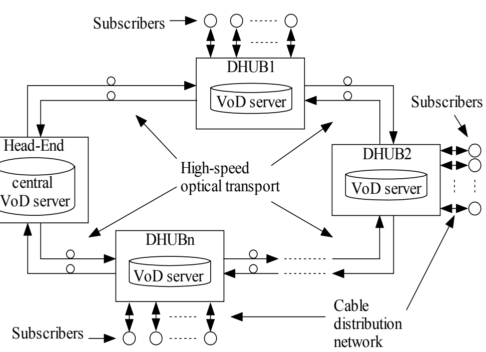

Fig. 3. Hybrid VoD system architecture.

In Fig. 3 a hybrid VoD system is shown. The head-end and the DHUBs are connected with high-speed optical transport. Each DHUB serves hundreds of subscribers through coax cable distribution network. The central VoD server is located at the head-end. In the local servers installed within the DHUBs the video content is duplicated only for those movies that are most preferred.

The investigations described here are based on the hybrid VoD architecture.

4. Types and Formats of the Transmitted Video Information

The video traffic transferred over modern VoD systems is a mixture of SD (Standard Definition) and HD (High Definition) video streams, the SD type being prevalent. Due to increased quality requirements towards information to be transferred the HD standard seems to find a wider application. Hence, HD video streams are expected to gain ground whenever information is transmitted over HFC networks.

The transmission of mixed video streams (of the SD and HD type) is a precondition for the inefficient use of the channel frequency band. Suppose video information is transmitted along a single downstream channel of capacity C = 50 Mbps, the video format used being MPEG-2. The bit rate of SD and HD video streams being 3.75 Mbps and 12.5 Mbps respectively, their possible ratio within the mixed video stream can be determined in order to provide the maximum of channel capacity used. The results obtained are shown in Tab. 1.

The pre-selected movies incoming to the subscriber's point can be classified into three categories - mass movies, other movies and VoD browse, e.g. Youtube or Vbox7 video catalogue browsing [6].

In Tab. 2 the percentage of each category in a mixed video stream and its time duration is shown, the experimental data referring to a real network operated by a large Bulgarian cable operator.

Number of video streams		**Necessary bit rate** [Mbps]	**Unused capacity** [Mbps]
HD, 12.5Mbps	SD, 3.75Mbps		
0	13	48.75	1.25
1	10	50	0
2	6	47.5	2.5
3	3	48.75	1.25
4	0	50	0

Tab. 1. Channel capacity used with the SD and HD mix.

	% of movies of particular type in SD format	**% of movies of particular type in HD format**	**Video stream average duration**
Mass movies	40 %	57 %	2 hours
Other movies	30 %	-	20 minutes
Video browse	30 %	43 %	15 minutes

Tab. 2. Percentage of each category in a mixed video stream and their time duration.

As seen, the greatest percentage of video information transmitted in all formats and of greatest average duration refers to mass movies. The overall duration of the requested video-stream μ_t can be calculated as follows:

$$\mu_t = \sum_{j=1}^{m} U_j \phi_j \qquad (1)$$

where U_j is a weighting coefficient referring to the percentage of a given category of video requests, m is the number of the movie type (m = 3 in the case) and Φ_j is the average duration of the j-type movie.

5. Investigation Results

In the research the following characteristics were studied: distribution laws of the twenty-four-hour video traffic, inter-arrival time of the VoD requests, and duration of the video streams requested. Statistical data processing was carried out upon data obtained from a Bulgarian cable operator (100 serving centers, each one of about 200 subscribers). Data about the reported random events (parameters) were collected within a 6-month period. The VoD architecture under study was of a hybrid type.

The statistical data processing of the data referring to the time parameter t is as follows. The values of t (n in number) that were experimentally measured are grouped within N intervals of duration Δt. For each interval the number m_j (j = 1, 2,…, N) of the t parameter values to drop within the corresponding interval and the statistical probability $p_j = m_j/n$ for t to belong to the j-th interval are determined. The data thus obtained are used to draw the t distribution histogram and polygon. For this purpose p_j is assumed to be a constant value within the j-th interval but to jump at its edges. The distribution polygon of t is obtained in the form of a broken line that connects the interval centers and gives a better idea about the distribution law of the parameter under study.

The basic parameters of the t distribution law are the mathematical expectation value $M(t)$, the standard deviation $\sigma(t)$ and the dispersion $\sigma^2(t)$ [7]:

$$\overline{M(t)} = \frac{1}{n}\sum_{j=1}^{N} t_j . m_j \quad ; \tag{2}$$

$$\overline{\sigma(t)} = \frac{1}{n}\left(\sum_{j=1}^{N}\left[t_j - M(t)\right]^2 m_j\right)^{1/2} \tag{3}$$

where t_j is the j-th time interval's center.

5.1 Twenty-Four-Hour Video Traffic Distribution

In Fig. 4 the histogram of the twenty-four-hour video traffic distribution is shown.

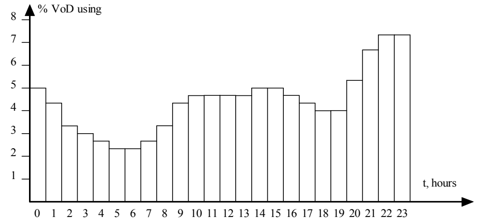

Fig. 4. Twenty-four-hour VoD requests intensity.

The histogram is based on data referring to Saturdays observations carried out within a six-month period. As monitored, on week-days all video traffic minimums and maximums do coincide hourly with the Saturday data, but the amplitude values are lower.

5.2 Average Inter-Arrival Time of the VoD Requests

Investigations on mass-audience TV movies were carried out in the time frame between 9 PM (21:00) and 11 PM (23:00) when the video traffic was at its maximum. In order to draw the histogram of the random value t (time between incoming VoD requests), its values were distributed among time intervals of duration Δt = 10 s. The analysis of the obtained results shows that nearly 78 % of the subscribers' requests are received within the very first 60 s of the implicated time interval. The histogram and the distribution polygon of the parameter under investigation can be seen in Fig. 5.

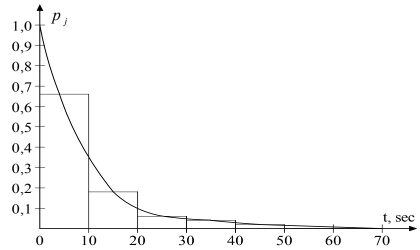

Fig. 5. Distribution histogram and polygon of the inter-arrival time of incoming VoD requests.

The average inter-arrival time of the VoD requests calculated with formula (2) is $M(t)$ = 10.95 s. In that case the time distribution between incoming VoD requests is described precisely enough with the following type of exponential law:

$$f(t) = \frac{1}{M(t)}\exp\left(-\frac{t}{M(t)}\right) = 0.0914\exp(-0.0914t)\,\cdot \tag{4}$$

5.3 Average Duration of the Requested Video-Streams

Data obtained from the observations are distributed within time intervals of duration Δt = 20 min. The histogram and the polygon of the requested video streams' duration distribution are shown in Fig. 6.

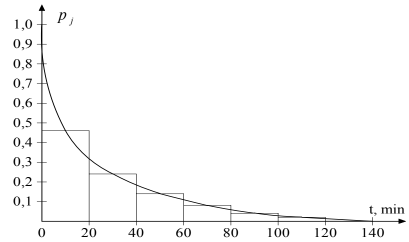

Fig. 6. Histogram and polygon of the requested video streams' duration distribution.

The distribution law of the investigated random value is of the exponential type

$$f(t) = 0.031\exp(-0.031t) \ , \tag{5}$$

and the average duration of the requested video streams is $M(t) = 32.18$ min.

5.4 Movies Distribution According to the Subscribers Preferences

Observations on 3500 movies during a 6-month period have been made. On the basis of the data that were collected and then statistically processed the dependence shown in Fig. 7 was obtained. Thus the relation between the proportion of accesses as a cumulative distribution function (CDF) and the movie index (the position a movie occupies if classified by popularity) determined by the number of subscribers' logs to the corresponding movie can be studied [8], [9].

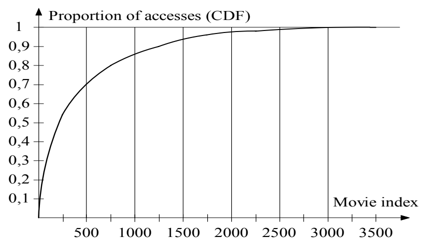

Fig. 7. CDF of videos sorted by popularity. A total of 3500 videos were requested at least once.

Analyses have shown that the users' preferences in respect to the movie content can be described with Pareto's law, 80 % of the video requests being addressed to 23 % of the movies in the network.

6. Algorithm for Video Content Distribution

In this work a flexible algorithm based on the subscribers' preferences is described which automatically distributes the video content from the head-end to the distribution hubs. The diagram in Fig. 8 illustrates the algorithm operation.

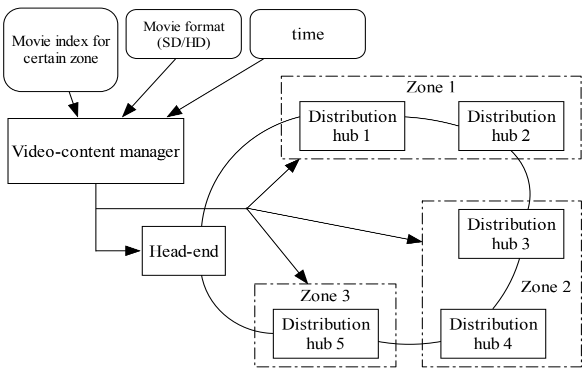

Fig. 8. Algorithm for video content distribution.

The DHUBs are set apart in logical zones each one containing one or more DHUBs and serving the subscribers whose video preferences are similar. Initially, the whole video information is recorded onto the central server, then duplicated onto the local servers but only for the movies that are supposed to be most preferred. After that the algorithm keeps on self-learning with the existing data in the network so that the video content in the distribution hubs is updated automatically through specified time period (from one to up to several days, according to the requests intensity). The update should be done at a given moment to avoid the risk of blocking the system. Investigations have shown that the morning period between 5 AM and 6 AM (when the video traffic intensity is at its minimum) is appropriate to this end. The update consists of deleting some of the old video content and recording a new one, data about the popularity of each movie being taken into consideration.

It is important to note that to compensate for the different transmission bit rates of the movies in SD and HD format the HD format movie index must be multiplied by four. Besides, HD-formatted movies have a bigger file size if compared with SD movies though their duration in minutes is still the same. Because of that reason the percentage of HD movies with respect to the overall number of movies should be considered when the necessary disk space is scheduled.

Information about the movie index is collected and updated case-by-case for each zone. If a movie is requested but the video session duration is less than 20 minutes (this value is chosen as described in 5.3) its movie index is not changed.

When the index of the old video content in the local servers is less than a given threshold it will be deleted and replaced by a new one whose index is above the threshold. The threshold depends on the local servers capacity (the disk space in GBytes).

As seen from the analysis in 5.4 the local server capacity has to be chosen in a way not to be less than 23 % of the central server capacity at the head-end. With this approach it is guaranteed that at least 80 % of the requested movies will be available in the local servers of each zone. If the local server capacity has not been properly calculated the system would not function efficiently. Smaller capacity causes both a video traffic increase and a risk of system blockage, but on the other hand huge capacity leads to increased equipment expenses.

In case the local server contains movies whose index is equal to 1 or more than 1 (e.g. movies requested at least once), small space of this server will be unused. Onto this unused space the operator will record random movies with a zero index. This case is possible in the initial phase of the algorithm operation when the video information gathered is still not sufficient.

After the local server is updated with new video content the system must decrease the traffic through the central distribution network in order to reduce the blockage risk. With such an approach no additional proxy-servers near the local servers in the DHUBs are necessary, which decreases the price of the hybrid VoD architecture.

When a subscriber requests a movie and meets the access conditions the movie transfer starts by the nearest point. Firstly, the system checks for the requested movie within the local server, after that in the other DHUBs and finally in the head-end. The decision for the transfer route depends on the routing protocol. This protocol takes into consideration the number of the points to the movie location and to the subscriber, as well as the traffic into the different system parts. The traffic load in different network segments can be considered through evaluation of the average VoD request inter-arrival time (see section 5.2) which is different for each zone. The shorter the average VoD request inter-arrival time the higher the video traffic load in this zone.

The video-content manager block can be realized as a software application that will automatically copy and delete movies on the local servers. In that case a criterion must be developed in order to minimize possible mistakes and system blockage. For example, during an existing video session to a certain subscriber the chosen movie must not be deleted. During the video-content update the transfers to subscribers must be avoided. During the server update process the server operates as a transit unit which redirects the requests to the DHUBs or to the head-end.

7. Conclusion

The investigations carried out on some characteristics of a hybrid-type VoD system allow the following conclusions to be drawn:

- The video-on-demand service is rather frequently used nowadays by CATV network subscribers. This is proved by the fact that 67 % of the VoD requests have been made in the hours of maximum video traffic transfer, at intervals less than 10 seconds.
- Most of the subscribers' preferences are related to brief video sessions, 50 % of the video streams being of up to 10 minutes duration.
- As for the video content the trend is that 80 % of the subscribers would prefer about 23 % of the video content offered.

The described flexible algorithm for video content distribution from the head-end to the distribution hubs that is based on investigation data has been used to increase the effectiveness of the VoD system here discussed.

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About Authors ...

Lidia JORDANOVA received the M.Sc. and Ph.D. degrees in radio communication technologies from the Technical University of Sofia, Bulgaria, in 1972 and 1978, respectively. Since 1995 she is an assoc. professor at the Depart. of Radio Communications and Video Technologies, and head of the Center for Wideband Communications and CATV at the Technical University of Sofia. She has published over 100 papers and is author of 9 books on radio communications equipment and systems. Her current research interests are in HFC CATV systems and microwave and fiber-optics integrated circuits design.

Jordan NENKOV was born in 1977. He received M.S. degree in aviation electrical engineering from the National Military University – Aviation Faculty, Dolna Mitropolia, Bulgaria in 2001. He is presently Ph.D. student at the Technical University – Faculty of Telecommunications, Sofia, Bulgaria. His current research interests are in VoD and IP-based services over HFC CATV systems.