Comparative Analysis between Centralized and P2P System Traffic in Terms of Providing VoD Service to Cable Television Network Subscribers

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Summary
The choice between a P2P and a conventional centralized realization of VoD service on cable television network can be made after a comparison of the traffic in different sections of the network. Until recently, the centralized architecture has been the most popular architecture for providing VoD service to subscribers of cable television network. With the growth of the network, however, this type of architecture has become inapplicable because of the need for a large number of outgoing video streams from the central VoD server, i.e. high bit rate through the central transmission network. The objective of this paper is to compare the necessary bit rates on different network sections of P2P and centralized VoD architecture and to study the influence of the more important parameters on these bit rates.

Key words:
VoD service, cable television network, P2P architecture, Erlang - B, video traffic

1. Introduction

Video on Demand (VoD) is one of the most popular services provided on the cable TV networks. The provision of this service, however, is associated with increased requirements to the network architecture in terms of bit rate necessary to transmit video information to subscribers.
Until recently, the centralized architecture has been the most popular architecture for providing VoD service to subscribers of cable television network. With the growth of the network, however, this type of architecture has become inapplicable because of the need for a large number of outgoing video streams from the central VoD server, i.e. high bit rate through the central transmission network.
The P2P architecture gains more and more popularity nowadays, which minimizes the traffic through the central transmission network. In order to implement this architecture it is necessary for the subscribers to have STB devices with sufficient storage capacity. The P2P architecture allows optimal usage of network resources by building multisource streams from several network subscribers to the requesting subscriber.
The choice between a P2P and a conventional centralized realization of VoD service on cable television network can be made after a comparison of the traffic in different sections of the network.
The design of VoD systems aims at reaching optimal video traffic distribution in order to achieve maximum efficiency and minimum cost.
Optimal provision of VoD service with the necessary bit rate to the network subscribers is one of the most important issues to cable operators.
The objective of this paper is to compare the necessary bit rates on different network sections of P2P and centralized VoD architecture and to study the influence of the more important parameters on these bit rates.

2. P2P and centralized VoD architectures

Peer to Peer VoD system architecture comprises several major components shown in Fig. 1.

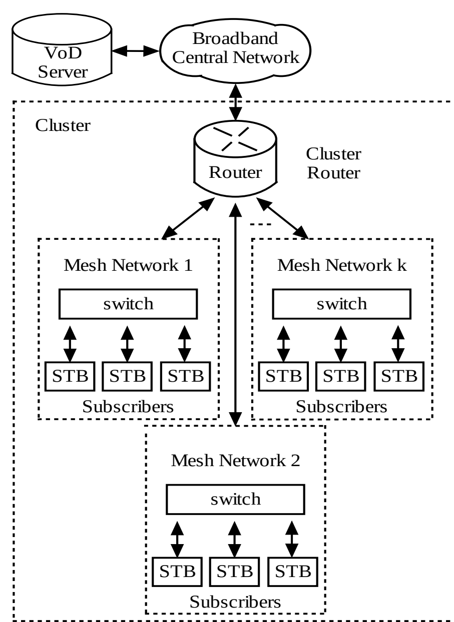

Fig. 1 P2P VoD architecture.

In this architecture, a large number of subscribers (or peers) request one and the same video content within short

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time period and cooperate with each other by exchanging this video content stored on their hard disks. All the video content initially exists on a centralized head end-server.
The subscribers' STB devices are typically asymmetrical in terms of the transmitted bit rate of the video information in incoming and outgoing direction.

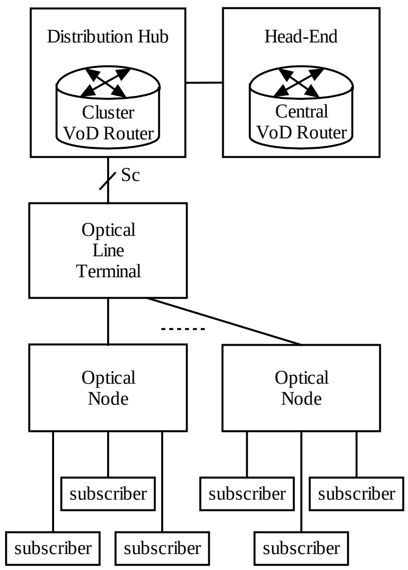

Fig. 2 Centralized FTTx VoD architecture.

In the centralized FTTx VoD system, whose architecture is shown in Fig. 2, each router at subscriber's side could serve a great number of routers of the following type [1]. The central VoD router and the cluster VoD router transmit the video content to the end of the VoD network. Afterwards, the cluster router retransmits the video streams to the optical network terminal, which, in its turn, redirects the video content to the optical network nodes located just next to the households (houses, apartment buildings etc.). Each optical node could serve a maximum of "h" number of households.

3. Traffic definition algorithm in P2P VoD system

Each VoD server is characterized with certain parameters, the most important of which are the maximum number of supported SD and HD video streams and the disk capacity.
In order to determine the number of needed servers in P2P VoD system, the traffic load in different network sections must be determined.
The assumption is that the subscriber will download the unpopular movies from the high capacity centralized head end-servers, while the popular ones are downloaded from its multicast mesh network partners (peers) in the cluster. The VoD service requests are two types: a normal request (request for movie initialization) and an interactive request (e.g. stop/pause, fast forward, fast reverse, etc).
We consider the VoD system as a full-access traffic system without waiting with losses and we can accept the requests for VoD as independent Poisson streams with exponential distribution of time between their attempts. This assumption provides us with an opportunity to use the practice-proven formula "Erlang-B", which can easily calculate the video traffic in the different sections of the VoD system. The time between the entries of requests for VoD is examined in [2]. If in a VoD system for a time period T (peak busy period) there are n requests successfully completed, each of which with duration t_j, the traffic A in erlangs can be calculated by the formula [3]:

$$A = \left(\sum_{j=1}^{n} t_j \right) T^{-1} \text{, erl,} \qquad (1)$$

If we accept that the average VoD requests rate λ for a period of time T is $\lambda = n / T$, requests per unit of time, (1) can be expressed as follows

$$A = \frac{n}{T} \frac{\sum_{j=1}^{n} t_j}{n} = \lambda \tau \text{, erl,} \qquad (2)$$

where τ is the average duration of requests. Thus, the traffic in a VoD system can be quantified via the intensity of entries of VoD requests and their average duration τ, measured by one and the same time unit.
In order to calculate the traffic in a mesh network of P2P VoD system, expression (2) must be transformed into a sum of two traffics, one of them being generated by the normal requests (A_n), and the other – from the interactive (A_i), i.e.

$$A = A_n + A_i = (n\lambda_n t_n \ / \ ZT) + (n\lambda_i t_i \ / \ T) \text{, erl,} \qquad (3)$$

where n is the number of active subscribers in a mesh network, λ_n and λ_i is the average number of normal (n) and interactive (i) requests for a defined period of time per a household, t_n and t_i is the average time for completion of normal and of interactive request, in minutes, T is the peak busy period, which is also expressed in minutes, Z is the multicast factor (i.e. the number of subscribers, who request the same movie within a short period of time and are served by the same server port).
The video traffic in a mesh network of P2P VoD system can be considered as containing two components. The first component is the traffic, generated by the subscribers when requesting popular movies, which they download from their multicast partners in the network (which is marked with A_m). The second component is the traffic, generated by the requests for unpopular movies, which the

subscribers download from the central VoD server in the head end-server (which is marked with A_{cm}). For these two components expression (3) is modified as follows:

$$A_m = [(n\lambda_n t_n \ / \ ZT) + (n\lambda_i t_i \ / \ T)] .(1 - P_u) , \quad (4)$$

$$A_{cm} = [(n\lambda_n t_n \ / \ ZT) + (n\lambda_i t_i \ / \ T)] .P_u , \quad (5)$$

where P_u is the probability of unpopular movie requesting, i.e. request for a movie downloaded from the head end-server. Since the distribution of movies popularity is most accurately approximated by the Distribution Law of Zipf/Paretto, it can be assumed that 80 % of the requests are for movies that are available in the local cluster and 20 % are for movies that need to be downloaded from the head end-server, i.e. $P_u = 0.2$.

The number of active subscribers in a mesh network can be calculated by the formula

$$n = hp / M \ , \quad (6)$$

where h is the number of households (flats) in a cluster of the VoD system, p is degree of penetration of VoD service in the cluster area (it shows the share of the active cluster area subscribers using the VoD service and its value varies from 0 to1), and M is the number of mesh networks per cluster area.

The traffic design of a P2P system is performed in the following sequence. Firstly, the traffic supported by mesh network peers A_m and the central transport network traffic A_{cm} are determined in erlangs.

The next step is to calculate the number of server ports, i.e. video streams, needed by the VoD mesh network to support traffic to a requesting client S_m. The following dependency is used:

$$P_b = \left[(A_m)^{S_m} \ / \ S_m!\right] . \left[\sum_{i=0}^{S_m} (A_m)^i \ / \ i!\right]^{-1} \ , \quad (7)$$

where P_b is the maximum admissible probability of blocking the traffic. Most of the cable operators accept $P_b = 0.003$ as admissible value and $P_b = 0.01$ as maximum [4]. The research in this study is carried out at $P_b = 0.01$.

The next step of design is to define the number of server ports, which are needed for the VoD mesh network to support the traffic generated when movies are downloaded from the head-end through the central network S_{cm}. This parameter is determined by the expression:

$$P_b = \left[(A_{cm})^{S_{cm}} \ / \ S_{cm}!\right] . \left[\sum_{i=0}^{S_{cm}} (A_{cm})^i \ / \ i!\right]^{-1} , \quad (8)$$

where $P_b = 0.01$.

Finally the necessary service bit rates in the different sections of P2P VoD system are calculated. The following symbols for them are accepted: BR_{csm} – bit rate per cluster link, BR_{mh} – bit rate per household, BR_{mht} – total network bit rate and BR_{onm} – bit rate per mesh network. For calculation of these parameters the following formulas are used:

$$BR_{csm} = S_{cm} Mr / D = 2S_{cm} r \ , \quad (9)$$

$$BR_{mh} = r(S_{cm} + S_m) / n \ , \quad (10)$$

$$BR_{mht} = xBR_{csm} \ , \quad (11)$$

$$BR_{onm} = (S_m + S_{cm}) r \ , \quad (12)$$

where r is the bit rate of the video stream (we assume that for movies in Standard Definition (SD) format the bit rate is 3.75 Mbps), x is the number of cluster areas in the VoD system, and D is the diversity factor. The parameter D shows the number of mesh networks in a cluster, where parts of the requested movie are recorded and it can vary from 1 to M.

4. Traffic Definition in Centralized VoD System

In order to compare the requirements regarding the bit rate on P2P and on centralized VoD system, it is necessary to compare the number of server ports, supported by the central transmission network S_c. For that purpose, Erlang-B formula is used:

$$P_b = \left[(A_c)^{S_c} \ / \ S_c!\right] . \left[\sum_{i=0}^{S_c} (A_c)^i \ / \ i!\right]^{-1} , \quad (13)$$

where P_b is the probability of blocking the traffic (it is assumed that $P_b = 0.01$), and A_c – the total network traffic in the centralized VoD system. The value of parameter A_c is calculated by the expression:

$$A_c = (xhP\lambda_n t_n / ZT) + (xhP\lambda_i t_i / T) \ , \quad (14)$$

where P is the degree of penetration of the VoD service in the cluster area of the system.

The necessary service bit rates in the different sections of the centralized VoD system are determined by the next dependencies:

$$BR_{clc} = S_c r \ / \ x = BR_c \ / \ x \ , \quad (15)$$

$$BR_{ch} = rS_c \ / \ (xhP) \ , \quad (16)$$

$$BR_c = rS_c \ , \quad (17)$$

$$BR_{onc} = rS_c \ / \ (Mx) \ , \quad (18)$$

where BR_{clc} is the necessary bit rate per cluster link, BR_{ch} is the necessary bit rate per household, BR_c is the total network bit rate, BR_{onc} is the necessary bit rate to service one optical node, and M is the number of optical nodes in the cluster area. This parameter is identical to the number of mesh networks in a cluster of P2P VoD system.

5. Input Data for Conducting the Analysis

When selecting the structure of the network, the requirements set in [4], [5] are kept. Considering that the maximum allowed number of subscribers in the network is 550 000, the number of households (houses, flats, small offices etc.) is selected to be 24 000. The network comprises a head end-server and 10 distribution hubs, each of them servicing 10 terminals of optical line (OLT). The single OLT feeds 12 optical nodes, and a single optical node services 20 households. Therefore, if we assume that every OLT is a single service center, then the network can be presented as composed of 100 service centers, each of them with 240 households.

From the P2P network point of view, the service center is presented as a cluster area, composed of definite number of mesh networks, which constantly exchange information between each other. This means that the considered network consists of 100 cluster areas, each of them services 12 mesh networks. The mesh network itself services 20 households.

Statistic data for 3500 movies in SD format is collected for a period of one year in order to research the main parameters. After processing the collected data, the dependence shown in Fig. 3 was obtained, which presents the seasonal changes of the parameters λ_n , λ_i and p. The analysis shows that it can be described by the expression:

$$F(t) = 1 - \exp(-t/\alpha)^{\beta} , \qquad (19)$$

where α and β are parameters of Weibull distribution. For the three sections, the parameter β accepts the following values: $\beta < 1$ (I), $\beta = 1$ (II) and $\beta > 1$ (III).

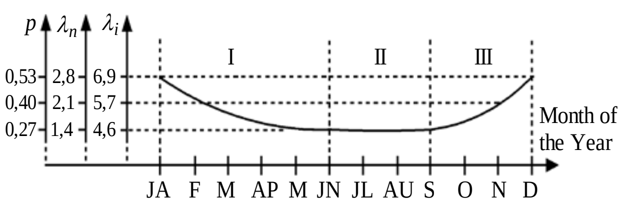

Fig. 3. Seasonal variations of p, λ_n and λ_i parameters

Based on the examination carried out, the following limits of variation of the studied parameters are determined: $\lambda_n = 1 \dots 3.5$; $\lambda_i = 4 \dots 8$ and $p = 0.2 \dots 0.6$.

When selecting a value of parameter D (diversity factor), which is characteristic of P2P VoD systems, two contradictory requirements are reported. In order to reduce the traffic through the central transport network, the value of D must be higher, but this increases the probability of errors. Therefore, taking into account the recommendations in [6], [7], [8], this work assumes that $D = M/2$.

The probability of an unpopular movie request (i.e. movie, which is not present in the multicast networks of the respective cluster and needs to be downloaded from the head-end) P_u is investigated in [2] and is approximately 0.2. The selection of this value stems from the fact that the distribution of movie popularity follows the Law of Zipf/ Pareto. According to it, about 80% of the requests are for 20% of the most popular movies, but which are downloaded from neighboring subscribers and not from the head-end.

As we know, the bit rate of the requested MPEG-2 TS video stream is 3.75 Mbps for SD (standard definition) and 15 Mbps for HD (high definition) format. Here we consider a system in which all movies are in SD format. If movies in both formats are transmitted through the system it does not affect its work. The difference is only in the required service bit rate in the different network sections, which for HD movies is four times higher than that of SD movies.

The peak busy period of the day T is selected after a study of the 24-hour video traffic at work [2], i.e. T = 10 hours (600 minutes).

In this case, the average execution time of a normal request t_n can be defined also as average length of a movie in SD format. This parameter has been studied in [9] and for the purposes of the analysis it is assumed that $t_n \approx 114$ minutes.

In order to determine the value of the parameter t_i (average execution time of the interactive request), the results obtained after processing the collected statistical data are used. The study in this work was carried out at t_i = 6 minutes.

Parameters T, λ_n , λ_i , t_n and t_i can be most accurately defined by installing the respective software on the head end-server or on the distribution hubs. Initially, the 24-hour period of the day is split provisionally into 1440 intervals, each lasting one minute, and then starts the reading of the number of normal and interactive requests for each interval. After a certain period of time, the statistical information necessary to determine the examined parameters is collected.

6. Simulation Results

The aim of this study is to evaluate the influence of some key parameters on the bit rate required to service different areas of the centralized and P2P VoD system. Objects of investigation are the multicast factor Z, the average number of interactive and normal movie requests (λ_i, λ_n) and the degree of penetration of VoD service in the cluster area p. The values of the parameters that were used in the simulation are given in the table below.

Table 1: Values of Parameters.

Para-meter	Value	Para-meter	Value	Para-meter	Value
T	600 min	M	12	h	240
t_n	114 min.	R	3.75 Mbit/s	P_b	0.01
t_i	6 min.	P_u	0,2	x	100

6.1 Multicast factor influence on the Service Bit Rate

When selecting the appropriate value of the multicast factor Z, two contradictory requirements are considered. On one hand, the value of Z must be large enough to save as much server ports (video streams) as possible. On the other hand, the value of Z must be small enough for the subscribers not to wait for delivery of selected movie too long. In this study the values of Z within the range [1÷60] are selected, and it is assumed that $\lambda_n = 2.1$, $\lambda_i = 5.7$ and $p = 0.4$. The results are shown in Fig. 4, 5, 6 and 7.

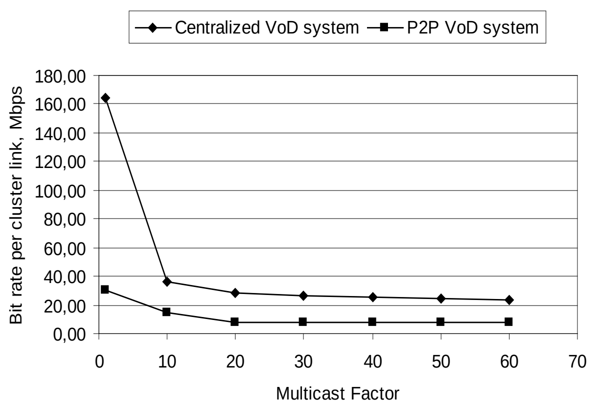

Fig. 4. Dependencies of BR_{csm} and BR_{clc} from Z

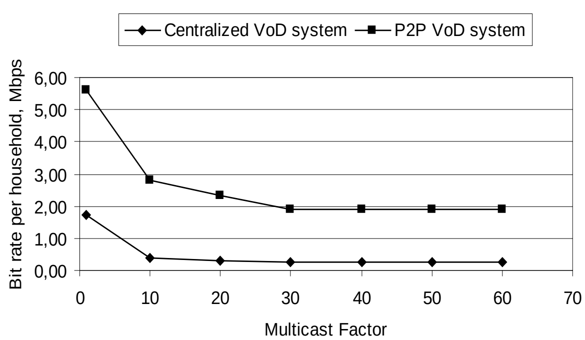

Fig. 5. Dependencies of BR_{mh} and BR_{ch} from Z

The following conclusions can be drawn after the analysis of the results of the study:

1) The service bit rate necessary for the various sections of the network and for both types of systems decreases with the increase of the multicast factor Z.

2) The centralized VoD system requires higher bit rate per cluster link and higher total network bit rate.

3) P2P VoD system requires higher bit rate per household and higher bit rate per optical node, and per mesh network respectively.

4) The most appropriate values of the parameter Z can be considered those that fall within the range [10 ÷ 40].

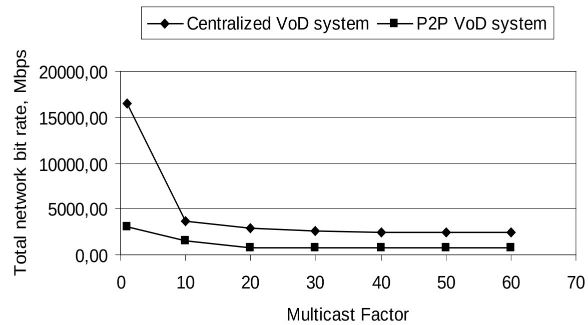

Fig. 6. Dependencies of BR_{mht} and BR_c from Z

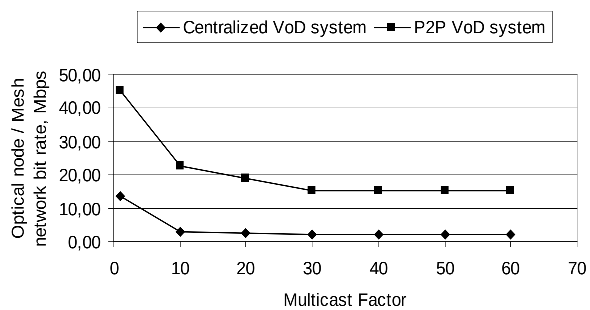

Fig. 7. Dependencies of BR_{onc} and BR_{onm} from Z

6.2 Influence of the Average Number of Interactive Movie Requests on the Service Bit Rate

The values of λ_i parameter used in this study fall within the range [4 ÷ 8] and the results are shown in Fig. 8, 9, 10 and 11. They refer to the case where $\lambda_n = 2.1$, $Z = 20$ and $p = 0.4$.

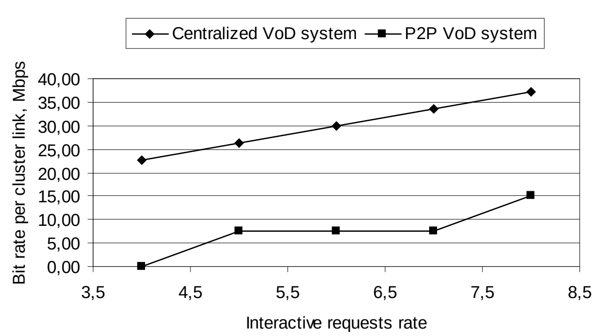

Fig. 8. Dependencies of BR_{csm} and BR_{clc} from λ_i

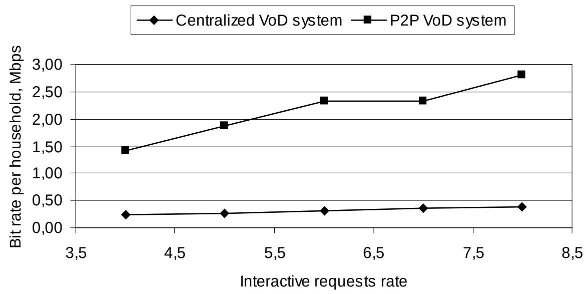

Fig. 9. Dependencies of BR_{mh} and BR_{ch} from λ_i

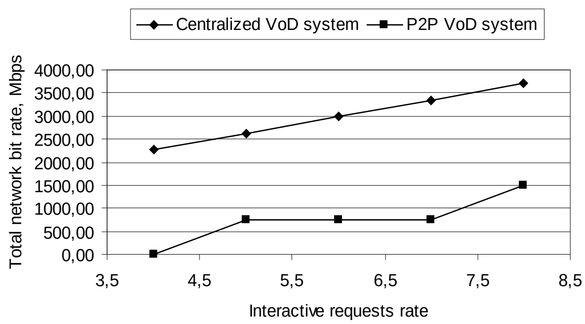

Fig. 10. Dependencies of BR_{mht} and BR_c from λ_i

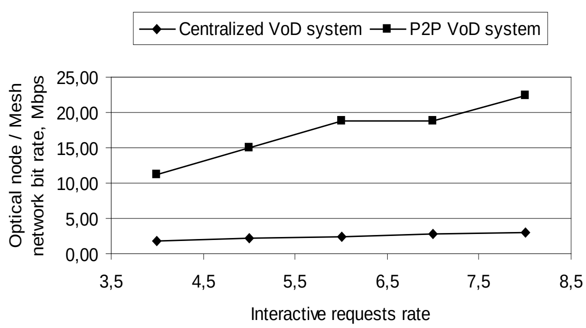

Fig. 11. Dependencies of BR_{onc} and BR_{onm} from λ_i

Obviously, for both types of VoD systems the increase of λ_i results in an increase of the required service bit rate for the network sections, and for the centralized system this is a linear dependence. This study confirms the conclusions already made that with the centralized VoD system the bit rate per cluster link and the total network bit rate are higher, while the P2P VoD system requires higher service bit rate per households and per optical node / mesh network.

6.3 Influence of the Parameters λ_n and *p*

For the analysis it is assumed that Z = 20, λ_i =5.7, and the range of variation of the studied parameters is as follows: penetration rate of VoD service in the cluster area $p = 0.2 \div 0.6$ and average number of normal requests per household $\lambda_n = 1 \div 3.5$.

When $p = 0.4$ and $\lambda_n = 3.5$ the following service network bit rates for the four network sections of both types of VoD systems are obtained:

BR_{clc} = 33,56 Mbps and BR_{csm} = 7,5 Mbps;
BR_{ch} = 0,35 Mbps and BR_{mh} = 2,34 Mbps;
BR_c = 3356,25 Mbps and BR_{mht} = 750 Mbps;
BR_{onc} = 2,8 Mbps and BR_{onm} = 18,75 Mbps.

When $p = 0.6$ and $\lambda_n = 2.1$ the necessary bit rates change as follows:

BR_{clc} = 42,68 Mbps and BR_{csm} = 7,5 Mbps;
BR_{ch} = 0,3 Mbps and BR_{mh} = 2,34 Mbps;
BR_c = 4267,5 Mbps and BR_{mht} = 750 Mbps;
BR_{onc} = 3,56 Mbps and BR_{onm} = 18,75 Mbps.

Thus, the results show that the necessary service bit rates in P2P VoD system at $p = 0.4$ and $\lambda_n = 3.5$ and at $p = 0.6$ and $\lambda_n = 2.1$ are the same.

From the studies carried out, we can conclude that the influence of the parameter *p* on the service bit rate in the different sections of the centralized and P2P VoD system is similar to the influence of the parameters λ_i and λ_n, and the difference is in the service bit rate required for a household with the P2P system where there is a pronounced maximum of BR_{mh} at $p = 0,2$.

9. Conclusion

The described model for studying the traffic characteristics of the centralized and P2P VoD systems allows us to calculate the necessary bit rate in the different network sections and the minimum possible number of video servers by the number of serving stations and certain number of subscribers to them, the video format and the possibility for system blocking.

The results of the studies of the main parameters of the traffic models are useful for planning the network structure in view of maintaining its availability regardless of the seasonal alterations of these parameters.

As a result of the studies, the selection of P2P VoD system could be considered appropriate when minimum traffic is required through the central part of the network, e.g. minimum total network bit rate and minimum bit rate per cluster link. The centralized VoD system, on its side, requires lower bit rates per household and per an optical node, which allows its easier building in small population networks where the traffic through the central part is not so heavy.

Acknowledgments

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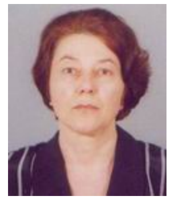

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