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Design of a Dynamic Allocation of Frequency Channels to Services in CATV Networks

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Abstract:

This paper deals with a model of the intelligent interactive CATV network design. Function of this model is described as the Markov process. The design of the frequency band segmentation of a coaxial cable and new network elements are shortly described in the introduction. The frequency band segments are studied analytically while the network traffic is simulated by network simulation model. The analytical solution and simulation on real data are discussed in the conclusion.

Keywords:

CATV, HFC network, Queuing theory, Kolmogorov theorem, mathematical model, simulation model.

1. Introduction

The aim of intelligence in the proposed model of the consumer interactive CATV network is to utilize frequency band of a coaxial cable effectively. The new component called the Control Centre of Coaxial Network (CCCN) has to be added to the existing network. CCCN is situated on the optic-coax network interface. The function of CCCN is the operational management of television and VoD (Video on Demand) services. According to the customer requests, CCCN inserts received video programs into free frequency channels which are placed in the video services sub-band. Server for packet prioritizing is another new network element that recognizes the type of the service that is transmitted in a packet and allocates a priority class number to it.

The bandwidth management server is the main element of the intelligent network. It is situated in the head-end of the network. This server defines the user type on the

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basis of received priority packets and IP addresses of the end user boxes (EUBs) [1], [2], [5]. Further, it manages data traffic in the network in accordance with information about frequency band filling. There are three presupposed service segments in the frequency band of a coaxial cable. The bandwidth management limits the transmission capacity of the third segment according to the size of the first and the second segment.

2. Segmentation of the Downstream Frequency Band

The frequency band is divided into the upstream and downstream transmission traffic directions [4]. The downstream bandwidth can be divided into the analogue video, digital video, and data (see Table 1).

Tab. 1 Frequency band in CATV networks

Bandwidth [MHz]	0 ÷ 42	54 ÷ 550	550 ÷ 750	750 ÷ 860
Service	Data	Analog video	Digital video	Data
	Upstream	Downstream		

The size of these sub-bands can vary in different networks. It depends on the network properties and on the type of provided services. It is important to point out that these sub-bands stay constant throughout usage.

The segmentation of the frequency band for downstream is presumed in the network model. The segment can be defined as a frequency band with a variable size during the operation of a specific service type or a specific user. The services which can be provided in the downstream bandwidth are video and data services.

The bandwidth management server defines two types of users from data services point of view:

- A-user – uses data services except peer-to-peer, FTP, Torrent services, etc.;
- B-user – uses all types of data services.

We modify the current CATV network to the bandwidth segmentation. Only downstream traffic and the following segments have been considered:

- TV segment – is intended for video services. Only DVB-C video services are considered.
- D1 segment – is designed for IP data services (IPTV, VoIP, web browsing). There are only A-users in this segment.
- D2 segment: B-users receive data in this segment. This segment occupies free frequency channels and ensures constant traffic in the frequency band of a coaxial cable (if it is required).

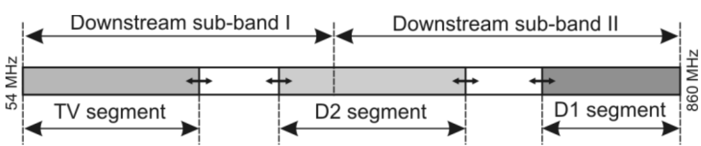


Fig. 1 Downstream frequency band segmentation

The downstream frequency band is divided into two bands with the constant size which are defined by a service provider:

The downstream sub-band I – The video channels creating the TV segment is inserted into this sub-band. Frequency channels are occupied step by step, beginning with the lowest carrier frequency. When this band is fully occupied with video programs, the other requests for other video services are refused.

The downstream sub-band II – Analogically to the previous case, the services of customers of type A are inserted into the downstream sub-band II. These services occupy, step by step, frequency channels from maximum carrier frequency.

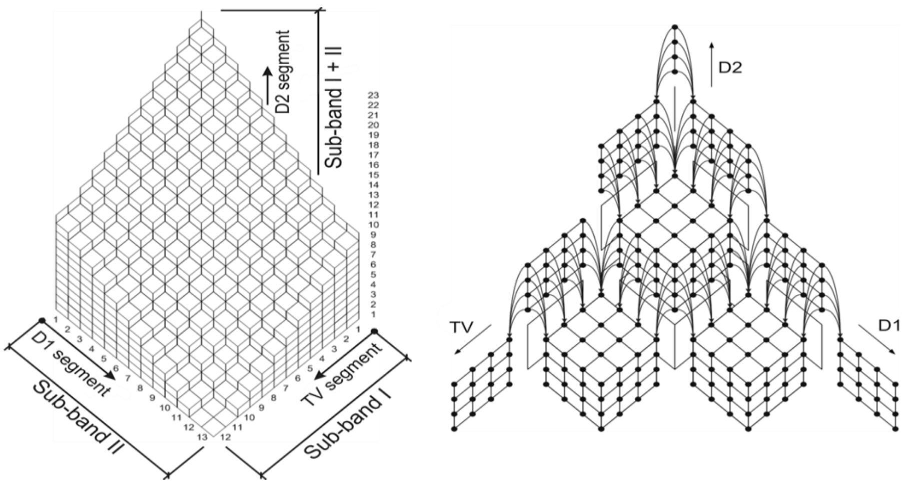
Customers of type B services are inserted into downstream sub-band I and downstream sub-band II according to the number of free channels.

3. Mathematical Model

Three types of customers and their adequate frequency segments exist in the system. The transition graph will also have three axis in the co-ordinal rectangular system (Fig. 2 a).

- X-Axis assigns the TV segment. The number of states being on this axis depends on the size of downstream sub-band I and on the number of video signals in one frequency channel.
- Y-Axis assigns the D1 segment, which is located in downstream sub-band II.
- Z-Axis assigns the D2 segment. The transmission rate for one D2 segment service depends on the number of operated D2 services, as well as on the TV and D1 segment size.

On the basis of standard DOCSIS 3.0 [4], the frequency band is divided into four conjunct frequency channels. Therefore the transmission graph of the channel consists of virtual cubes of dimension 4x4x4. (Fig. 2 b).



(a) (b)

Fig. 2 Transmission graph of segmentation of the downstream frequency band. (a) Design of transmission graph. (b) Detail of transmission graph with frequency channels

The user can request a service in the network at any time whereby the number of occupied frequencies' channels gains a certain number of states. We are dealing with a system with continuous arrival time and with non-continuous occupancy state of frequencies' channels. Internal occupation dependence of frequencies' channels depends on the present only, not the past. It is an extensive Markov process. Probability of states $p(t) = (p_0(t), p_1(t), \ldots, p_m(t))$ may be figured out from the solution of system of Kolmogorov differential equations for $j = 0, 1, \ldots, m$ in the form

$$\frac{\mathrm{d}\, p_j(t)}{\mathrm{d}t} = -\lambda_{jj}\, p_j(t) + \sum_{k \neq j} \lambda_{kj}\, p_k(t) \tag{1}$$

On the basic formula (1) and transmission graph (Fig. 2) was created Kolmogorov differential equations for mathematic model.

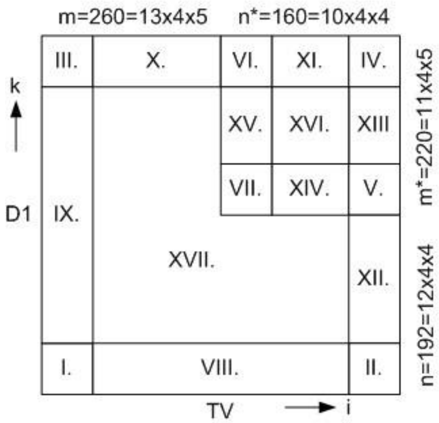
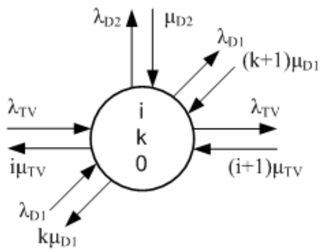


Fig. 3 First layer of transmission graph when D2 is zero.



$$i \in \langle 1;159 \rangle \quad \cup \quad k \in \langle 1;219 \rangle$$
$$i \in \langle 160;191 \rangle \quad \cup \quad k \in \langle 1;219 \rangle$$
$$i \in \langle 160;191 \rangle \quad \cup \quad k \in \langle 220;259 \rangle$$

Fig. 4 Transition status [i, k, 0] in XVII. area.

Kolmogorov differential equation for transition status in Fig. 4:

$$XVII. \qquad \frac{\partial \overset{i}{p}{}_0^{k}(t)}{\partial t} = -\left(\lambda_{TV} + \lambda_{D1} + \lambda_{D2} + i \cdot \mu_{TV} + k \cdot \mu_{D1}\right) \cdot \overset{i}{p}{}_0^{k}(t) + \lambda_{TV} \cdot \overset{i-1}{p}{}_0^{k}(t) + \\ + \lambda_{D1} \cdot \overset{i}{p}{}_0^{k-1}(t) + (i+1) \cdot \mu_{TV} \cdot \overset{i+1}{p}{}_0^{k}(t) + (k+1) \cdot \mu_{D1} \cdot \overset{i}{p}{}_0^{k+1} + \mu_{D2} \cdot \overset{i}{p}{}_1^{k}(t) \tag{2}$$

where λ is the intensity of incomings,
μ is the intensity of service.

Mathematic model contain 43 types of equations. We have calculated these equations in the matrix form

$$p'(t) = p(t) \cdot Q \tag{3}$$

where Q is a the transition matrix of intensity in the form

$$Q = \begin{pmatrix} -\lambda_{00} & \lambda_{01} & \lambda_{02} & \cdots \\ \lambda_{10} & -\lambda_{11} & \lambda_{12} & \cdots \\ \lambda_{20} & \lambda_{21} & -\lambda_{22} & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{pmatrix} \tag{4}$$

Systems' solution (3) with the initial conditions $p(0)$ and stationary matrix Q might be theoretically found in the form

$$p(t) = p(0) \cdot \exp(Q \cdot t) \tag{5}$$

However, numerical solution is difficult.

If a limited distribution of p process states exists, then Kolmogorov equations will be transformed (for homogeneous process) into the form

$$p \cdot Q = 0, \quad \vec{e} \cdot p = 1 \tag{6}$$

where $\vec{e} = (1,1,\ldots,1,1)$.

Instead of differential equations system, it is sufficient to calculate the system of linear equations

$$A \cdot p^T = b^T \tag{7}$$

where $b = (0,0,\ldots,0,1)$ and

$$A = \begin{pmatrix} -\lambda_{00} & \lambda_{10} & \lambda_{20} & \cdots \\ \lambda_{01} & -\lambda_{11} & \lambda_{21} & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ 1 & 1 & 1 & 1 \end{pmatrix} \tag{8}$$

If we transpose the intensity matrix Q and replace arbitrary (e.g. last) equation with the normalization condition from (6), we will obtain the matrix A. The system of equations (7) has only unique solution if it consists of positive elements and can be calculated algebraically in the form $p^T = A^{-1} \cdot b^T$ [6, 7].

We have chosen the size of the downstream band of 12 frequency channels for simplification of mathematical model. In this model every service fills up just one channel. By Kandall classification, we are able to define this frequency band as M/M/12 system, but this system contains three types of services. The input parameters for mathematical and simulation model were: $\lambda_{TV} = 3.5$; $\lambda_{D1} = 3.5$; $\lambda_{D2} = 3$; $\mu_{TV} = 1$; $\mu_{D1} = 1$; $\mu_{D2} = 1$. Such values of the input parameters were designed, so that they meet maximum limit of the D2 segment size. Calculated values are showed in Fig. 7.

4. Simulation Model

The MATLAB program was selected as a simulation environment. The whole simulation model consists of the following steps:

1. The generator of requests for an open system which generates arrival and departure exponential times of services for particular segments on the basis of the input parameters.
2. The algorithm of the channel occupancy, which scans the coaxial band load and inserts the arrival services into particular empty frequency channels. For

every transition status, this algorithm detects occupation time. Percentage values of these occupation times are showed in Fig. 7.

3. The graphic and the computing processing of the results that evaluates the efficiency of the system.

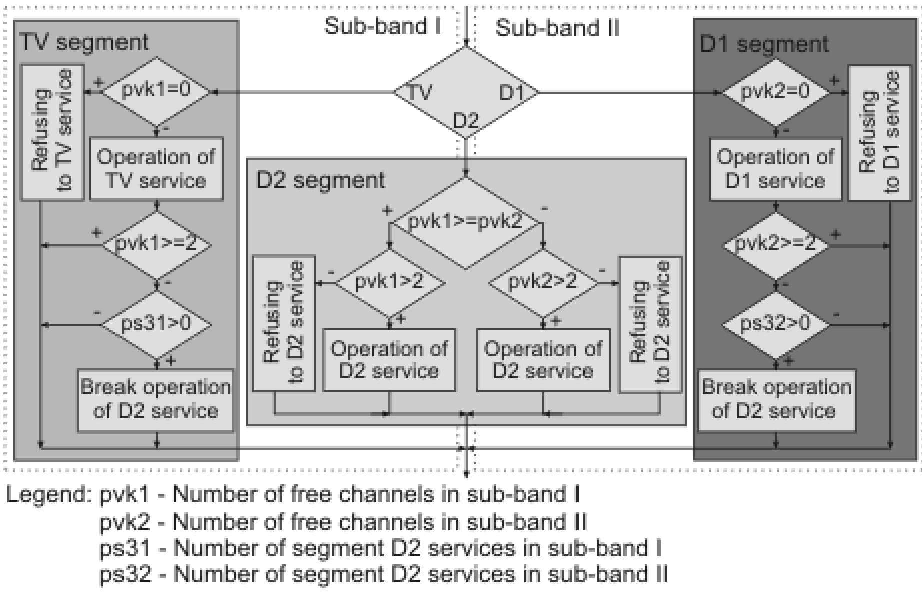


Fig. 5 Flow diagram of insert services on frequency band.

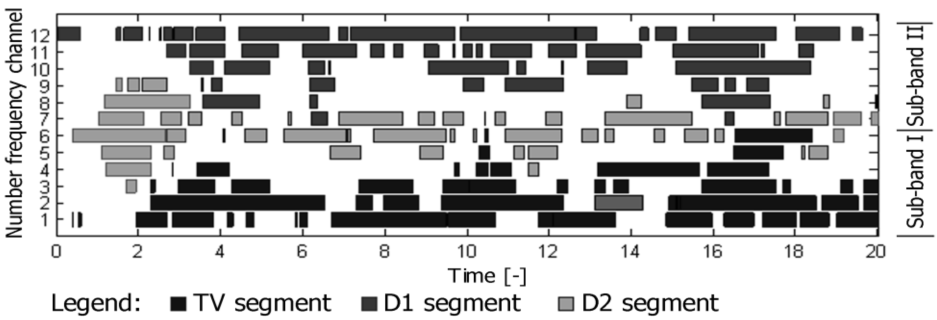


Fig. 6 Time graph of the total occupation of frequency band

5. Conclusion

1) These values of blocking probability were calculated in the mathematical model for maximum limit of the D2 segment:

- TV segment: $p_{odmTV} = 0.082484$
- D1 segment: $p_{odmD1} = 0.082484$
- D2 segment: $p_{odmD2} = 0.390014$

2) For simulation of this mathematical model, 29899 services were generated during 3000 time units in the simulation model. The calculated quantity of refused requests from the total amount in particular segments are:

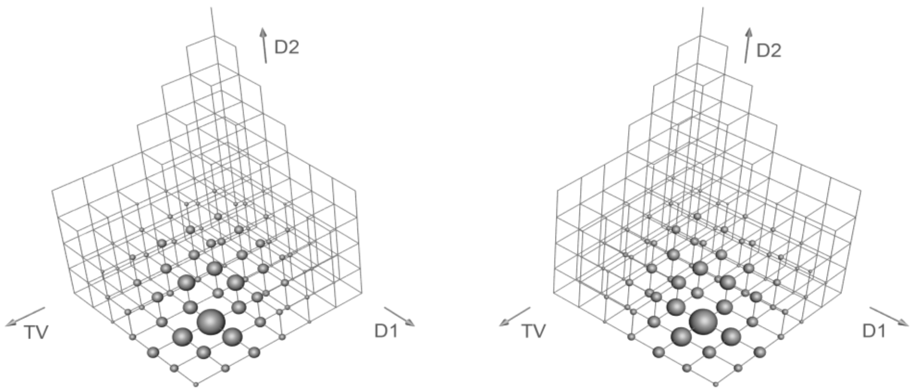
- TV segment: 0.083556
- D1 segment: 0.079378
- D2 segment: 0.360199

3) The calculated quantity of refused requests from the states in case the frequency band is full in the particular segment:

- TV segment: 0.084407
- D1 segment: 0.083275
- D2 segment: 0.353199

By the computing of the quantity of the refused requests from the total amount of the services, the error was 5.387 %. By calculating the quantity of the acquirement of the full band, the error was 6.445 % in comparison with the mathematical model. This is due to the fact that while computing the quantity of the full band, it is not necessary to refuse the arrival request in certain percent of the time of the filling. In these cases one frequency channel had been released before the new request came to the system.

The main advantage of the designed consumer system in comparison with the current HFC network means that only the services which are requested are found on the frequency band [8, 9]. The bandwidth of the coaxial cable which will be released by this method is allocated for the data services. In this case, it is possible that a state may occur when the whole frequency band of the coaxial cable is used only for the data transmission. This state cannot occur in the present-day networks because the bandwidth is massively occupied by video services. A certain disadvantage of this design is a necessity of investment into the new elements of the network.



Mathematic model   Simulation model

Fig. 7 Results of mathematical and simulation model

This figure illustrates the probabilities of the system residing in a given state, i.e. the larger the sphere, the higher the probability.

In existing HFC network, the bandwidth of channels is constant. Our design dynamic allocated bandwidth according to payload.

References

[1] EDWARDS, WK., NEWMAN, MW., SMITH, TV., SEDIVY, J. and IZADI, S. An Extensible Set-Top Box Platform for Home Media Applications. *IEEE Transaction on Consumer Electronics*, 2005, vol. 51, no. 4, p. 1175-1181, ISSN 0098-3063.

[2] HOTTMAR, V., SCHWARTZ, L. and TRSTENSKY, D. End User Box for Interactive Cable Television. *IEEE Transaction no Consumer Electronics*, 2007, vol. 53, no. 2, p. 412-415. ISSN 0098-3063.

[3] CICIORA, W., FARMER, J. and LARGE, D. *Modern Cable Television Technology: Video, Voice & Data Communications*. Waltham (MA): Morgan Kaufmann, 1998. 854 p. ISBN 1-55860-416-2.

[4] *Recommendation J.222.1 of International Communication Union*, [cit. 2009-03-17]. http://www.itu.int/rec/T-REC-J.222.1-200707-I/en.

[5] KRBILOVA, I., HOTTMAR, V., and ADAMEC, B. Home access network model specifications. *Infocommunications Journal*, 2009, vol. LXIV, no. 1, p. 41-45. ISSN 0018-2028.

[6] ROSS, SM. *Introduction to probability models.* 6th ed. Academic Press, 1997. 669 p. ISBN 0-12-598470-6.

[7] KLEIROCK, L. *Queuing Systems. Volume I + II: Theory*. Wiley 1975, ISBN 0-471-49110-1.

[8] MIKUS, L. et al. *Internet*, *Intranet*, *Database systems* (in Slovak). Bratislava: STU, 2000. 222 p. ISBN 80-227-1676-6.

[9] RADOS, I. and SCHWARTZ, L. Analysis of Impact Different Node Architectures and Wavelength Channel Protection on the Availability WDM Ring Networks. *Communications*, 2009, vol. 11, no. 4, p. 28-37, ISSN 1335-4205.

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