

Using an Effective Algorithm to Resolve the Video-on-Demand Service Network Resource Allocation Problem

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Abstract— Video-on-demand (VOD) can broadly be categorized into two groups, namely Interactive VOD (IVOD) and near VOD (NVOD). This paper examines the resource allocation problems in a VOD network which provides a mixture of IVOD and NVOD services (RAPINVOD). The RAPINVOD problem is to determine where to install VSs for IVOD services, taking into consideration customers' demand and which programs should be stored at each VS for both IVOD and NVOD services so that the total operating costs can be minimized. The paper addresses the RAPINVOD issue by using an effective dynamic programming algorithm which extends the key idea of the earlier dynamic programming for solving the resource allocation problem in a IVOD service.

Keywords— Video-on-demand (VOD), interactive VOD (IVOD), near VOD (NVOD), resource allocation, dynamic programming

I. INTRODUCTION

The emergence of broadband networks and the advance of several technologies such as ATM (Asynchronous Transfer Mode), image compression/retrieval technology as well as multimedia storage/transmission technology facilitate the growth of bandwidth interactive services such as video-on-demand (VOD), video conferencing, home shopping, etc. Among others, VOD seems to be an attractive service in that telecommunication companies believe its market will flourish in the next few years [1, 2].

A video-on-demand (VOD) is a multimedia content based system using a broadband network to provide its contents to a customer or customers of the system. Each customer is allowed to watch the video on demand and also takes control over the video with functions very similar to a VCR, such as play, pause, stop, and forward at any time.

Although there are different ways of viewing the type of a VOD, the types of VOD can virtually be classified into two major groups – interactive video-on-demand (IVOD) and near video-on-demand (NVOD) [3-5]. IVOD is a real-time service that provides a customer with a requested program for the customer to control. It requires expensive and highly developed Video Servers (VSs) and storage media to support

the real-time service. It incurs a large amount of program storage and transmission costs because of the fact that it demands point-to-point connections. NVOD, which is not a real-time service, periodically distributes some programs on several channels for each program so that customers can watch their requested programs from the beginning, after waiting for a relatively short period of time. NVOD requires relatively cheaper VS and storage media as opposed to those for IVOD services [6]. In addition, NVOD service requires a relatively small amount of program storage and involves lower transmission costs compared with IVOD services because one channel can be allocated to several customers simultaneously.

Central to a VOD network deployment, is the resource allocation problem, which requires a systematic approach that can determine where to deploy storage and streaming devices to reduce the total operating costs as much as possible [7]. However, to the best of our knowledge, the resource allocation problem in a VOD network has yet to be carefully analysed by researchers in the field. For example, in [8-10] they have proposed only a service policy for the mixture of IVOD and NVOD services such that some popular programs are distributed through NVOD service since the total cost will be increased if all the programs are distributed only through IVOD service. Technologies and cost required for IVOD and NVOD services were analysed by [7, 8, 11, 12] while [13] proposed a dynamic programming algorithm for the resource allocation problem in a VOD network providing only IVOD service.

The main purpose of this paper is to determine where to install VSs for IVOD services taking into consideration customers' demand and which program should be stored at each VS for both IVOD and NVOD services so that the total operating costs can be minimised. There might be several costs related to the operation of the mixed IVOD and NVOD services, nevertheless, due to their common issues in VOD service networks, three kinds of costs for each service will be considered, which include a program transmission cost, a program storage cost, and a VS installation cost.

The rest of the paper is organized as follows. In Section II, we describe VOD network structures with several assumptions and then introduce the concepts of program vision probability

and mean service demand. We also define the rate of lost service requests for an NVOD program. Section III addresses a dynamic programming for the RAPIVOD problem. In Section IV, we propose an extension of the dynamic programming algorithm, as discussed in Section III, to provide a solution for the RAPINVOD problem. Finally, we summarize the paper and provide some indication of our future work in Section V.

II. A TREE-STRUCTURED VOD NETWORK

In this paper, we consider two kinds of directed and tree-structured VOD networks, one providing only IVOD services and the other providing a mixture of IVOD and NVOD services. These networks consist of N interconnected Central Offices (COs) represented by nodes which are labelled in the Breadth First Search (BFS) order. It is assumed that at most, one VS for IVOD services can be installed for each CO and exactly one VS for NVOD services can be installed at the root node of the network. The program warehouse containing the programs to be provided is located at the root node of the network. The program warehouse provides some programs which are initially stored at the program storage of a video server (VS) in a CO on a schedule whenever customers request those programs. We also assume that each customer is connected to exactly one leaf node (CO) in the network by a dedicated link so that the transmission cost from the leaf node to the customer can be ignored. Each CO corresponding to a non-leaf node not only transfers IVOD programs from the CO to the immediately linked COs (i.e., its successors), but also copies NVOD programs distributed from a VS for NVOD services and multi-broadcasts those to its successors. An example of such a VOD network is shown in Figure. 1.

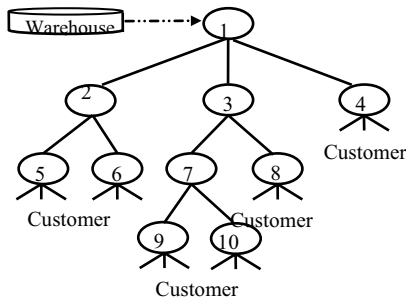


Figure 1. An example of tree-structured VOD network

Let $P[i,1]$ be the set of nodes on the path from node i to the root node 1, i.e., $P[i,1] = \{i, i_1 = PD_i, i_2 = PD_{i_1}, \dots, 1\}$, where PD_n is the predecessor of node n for each $n = 2, 3, \dots, N$. Then it is assumed that a customer connected to a leaf node i can receive the requested IVOD program from a VS on the path $P[i,1]$. Therefore, all of the IVOD programs requested by customers connected to the leaf node i should be stored at some VS on the path $P[i,1]$. We assume that the unit storage cost for every program is identical for all COs and the link capacity between two consecutive COs is unlimited.

Let J be the total number of programs being provided in the network. It is assumed that all of the programs are sorted in decreasing order of customers' preference and an IVOD program with higher preference is stored at a VS closer to customers in order to reduce the transmission cost. Moreover it is assumed that a more highly preferred NVOD program has a higher priority to be stored at the root node since more customers will be served on each channel for an NVOD program.

NVOD program j is distributed on m_j channels from the root node where we assume that $m_j \geq m_i$ if $i < j$ so that the rate of lost service requests for NVOD programs can be reduced [10]. The service provider then needs to determine the number of channels for each NVOD program.

A. Program Vision Probability and Mean Service Demand

Given that the demand for each program is determined by customers preference, which is sorted in a decreasing order, although it varies with several factors such as service time, service type (IVOD or NVOD service), and customers location, etc. [14] defined the *vision probability* of program j as follows:

$$P_j = \frac{P_{j-1}}{D_{HP}}, j = 2, 3, \dots, J, P_1 = \frac{1 - (1/D_{HP})}{1 - (1/D_{HP})^J}, \sum_{j=1}^J P_j = 1, \quad (1)$$

where D_{HP} is the ratio between the $(j-1)$ -th and j -th program vision probabilities.

Note that $P_1 \geq P_2 \geq \dots \geq P_J$ and thus $D_{HP} \geq 1$. It is assumed that the same program requested by customers connected to all leaf nodes in the network has the same program vision probability.

The *mean service demand* at node n can be defined as being the mean traffic volume occurring during one unit of time of the busiest period. The mean traffic volume is the product of three values: the number of customers connected to the node n , the probability that customers will request the service during the busiest period, and the mean service time.

Let L_n be the set of successors of node n (i.e. $L_n = \{q \in V | PD_q = n\}$). If n is a leaf node (i.e. $L_n = \emptyset$), then the mean service demand R_n at node n can be determined by the following values: the mean traffic volume at node n / (the unit service time). For nodes other than leaf nodes (i.e. n such that $L_n \neq \emptyset$), $R_n = \sum_{q \in W} R_q$ where $W = \{q \in T(n) | L_q = \emptyset\}$.

B. Rate of Lost Service Requests for an NVOD Program

We define the *rate of lost service requests* for an NVOD program as being the probability that a customer who requested the NVOD program cancels the request. An NVOD program with vision probability P_j is distributed on m_j number of channels. Then, if $V(m_j)$ is the time interval between the starts of two consecutive distributions of this NVOD program, i.e., the maximum amount of time that a customer should await the program can be obtained by

$$V(m_j) = \frac{\tau_j}{m_j}, j = 1, 2, 3, \dots, J \quad (2)$$

where $0 < V(m_j) < \infty$ and $\tau_j > 0$ is the service duration of program.

Now, let the random variable T be the time that a customer waits for the requested NVOD program, with $f(t)$ its probability density function. Then the probability that a customer will wait for more than t hours is

$$P(T > t) = \int_t^\infty f(x)dx \quad (3)$$

Therefore, $P_f(V(m_j))$, the probability that a customer will wait the requested NVOD program with vision probability P_j , can be calculated by

$$P_f(V(m_j)) = \int_0^{V(m_j)} P(T > t)dt / V(m_j) \quad (4)$$

Consequently, the rate of lost service requests for an NVOD program with vision probability P_j , denoted by $\bar{P}_f(V(m_j))$, is

$$\bar{P}_f(V(m_j)) = 1 - P_f(V(m_j)) \quad (5)$$

For example, if T is exponentially distributed with parameter δ , i.e., if $f(t) = \delta \exp(-\delta t)$ with $0 < t < \infty$ and $\delta > 0$, then

$$P_f(V(m_j)) = \frac{m_j}{\tau_j \delta} \left(1 - \exp\left(-\frac{\tau_j \delta}{m_j}\right) \right) \quad (6)$$

Here, the parameter δ is the mean queuing rate that a customer will receive an NVOD service.

Since NVOD service is usually cheaper than IVOD service and each customer also makes a decision to wait or not to await the requested NVOD program, we assume the following: (i) if a program is distributed through NVOD service, then a customer requested the program wants to receive NVOD service rather than IVOD service; (ii) customers who choose not to await the requested NVOD programs request the IVOD service in the ratio of γ , $0 \leq \gamma \leq 1$. Consequently, the impatient customers who choose not to await the requested NVOD programs clear their requests in the ratio of $1 - \gamma$.

III. DYNAMIC PROGRAMMING FOR RAPIVOD

In this paper we consider three kinds of costs for IVOD service: a program transmission cost, a program storage cost, and a VS installation cost. Then the resource allocation problem in a VOD network providing only IVOD service (RAPIVOD) is to decide where we should install VSs, which and how many programs should be stored at each VS, so that all the demands are satisfied with the minimum total cost. We propose a dynamic programming algorithm for solving RAPIVOD in this section.

Let $TC_n(k)$ be the cost of the program transmission on arc n (PD_n, n) when k programs are stored on $T(n)$. The transmission cost of the remaining $(J-k)$ programs, which will have lower program vision probabilities, on arc n depends upon their mean service demands. Therefore, $TC_n(k)$ can be expressed as follows:

$$TC_n(k) = \begin{cases} g_1 \left(C_t, D_n, \sum_{j=k+1}^J (R_n \times P_j) \right), & \text{if } n \neq 1 \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

where C_t is the unit transmission cost of an IVOD program and D_n is the distance between node n and its predecessor PD_n .

The third quantity $\sum_{j=k+1}^J (R_n \times P_j)$ in (7) represents the total amount of mean service demands on node n which is equal to the total traffic volume on arc n during the busiest period of time when k kinds of programs are assumed to be stored on $T(n)$.

Let $SC(k, x_n)$ be the cost function of the program storage on node n when x_n kinds of programs out of k ones are stored at node n and the remaining $k - x_n$ kinds of programs are stored on $T(q)$ for all $q \in L_n$ (i.e., $k - x_n$ kinds of programs are stored at some nodes on the path $P[u, q]$ for each leaf node $u \in T(q)$ and all $q \in L_n$). Let $\lceil x \rceil$ be the smallest integer larger than or equal to x . Then $SC(k, x_n)$ can be expressed as follows:

$$SC(k, x_n) = \begin{cases} g_2 \left(C_s, \sum_{j=k-x_n+1}^k \left\lceil \frac{R_n \times P_j}{h} \right\rceil \right), & \text{if } x_n \neq 0 \\ 0, & \text{otherwise} \end{cases} \quad (8)$$

where C_s is the unit storage cost of an IVOD program and h is the number of multiple accesses for an IVOD program. The quantity $\left\lceil \frac{R_n \times P_j}{h} \right\rceil$ in (8) represents the number of programs with the j -th program vision probability stored at a VS located at node n .

If at least one program is stored at node n (i.e., if $x_n \neq 0$), then a VS should be installed in node n . Let $IC(k, x_n)$ be the cost function of the installation of a VS on node n under the same situation given for $SC(k, x_n)$. Then $IC(k, x_n)$ can be expressed as follows:

$$IC(k, x_n) = g_3(C_v, y(x_n)), \text{ where } y(x_n) = \begin{cases} 1, & \text{if } x_n \neq 0 \\ 0, & \text{otherwise,} \end{cases} \quad (9)$$

where C_v is the installation cost of a VS for IVOD service.

For a given node n , there are k kinds of programs stored on $T(n)$ for $k = 0, 1, 2, \dots, J$. Let $f(n, k)$ be the minimum total cost related to storing k kinds of programs on $T(n)$. Suppose that we have found $f(q, k)$ for all $q \in L_n$ and $k = 0, 1, 2, \dots, J$. Then $f(n, k)$ can be determined by the following recursive formula:

$$f(n, k) = \begin{cases} \min_{0 \leq x_n \leq k} \left\{ SC(k, x_n) + IC(k, x_n) + \sum_{q \in L_n} f(q, k - x_n) \right\} + TC_n(k), & \text{if } L_n \neq \emptyset \\ SC(k, k) + IC(k, k) + TC_n(k), & \text{otherwise.} \end{cases}$$

The main idea of our dynamic programming approach can now be summarized as follows. First, begin with the leaf node N . If k kinds of programs are stored on $T(N) = \{N\}$, then all of those programs should be stored at node N itself and the $(J-k)$ number of programs with the lower program vision probabilities than the k -th (i.e., programs with the program vision probability from $(k+1)$ -th to the J -th) should be stored at some VSs on the path $P[PD_N, 1]$. Therefore, to find the

minimum total cost $f(N,k)$ for all $k = 0, 1, 2, \dots, J$, the cost of storing k kinds of programs at node N , the video server installation cost at node N , and the transmission cost of the $J-k$ number of programs on arc N should be evaluated by considering the service demand for each program at node N . Consequently, $f(N,k)$ can be obtained by the sum of those costs, i.e., $SC(k,k)+IC(k,k)+TC_N(k)$, for all $k = 0, 1, 2, \dots, J$. Next, consider the complete subtree $T(N-1)$ of $\bar{T}$ rooted at node $N-1$. If the node $N-1$ is a leaf node, then $T(N-1)=\{N-1\}$ and thus $f(N-1,k)$ can be obtained by the same argument for $f(N,k)$, which is equal to $SC(k,k)+IC(k,k)+TC_{N-1}(k)$, for all $k = 0, 1, 2, \dots, J$. Otherwise (i.e., if $L_{N-1} \neq \emptyset$), $T(N-1)$ consists of $\{N-1, N\}$ where $PD_N = N-1$. Suppose that k kinds of programs are stored on $T(N-1)$ and x_{N-1} kinds of programs are stored at node $N-1$. Then, to find $f(N-1,k)$, it is enough to evaluate the cost of storing x_{N-1} kinds of programs at node $N-1$, the video server installation cost at node $N-1$, and the transmission cost of the $(J-k)$ number of programs on arc $N-1$ for each $x_{N-1}=0,1,\dots,k$, since $k-x_{N-1}$ kinds of programs are stored at node N and we have already found the minimum total cost $f(N, k-x_{N-1})$. Therefore, $f(N-1,k)$ can be obtained by

$$\min_{0 \leq x_{N-1} \leq k} \{SC(k, x_{N-1}) + IC(k, x_{N-1}) + f(N, k - x_{N-1})\} + TC_{N-1}(k)$$

The above procedure is continued by visiting nodes in the reverse of BFS order until we arrive at the root node 1 of $\bar{T}$, and finally find the optimal value $f(1,J)$ of RAPIVOD.

To find the optimal solution x_n^* for $n=1, 2, \dots, N$, we first define the following value for each $n=1, 2, \dots, N$ and $k=0, 1, 2, \dots, J$:

$$x(n,k) = \begin{cases} \operatorname{argmin}_{0 \leq x_n \leq k} \left\{ SC(k, x_n) + IC(k, x_n) + \sum_{q \in L_n} f(q, k - x_n) \right\}, & \text{if } L_n \neq \emptyset \\ k, & \text{otherwise} \end{cases}$$

Then the optimal solution, which holds the information about the video server location and the kinds of programs stored in the video server, can be obtained by $x_n^* = x(n, J - w)$ in the BFS order for all $n = 2, 3, \dots, N$, where $w = \sum_{i \in P[PD_n, 1]} x_i^*$ and $x_1^* = x(1, J)$.

IV. EXTENSION TO THE MIXED SERVICE OF IVOD AND NVOD

In this section, we propose a dynamic programming for solving the resource allocation problem in a VOD network providing mixed IVOD and NVOD (RAPINVOD). For mixed IVOD and NVOD service, we first need to determine an efficient rule for determining the number of channels assigned to each NVOD program. Note that we have assumed that impatient customers unwilling to await the NVOD service will receive IVOD service in the ratio of γ , $0 \leq \gamma \leq 1$. For this case, we might consider several possible

rules for determining the number of channels of each NVOD program. Instead, we propose a rule which assigns the number such that the expected number of customers who cancel their NVOD service requests do not exceed L , where L is a fixed number. In fact, let m_j be the number of channels for an NVOD program with the j -th program vision probability. Then m_j is determined by the minimum number of channels satisfying $\bar{P}_f(V(m_j)) \times (R_1 \times P_j) \leq L$, where $\bar{P}_f(V(m_j))$ is given in formula (5) and $R_1 \times P_j$ represents the expected service demand for an NVOD program with the j -th program vision probability, since a VS for NVOD service can be installed only at node 1. Note that the mean service demand for an IVOD program with the j -th program vision probability is $\bar{P}_f(V(m_j)) \times (R_1 \times P_j) \times \gamma$. The procedure for finding m_j can be described as follows.

Procedure Find m_j

Step 1. (Initialization) $\bar{m}_j \leftarrow 0$;

Step 2. $\bar{m}_j \leftarrow \bar{m}_j + 1$;

Step 3. $\bar{P}_f(V(\bar{m}_j)) \leftarrow 1 - P_f(V(\bar{m}_j))$;

Step 4. If $\bar{P}_f(V(\bar{m}_j)) \times (R_1 \times P_j) > L$, then go to Step 2.

Step 5. $m_j \leftarrow \bar{m}_j$; Stop

Once we obtain the number of channels, m_j , for all $j=1,2,\dots,J$, we are able to decide which and how many programs should be served through IVOD and through NVOD, so as to minimize the sum of the operating costs of IVOD and NVOD services. Before we formulate the problem RAPINVOD, we first introduce three kinds of cost for NVOD service the transmission cost, the storage cost, and the video server installation cost.

Let NTC_s be the transmission cost for s kinds of NVOD programs stored at a VS on node 1 to all leaf nodes connected to customers by using m_j number of channels. For convenience, we set $m_0 = 0$. Then, NTC_s can be expressed as follows:

$$NTC_s = \sum_{n=2}^N \left(\sum_{j=0}^s (nct \times D_n \times m_j) \right)^{\phi'_t} \quad (10)$$

where nct is the transmission cost for an NVOD program per unit distance and ϕ'_t is the parameter for the transmission cost with $\phi'_t \geq 0$.

Let NSC_s be the storage cost for s kinds of NVOD programs at a VS on node 1. Then NSC_s can be expressed as follows:

$$NSC_s = \left(\sum_{j=0}^s \left(ncs \times \left\lceil \frac{m_j}{H} \right\rceil \right) \right)^{\phi'_s} \quad (11)$$

where ncs is the unit storage cost for an NVOD program and ϕ'_s is the parameter for the storage cost with $\phi'_s \geq 0$.

The quantity $\left\lceil \frac{m_j}{H} \right\rceil$ in (11) represents the number of programs with the j -th program vision probability stored at VS on node 1 for NVOD service.

Let NFC_s be the installation cost of a VS for NVOD service on node 1 when s kinds of programs are served by NVOD. Then, since a VS for NVOD service should be installed at node 1 if at least one program is served by NVOD, NFC_s can be expressed as follows:

$$NFC_s = ncv \times y_s, \quad (12)$$

where ncv is the installation cost of a VS for NVOD service and y_s is defined by

$$y_s = \begin{cases} 1, & \text{if } s \neq 0 \\ 0, & \text{otherwise.} \end{cases}$$

With the above three costs related to NVOD service, the problem RAPINVOD can be formulated as follows:

$$\min_{0 \leq s \leq J} \{NTC_s + NSC_s + NFC_s + f_s(1, J)\}, \quad (13)$$

where $f_s(1, J)$ is the minimum total cost for providing IVOD programs with the program vision probabilities rearranged by considering the rate of lost service requests for s kinds of NVOD programs and can be obtained by the dynamic programming algorithm given in Section III.

We now summarize the main idea of our dynamic programming procedure for solving RAPINVOD. Initially, the number of channels for each NVOD program is obtained by applying the procedure 'Find m_j '. We first evaluate the IVOD operating cost corresponding to providing only IVOD service by applying the algorithm given in Section III and then begin by allocating programs to the VS for NVOD service in the decreasing order of program vision probabilities and finding the total cost, i.e., the sum of the NVOD and IVOD operating costs. In finding the IVOD operating cost, all the programs for IVOD service should be rearranged in decreasing order of program vision probabilities because all the customers who cancel the requested NVOD programs receive IVOD service in the ratio of γ and thus the program vision probabilities of programs for IVOD service that are also allocated for NVOD service should be changed. Once we determine the maximum number, s^* , of kinds of programs which should be stored at the VS for NVOD service, the locations of VSs for IVOD service and the kind and number of IVOD programs stored at each VS can be found simultaneously when $f_{s^*}(1, J)$ is evaluated using the algorithm given in Section III. We now describe our dynamic programming procedure for solving formula (13) as follows:

Procedure Solve_RAPINVOD

Step 1. (Initialization) Find m_j for all $j = 1, 2, \dots, J$;

$$TCOST \leftarrow \infty; s^* \leftarrow 0; s \leftarrow 0;$$

Step 2. $NCOST \leftarrow NTC_s + NSC_s + NFC_s$;

Step 3. If $s = 0$, then go to Step 6;

Step 4. $P_s \leftarrow P_s \times \bar{P}(V(m_s)) \times \gamma$;

Step 5. Sort all the programs in descending order of their updated program vision probabilities;

Step 6. Evaluate $f_s(1, J)$;

Step 7. If $NCOST + f_s(1, J) < TCOST$, then

$$TCOST \leftarrow NCOST + f_s(1, J); s^* \leftarrow s;$$

Step 8. If $s < J$, then $s \leftarrow s + 1$ and go to Step 2;

Otherwise, stop;

Note that the returned values $TCOST$ and s^* from the procedure 'Solve_RAPINVOD' are the optimal value and the optimal number of kinds of programs for NVOD service, respectively. Moreover, the total number of programs stored at a VS on node 1 for NVOD service is $\sum_{j=0}^{s^*} \left\lceil \frac{m_j}{H} \right\rceil$.

We now use the example given in Fig. 1 to demonstrate our algorithm. All the assumptions for IVOD service are still the same as those used in Section III, except that the cost functions of the program transmission and the program storage for IVOD service as well as NVOD service are assumed to be linear (i.e., $\phi_t, \phi'_t, \phi_s, \phi'_s = 1$). It is a condition that the program transmission cost, the program storage cost, and the video server installation cost for IVOD service are more expensive than those for NVOD service. The condition still holds that the unit transmission cost of an NVOD program is more expensive than the unit storage cost of the program. Moreover, it is essential that all the customers unwilling to await the NVOD service will receive IVOD service (i.e., $\gamma = 1$) and the mean queuing time that a customer will await the requested NVOD program is 20 minutes (i.e., $\delta = \frac{1}{20} = 0.05$). It is also assumed

that $L = 710$ and the service duration for all programs is identically equal to 120 minutes (i.e., $\tau_j = 120$ for all $j = 1, 2, \dots, J$). All values used for the example are summarized in Table 1.

TABLE 1. VALUES CORRESPONDING TO PARAMETER

Parameter	Value	Parameter	Value
J	100	γ	1
D_{HP}	1.06	δ	0.05
D_n	1	$\tau_j, j = 1, 2, \dots, J$	120
c_s/ncs	3/2	R_4	12,000
c_t/nct	4/3	R_5	7,000
c_v/ncv	200/150	R_6	9,000
h/H	10/10	R_8	9,000
ϕ_t/ϕ'_t	1/1	R_9	6,000
ϕ_s/ϕ'_s	1/1	R_{10}	7,000

We now apply the procedure 'Solve_RAPINVOD' to compute the optimal number, s^* , of kinds of programs for NVOD service giving the minimum total cost.

Figure 2 shows the change of the total cost with respect to the number of kinds of NVOD programs when $L = 710$. Consequently s^* is 28. Figure 3 shows the number of channels for each of the s^* kinds of programs for NVOD service.

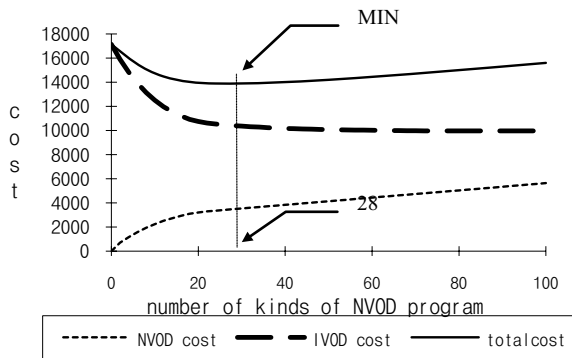


Figure 2. The change of total cost with respect to number of kinds of NVOD program when $L=710$

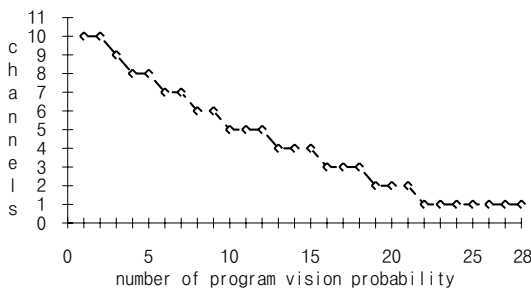


Figure 3. The number of channels for each of the s^* kinds of programs for NVOD service

The optimal solutions, including the locations of VSs for IVOD service and the kinds and number of IVOD programs stored at each VS, are shown in Table 2.

Finally, Figure 4 shows the change of the total cost for the example with respect to the change of L .

TABLE 2. OPTIMAL SOLUTIONS RELATED TO IVOD SERVICE FOR EXAMPLE

CO(n)	1	2	3	4	5	6	7	8	9	10
Amount	0	0	0	711	440	546	0	546	386	440
Kind	(0)	(0)	(0)	(1-100)	(1-100)	(1-100)	(0)	(1-100)	(1-100)	(1-100)

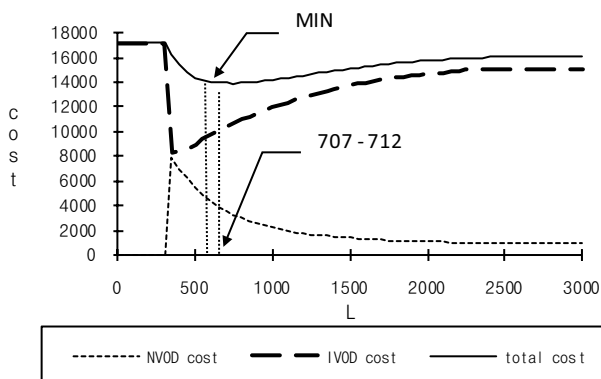


Figure 4. The change of the total cost with respect to the change of L

It can be seen that the optimal value is obtained when $707 \leq L \leq 712$. This implies that our algorithm not only solves RAPINVOOD under the predetermined service policy, but also provides the critical information to service providers when they have to prepare their service policy for providing a mix of IVOD and NVOD services beforehand.

V. CONCLUSIONS

In this paper we have first introduced a dynamic programming algorithm for optimally providing only IVOD service (RAPINVOOD). Then we have proposed a procedure for determining the number of channels assigned to each NVOD program under the assumption that the mean number of customers who cancel their requests for NVOD service is given. Finally we have proposed an efficient dynamic programming algorithm for optimally providing a mix of IVOD and NVOD services (RAPINVOOD) by extending the key idea of the earlier dynamic programming for solving RAPINVOOD.

We are currently working on applying our algorithm to cover several optimization problems which arise in resource allocation problems in networks that provide various types of multimedia services.

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