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File Allocation Designs for Distributed Multimedia Information Networks

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SUMMARY In this paper, we study the optimal allocation of multimedia files in distributed network systems. In these systems, the files are shared by users connected with different servers geographically separated, and each file must be stored in at least one of servers. Users can access any files stored in any servers connected with high-speed communication networks. Copies of the files accessed frequently are to be stored in several servers that have databases. So, it is one of the most important problems how to assign the files to servers in view of costs and delays. Considering these problems in heterogeneous network environments, we present a new system model that covers wide range of multimedia network applications like VOD, CALS, and so on. In these systems, it is obvious that there is trading-off relationship between costs and delays. Our objective is to find the optimal file allocation such that the total cost is minimized subject to the total delay. We introduce a 0–1 integer programming formulation for the optimization problem, and find the optimal file allocation by solving these formulae.

key words: *distributed processing, distributed database system, optimal file allocation, video on demand, multimedia information network, heterogeneous network*

1. Introduction

Recently, various information and communication services have been provided to homes and individuals as well as businesses, by the developments of multimedia network technology and the wide usage of workstations and personal computers. There has been a great trend to shift from centralized systems to distributed systems. We may easily imagine that it will be preferable to allocate important and popular files in several servers duplicately in view of the delay, system scalability, reliability, and so on. In these distributed information networks for multimedia services, each server is not necessarily required the same capacity, service rates and communication rates. Also, size of files, access rates from users and rewriting rates to files are different in each subnetwork. In addition, there is significant differences between the local communication costs and the global communication costs in distributed systems. We should consider various problems in distributed systems in view of heterogeneous network environments.

These distributed systems consist of several servers, with multimedia databases, that separate to each other geographically, and each server constitutes a subnetwork with a number of users. Each server is connected to one another by a high-speed communication network, and the whole system works as a distributed database system. In these distributed database systems, files must be stored in at least one of servers, and are shared by several users connected with different servers. Users can access any files stored in any servers. Copies of the files accessed frequently are to be stored in several servers. Then, in distributed systems, it becomes very important problems which server stores the files required by users, because there are remarkable differences in the distance between to a local database and to the other databases.

Thus, we should consider if it is accessed frequently or not, and find optimal allocation of files. Each server should store the files that it accesses frequently to reduce the communication cost and delay. However, the duplicated storage of the same files in the system cause to increasing in the storage cost required to store them. Also, there is necessity to keep the data consistency, and then the rewriting cost is increasing. Moreover, we should take account of the difference between the local communication costs and the global communication costs described above, which is an important element for distributing files. We should consider the optimal file allocation problem in view of these problems.

C.C.Bisdikian and B.V.Patel presented the optimal file allocation to minimize costs in distributed VOD systems [2]. However, they did not consider delays. It is obvious that there is a trading-off relationship between costs and delays. Our objective is to find the optimal file allocation such that the total cost is minimized subject to the total delay in distributed systems.

It is necessary to introduce a new useful model, which may be applied to heterogeneous network environments, to find the optimal file allocation. In this paper, we present a new system model that can evaluate the optimization in considering the problems described above. We may apply this model to various network environments, that is, capacity of server, communication rates, etc., by controlling several parameters. Moreover, we consider the consistency among the same files in this model. This model covers wide range of multimedia network applications such as VOD, CALS, and so on. In addition, we introduce a 0–1 integer programming formulation for the optimization problem on the basis of this model, and find the optimal file allocation by

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solving these formulae.

In this paper, first, we present a new model that is applied to wide range of multimedia network applications in Sect. 2. In Sect. 3, we formulate the optimal file allocation problem as a 0–1 integer programming in considering various elements of cost and delay in view of problems presented above. In Sect. 4, we show the numerical results and discuss them from a number of viewpoints. Finally, we describe our conclusions in Sect. 5.

2. Model

We introduce a new model of a distributed information network system that may be applied to wide range of multimedia network applications.

In Fig. 1, we show an example of a distributed information network system. As shown in Fig. 1, this system consists of servers, users, files, communication lines, and a high-speed communication network.

There exist s servers in the system. Each server is denoted by S_i $(1 \leqq i \leqq s)$, and has the storage capacity of B_i. It is assumed that each user of system is connected with one of servers, which is called a local server. The users connected with the server S_i is called *i-users*. In this system, each server is connected by the high-speed communication network, and the whole system works as a distributed database system. In addition, we consider the selection of communication lines between servers and the communication network, since quality and costs of communication are dependent on what classes of lines we use mainly. There are u classes of lines that we may select, which is classified according to line quality and transmission rates. Each server selects and uses a line of class n $(1 \leqq n \leqq u)$. Each subnetwork may take individual communication rates by selection of lines.

Also, the number of multimedia files is m, and each file is denoted by M_k $(1 \leqq k \leqq m)$. The maximum duplicate number of the file M_k is r_k. It is possible to allocate the same files in several servers, if the number of copies of the file M_k is less than or equal to r_k. It is assumed that the size of the file M_k is denoted by F_k. Each server can store these multimedia files so long as the total size of files does not exceed the capacity of the server.

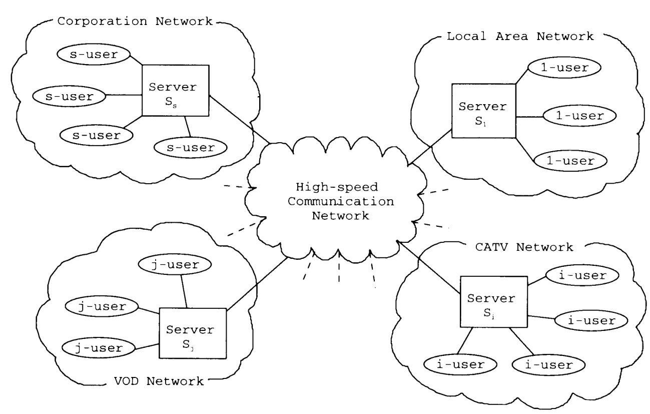

Fig. 1 A distributed information network system.

i-users generate file access flow, where the average is λ_i per unit time. This amount of flow generates queuing time at servers. We should assume the queuing process as M/G/1. In analyzing of M/G/1 systems, we have to measure service distributions in the real systems, and we decide several parameters, averages, variances, and so on. However, we don't have any practical evaluations. Here we take M/D/1 for analytical simplicity instead of M/G/1. The access sizes from *i-users* for the multimedia files M_k is denoted by L_{ik}. This access size is less than or equal to the file size F_k. Also, let P_{ik} be defined as the access probability from *i-users* for the multimedia files M_k $(\sum_k P_{ik} = 1)$. The parameter P_{ik} determines the traffic matrix in the system. Especially, if the access probabilities have the same value for the same k, the system is file symmetric. Moreover, the probability that *i-users* rewrite the file M_k is denoted by Pw_{ik}. We may discuss various kinds of multimedia network applications according to the value of Pw_{ik}. If we consider VOD system, we must determine that all Pw_{ik} is equal to zero. If Pw_{ik} is more large, we may consider that there happens to rewrite the files frequently, such as CALS. In this paper, we apply the write-through consistency protocol to the rewriting protocol.

To formulate *the Optimal File Allocation Problem*, we define two major variables as follows.

1. The variables on the allocation of files X_{ik} [1].

$$X_{ik} = \begin{cases} 1 & (M_k \text{ is stored in } S_i) \\ 0 & (\text{otherwise}) \end{cases} \tag{1}$$

2. The variables on the selection of lines classes Y_{in}.

$$Y_{in} = \begin{cases} 1 & (S_i \text{ uses the line of class } n) \\ 0 & (\text{otherwise}) \end{cases} \tag{2}$$

3. Formulation

Our objective is to find the optimal file allocation such that the total cost is minimized in the distributed system defined in the previous section. The cost is very important criterion to evaluate a distributed database system. However, some systems that optimizes only the cost is not so useful, because the system may require a great total delay. This is why we take account of the total delay as the restriction condition.

In this paper, we formulate[†] the problem to minimize the total cost per unit time required in the whole

[†] In the following formulation, it is assumed that $\sum_i$ denotes the summation for servers in the system, $\sum_k$ denotes the summation for files in the system, and $\sum_n$ denotes the selection of line classes.

system, subject to the total delay in the whole system and the facility cost.

3.1 Primary Conditions

Under the assumptions presented in the previous section, we add the following three conditions as primary conditions.

1. The number of copies of file M_k in the system is less than or equal to r_k, that is,

$$1 \leqq \sum_i X_{ik} \leqq r_k \tag{3}$$

2. Server S_i can store files so long as the total size of files does not exceed the capacity of the server, that is,

$$\sum_k X_{ik} F_k \leqq B_i \tag{4}$$

3. Each server selects and uses one of u classes of lines between servers and the communication network, that is,

$$\sum_n Y_{in} = 1 \tag{5}$$

3.2 Objective Function

We formulate the total cost per unit time as the objective function. It is assumed that the total cost C consists of four elements. Those are the communication cost Ct_{ik}, the server cost Crs_{ik}, the storage cost Cst_i, and the line cost Crl_i. The communication cost and the server cost are required for each access from an *i-user* for a file M_k, and we make the communication cost and the server cost per unit time by multiplying by the average access rate λ_i from *i-users* to files per unit time. Also, a server S_i requires the storage cost and the line cost per unit time. That is,

$$C = \sum_i \left(\lambda_i \sum_k (Ct_{ik} + Crs_{ik}) + Cst_i + Crl_i \right) \tag{6}$$

We may find the optimal file allocation and the optimal selection of lines which minimize the total cost, by solving this expression for X_{ik} and Y_{in} subject to the conditions in the next subsection.

We give full details of the communication cost, the server cost, the storage cost, and the line cost in the following.

3.2.1 Communication Cost

We assume that the communication cost is required to communicate between a user site and a file site. For example, when an *i-user* accesses for a file M_k, the communication cost Ct_{ik} will be required to communicate between an *i-user* and a server that stores the file M_k. In this paper, this communication cost is the sum of the cost required to communicate between an *i-user* and the server S_i, between the server S_i and the communication network, and between the communication network and the server stored the file M_k. If a local server S_i stores the file M_k, the communication cost Ct_{ik} is required to communicate only between an *i-user* and the local server.

Also, in this paper, if a file required from a user is not stored in the local server and some remote servers store the file, the user accesses the server that has the minimum sum of the communication cost and the server cost.

We formulate the communication cost Ct_{ik} in an access from an *i-user* to a file M_k. Let Ctl_i be defined as the local communication cost coefficient between an *i-user* and a local server S_i. Let Ctr_{in} be defined as the remote communication cost coefficient between a server S_i joined to a line of the class n and the communication network. These coefficients have fixed values for individual lines.

$$Ct_{ik} = \left(X_{ik}\mathsf{Ctl}_i + \mathbf{Xf}_{ij}\mathbf{Cy}_{ij} \right) L_{ik} P_{ik} \tag{7}$$

Here, it is assumed that index j equals to the value that minimize the following function on the positive side $(1 \leqq j \leqq s)$.

$$h1_{min}(j) = \mathbf{Xf}_{ij} \left(\mathbf{Cy}_{ij} + \mathsf{Csa}_j \right) \tag{8}$$

Csa_j is the access cost coefficient required to serve at the server S_j as described in next passage. Also, we define $\mathbf{Xf}_{ij}$ and $\mathbf{Cy}_{ij}$ as follows.

$$\mathbf{Xf}_{ij} = (1 - X_{ik}) X_{jk} \tag{9}$$

$$\mathbf{Cy}_{ij} = \mathsf{Ctl}_i + \sum_n \mathsf{Ctr}_{in} Y_{in} + \sum_n \mathsf{Ctr}_{jn} Y_{jn} \tag{10}$$

3.2.2 Server Cost

We assume that the server cost is required to serve at the server in an access from a user for a file. Similarly, if a file required from a user is not stored in the local server and some remote servers store the file, the user accesses the server that has the minimum sum of the communication cost and the server cost.

We formulate the server cost Crs_{ik} in an access from an *i-user* to a file M_k. We consider three kinds of costs.

1. The access cost required to serve at the server

2. The rewriting cost required to rewrite files which is increasing as the same file is stored duplicately
3. The relay cost that is required to relay when the server does not have the request file from local users

The rewriting cost includes the cost required to communication in rewriting. Let Csa_i, Csw_i, and Csr_i be defined as the access cost coefficient, the rewriting cost coefficient, and the relay cost coefficient at the server S_i each other. They depend on the coefficient Crs_i, that is, $\mathsf{Csa}_i = a \cdot \mathsf{Crs}_i$, $\mathsf{Csw}_i = w \cdot \mathsf{Crs}_i$, and $\mathsf{Csr}_i = r \cdot \mathsf{Crs}_i$. We can select values of the coefficient a, w, r according to systems. Here, let Crs_i be the server cost coefficient of the server S_i, and this coefficient has a fixed value for an individual server.

$$\begin{aligned} &Crs_{ik} \\ &= (X_{ik}\mathsf{Csa}_i + (1 - X_{ik})\mathsf{Csr}_i + \mathbf{Xf}_{ij}\mathsf{Csa}_j) L_{ik}P_{ik} \\ &\quad + \left(\sum_{l \neq i} (X_{lk}\mathsf{Csw}_l)\right) RCnfP_{ik}Pw_{ik} \end{aligned} \tag{11}$$

Here, it is assumed that index j equals to the value that minimize the function $h1_{min}(j)$ (Eq. (8)) on the positive side, too ($1 \leqq j \leqq s$). Also, $RCnf$ will be defined as the local-global difference of the communication cost in the next section.

3.2.3 Storage Cost

We assume that the storage cost is required for each server to store multimedia files. It is required on unit time basis and does not depend on the frequency of accesses. In this paper, the storage cost depends on the size of all files stored at a server. We formulate the storage cost Cst_i of server S_i. Let Cst be the storage cost coefficient, which has a fixed value in common for all servers.

$$Cst_i = \mathsf{Cst} \sum_k X_{ik}F_k \tag{12}$$

3.2.4 Line Cost

We assume that the line cost is required to use a communication line between each server and the high-speed communication network. This is required on unit time basis and does not depend on the frequency of accesses, like the storage cost. Let Crl_{in} be defined as the line cost coefficient between a server S_i joined to a line of the class n and the communication network. We formulate the line cost between a server S_i and the communication network.

$$Crl_i = \sum_n \mathsf{Crl}_{in}Y_{in} \tag{13}$$

3.3 Restriction Conditions

We formulate the total delay and the facility cost as the restriction conditions for the optimal file allocation problem. We find the optimal file allocation by solving the objective function C formulated above subject to the following restrict conditions.

3.3.1 Total Delay

We formulate the total delay. It is assumed that the total delay consists of the communication delay Dt_{ik}, the service delay Dx_i, and the rewriting delay Dw_i. For each access from an *i-user* for a file M_k, an *i-user* has to spend these delays. Let D_{max} be defined as the maximum total delay, and the total delay is as follows.

$$\begin{aligned} D = &\sum_i \left(\lambda_i \left(\sum_k Dt_{ik} + Dw_i\right) + \lambda_i^* Dx_i\right) \\ &\leqq D_{max} \end{aligned} \tag{14}$$

We will explain λ_i^* later (Eq. (19)). The average delay Da is defined as follows.

$$Da = \frac{D}{\sum_i \lambda_i} \tag{15}$$

[**Communication Delay**]
The communication delay is required to communicate from a user to a file per an access. Let Dtl_i be defined as the local communication delay coefficient between an *i-user* and a local server S_i. Let Dtr_{in} be defined as the remote communication delay coefficient between a server S_i joined to a line of the class n and the communication network. We formulate the communication delay Dt_{ik} in an access from an *i-user* for a file M_k as follows. Here, it is assumed that index j equals to the value that minimize the function $h1_{min}(j)$ (Eq. (8)) on the positive side, too ($1 \leqq j \leqq s$).

$$Dt_{ik} = (X_{ik}\mathsf{Dtl}_i + \mathbf{Xf}_{ij}\mathbf{Dy}_{ij}) L_{ik}P_{ik} \tag{16}$$

Also, we define $\mathbf{Dy}_{ij}$ as follows.

$$\mathbf{Dy}_{ij} = \mathsf{Dtl}_i + \sum_n \mathsf{Dtr}_{in}Y_{in} + \sum_n \mathsf{Dtr}_{jn}Y_{jn} \tag{17}$$

[**Service Delay**]
The service delay is required to serve a file by a user per a service. We may assume this delay behavior as M/G/1, and here we take M/D/1 for analytical simplicity. We can formulate the service delay Dx_i in a server S_i by the *Pollaczek-Khinchin mean-value formula* and *Little's result*[3]. A service in a server S_i is assumed to take the service time x_i on average.

$$Dx_i = x_i + \frac{\lambda_i^* x_i^2}{2(1 - \lambda_i^* x_i)} \tag{18}$$

Here, we do not use the flow λ_i but λ_i^* as the mean arrival rate. When we consider service in each server, we should consider not only λ_i access on average from local users but also accesses from users connected with other servers. Thus, we formulate λ_i^* .

$$\lambda_i^* = \lambda_i + \sum_{j'} \delta(j-i) \sum_k (\mathbf{Xf}_{j'i}\lambda_{j'}P_{j'k}) \tag{19}$$

Here, it is assumed that j equals to the value that minimize the following function $h2_{min}(j)$ on the positive side $(1 \leqq j \leqq s)$.

$$h2_{min}(j) = \mathbf{Xf}_{j'j}(\mathbf{Cy}_{j'j} + \mathsf{Csa}_j) \tag{20}$$

$$\delta(t) = \begin{cases} 1 & (t=0) \\ 0 & (t \neq 0) \end{cases} \tag{21}$$

[**Rewriting Delay**]
The rewriting delay is required to keep the data consistency when the same file is allocated in more than or equal to two servers. This rewriting delay is evaluated per a rewriting from a user to a file and includes a delay required to communication in rewriting. In this paper, we apply the write-through consistency protocol. The rewriting delay coefficient is denoted by Dw. We formulate the rewriting delay Dw_i in rewriting from an *i-user* to a file M_k.

$$Dw_i = \sum_k \mathsf{Dw}RDnf\,(W_k - 1 + \delta(W_k))\,P_{ik}Pw_{ik} \tag{22}$$

Here, $RDnf$ will be defined as the local-global difference of the communication delay in the next section. Also, W_k is the number of files in the whole system, and denoted as follows.

$$W_k = \sum_i X_{ik} \tag{23}$$

3.3.2 Facility Cost

The facility cost is required to invest in setting up servers and lines primarily. It depends on a capacity of a server and the class of lines. Let Cf_{max} be defined as the maximum facility cost. Here, Cf_n is defined as the facility cost coefficient of a line of class n, and Cb is defined as the capacity cost coefficient. The facility cost is as follows.

$$Cf = \sum_i \left(\sum_n \mathsf{Cf}_n Y_{in} + \mathsf{Cb}B_i \right) \leq Cf_{max} \tag{24}$$

4. Numerical Results and Considerations

In this section, we show numerical results of *the Optimal File Allocation Problem* formulated in the previous section.

4.1 System Parameters for Numerical Results

In Fig. 2, we show the model of the distributed database system. Here, we consider the system parameters as follows. There exist 4 servers ($s = 4$), and the capacity of each server is 30[Gbyte] ($B_i = 30000, 1 \leqq i \leqq 4$). There is 1 class of lines ($u = 1$), which is used between servers and the communication network. Thus, we do not consider the line selection in this paper. Also, there exist 6 kinds of multimedia files ($m = 6$), and the size of each file is 5[Gbyte] ($F_k = 5000, 1 \leqq k \leqq 6$). The maximum number of copies of a file M_k is less than 4 ($r_k = 4$). In this paper, we consider the capacity of servers, the size of files, and so on are identical for analytical symplicity. However, we may deal with many kinds of multimedia networks by controlloing these system parameters in our model.

Considering the optimal file allocation problem, we define the distribution rate Rd for performance measure as follows.

$$Rd = \frac{\sum_i \sum_k X_{ik}}{m} \tag{25}$$

Rd is the ratio of the number of all files allocated in the system to the number of kinds of files.

Also, we define the coefficient of variation of server utilization frequency Cv in order to evaluate the balance of the network utilization. Here, we define the server utilization frequency as f_i.

$$f_i = \sum_k \lambda_i^* P_{ik} X_{ik} \tag{26}$$

The mean value of f_i gives as following equation.

$$E[f_i] = \frac{\sum_i f_i}{s} \tag{27}$$

Let σ_f be the standard deviation of f_i, we can give σ_f by use of these as follows.

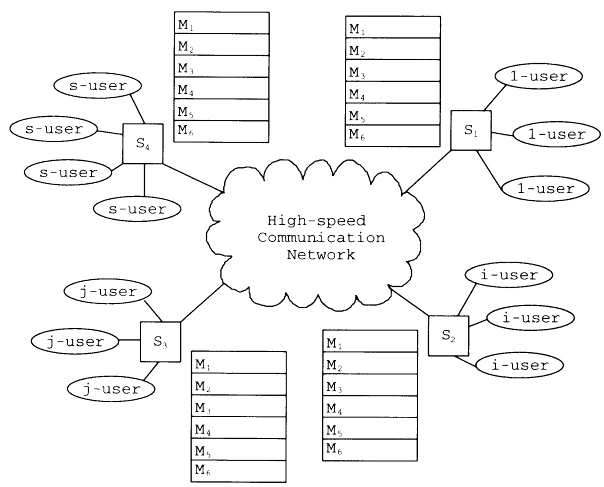

Fig. 2 An example of a distributed information network system ($s = 4, u = 1, m = 6$).

$$\sigma_f = \sqrt{\frac{\sum_i (f_i - E[f_i])^2}{s}} \tag{28}$$

We can give Cv by use of the above as follows.

$$Cv = \frac{\sigma_f}{E[f_i]} \tag{29}$$

Moreover, we define the other parameters that deal with the economic environments of the distributed systems as follows.

1. The local-global difference of the communication cost : $RCnf$
2. The local-global difference of the communication delay : $RDnf$
3. The service-communication rate : Rst
4. The cost rate of line class : $C\_rate[n]$
5. The speed rate of line class : $v\_rate[n]$

We denoted the coefficients, which is defined in Sects. of 3.2 and 3.3, by the above parameters as follows.

1. The remote communication cost coefficient between a server S_i joined to a line of the class n and the communication network Ctr_{in}

$$\mathsf{Ctr}_{in} = RCnf \cdot C\_rate[n] \cdot \mathsf{Ctl}_i \tag{30}$$

2. The cost coefficient of the server S_i Crs_i

$$\mathsf{Crs}_i = Rst \cdot \mathsf{Ctl}_i \tag{31}$$

3. The cost coefficient of the line of the class n between a server S_i and the communication network Crl_{in}

$$\mathsf{Crl}_{in} = C\_rate[n] \cdot \mathsf{Cl}_i \tag{32}$$

Here, let Cl_i to be the line cost coefficient between a server S_i and the communication network.

4. The remote communication delay coefficient between a server S_i joined to a line of the class n and the communication network Dtr_{in}

$$\mathsf{Dtr}_{in} = RDnf \cdot \mathsf{Dtl}_i / v\_rate[n] \tag{33}$$

On the basis of our definition, we select the values of parameters for numerical calculation as follows.

1. The larger a local-global difference $RCnf$ is, the more increasing a difference of the communication cost between to a local server and to the other servers is. To consider the impact of $RCnf$ to the distribution rate, we have the following values for $RCnf$.

$$RCnf = 1, 2, 3, \ldots, 10$$

2. The service-communication rate Rst denotes the ratio of the local communication cost coefficient to the server cost coefficient. Thus, we may have various relations between the communication cost and the server cost by varying Rst. To consider the impact of Rst to the distribution rate, we have the following values for Rst.

$$Rst = 1.0, 10, 20$$

4.2 Numerical Results and Considerations

Here, we show the optimization results for the above problem. In this paper, we use the exhaustive search for optimization. We obtain the assignment of files to servers as the optimal solution. On the basis of this assignment, we calculate distribution rates, the total cost, the total delay, and so on. We describe our considerations about optimization results according to these criterion.

In Fig. 3, we show trading-off relationship between the storage costs and the communication costs. This figure shows the distribution property vs. the local-global differences of the communication cost $RCnf$ for different values of the storage cost coefficient Cst, i.e., 0.1, 0.5, 1.0, 5.0, 10. As mentioned before, Rd is the ratio

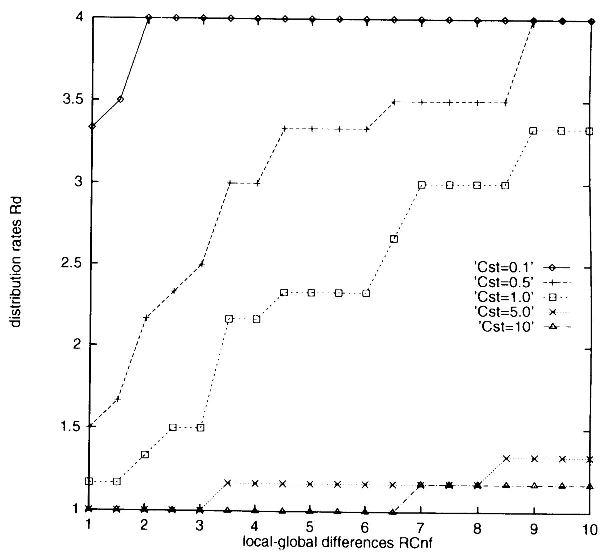

Fig. 3 A trading-off between the storage costs and the communication costs ($Rst = 1.0, RDnf = 5.0, Pw = 0.1$).

of the number of all files allocated in the system to the number of kinds of files. That is, Rd means that there exists the same files at Rd servers on the average. As shown in Fig. 3, when the storage cost coefficient Cst is larger, the distribution rates Rd become much smaller. When the storage costs are small and the communication costs are larger than the storage costs, files should be distributed to minimize the total cost. Particularly, in the case Cst $= 0.1$ and 0.5, the distribution rate Rd is saturated to 4.0. $Rd = 4$ means that all kinds of files are assigned in all servers. However, when the storage costs are very large, files should be centralized to minimize the total cost. In the case Cst $= 5.0$ and 10, each file is storaged in only one server approximately.

Moreover, as shown in Fig. 3, when $RCnf$ becomes large, more files tend to be distributed. As $RCnf$ grows larger, the communication costs to remote server become increasing. Thus, files become to be distributed and the distribution rates become increasing, so that files will be declined necessity to communicate and the communication costs will be reduced. This tendency is also generally evident. As you can see, when $RCnf = 10$, most servers should storage all kinds of files if the storage cost is not so large.

In Fig. 4, we show the property of coefficient of variation Cv vs. the local-global differences $RCnf$ for different values of the storage cost coefficient Cst. It is clear that the value of Cv becomes lower as $RCnf$ grows larger. As $RCnf$ grows larger, the distribution rates become larger in Fig. 3. Thus, this figure shows that the utilization frequency of server in the network becomes almost uniform as files become to be distributed. Compared with Fig. 3, you may see this tendency more apparently. When $Rd = 4$, that is, when all kinds of files are assigned in all servers, the value of Cv is nearing to 0.

Next, we show the effect of file rewriting. In Fig. 5, we show the distribution property vs. the local-global differences $RCnf$ for different values of the service-communication rate Rst when we take the rewriting probabilities Pw_{ik} as 0.1. As shown in Fig. 5, when $RCnf$ is small, the distribution rates Rd takes larger values for larger values of Rst. As Rst grows larger, the server costs become higher than the communication costs. In particular, the increasing in the relay costs required to relay at server affects this tendency. As the relay costs are increasing, files are distributed so that the relays will be not required at local server. However, when $RCnf$ is large, the property about Rst becomes inverse for the increasing in the rewriting costs. The rewriting costs required to rewrite at remote servers become larger as $RCnf$ grows larger. To reduce the rewriting costs, files tend to be centralized at servers that have more access as Rst is large. This tendency is much more apparent when the rewriting probabilities are large.

In Fig. 6, we show the distribution property vs. the local-global differences $RCnf$ for different values of the service-communication rate Rst, when we take the rewriting probabilities Pw_{ik} as 0.5. As you can see in Fig. 6, the distribution rates Rd takes much smaller values as Rst is large. The increasing in the rewriting costs affects this tendency greatly, for it happens to rewrite the files very often. When Rst is 20, we may judge that the rewriting costs become larger than the communication costs. In this case, the distribution rates Rd becomes smaller as $RCnf$ grows larger in spite of the increasing in the communication costs.

In Fig. 7, we show the distribution property for different values of the rewriting probabilities Pw_{ik} i.e., 0,

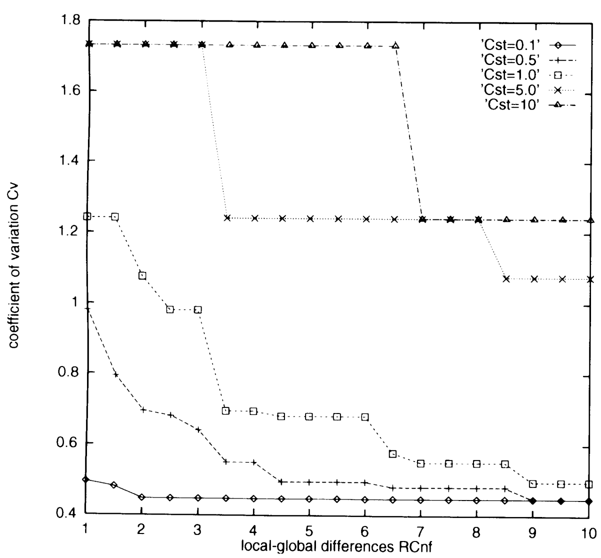

Fig. 4 A property of coefficient of variation Cv about $RCnf$ ($Rst = 1.0, RDnf = 5.0, Pw = 0.1$).

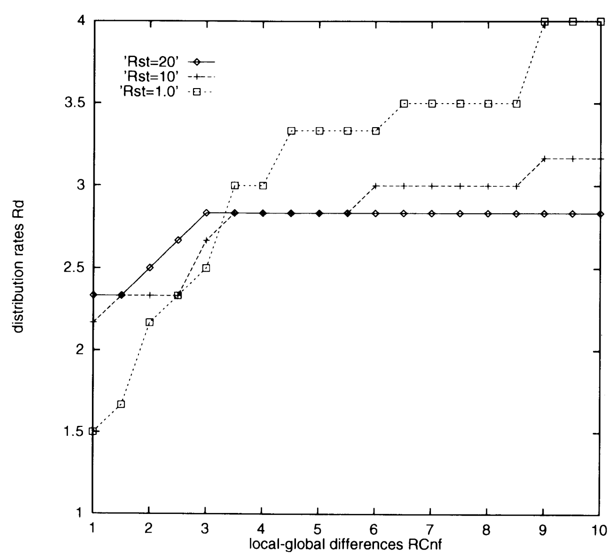

Fig. 5 A distribution property about $RCnf$ when $Pw = 0.1$ ($RDnf = 5.0, Cst = 0.5$).

0.1, 0.3, 0.5, when we take Rst as 10. As shown in this figure, the distribution rates Rd takes much larger values as Pw_{ik} is small. When $Pw_{ik} = 0$, that is, when file rewriting does not need to be considered such as VOD, Rd is very large even for small values of $RCnf$. However, when Pw_{ik} is large, Rd takes smaller values, for the increasing in the rewriting costs affects it more greatly. In the case Pw_{ik} is 0.5, that is, the frequency of rewriting is once per two access to files, each file is storaged in two server at most. In this paper, we apply the write-through consistency protocol to the rewriting protocol as described in Sect. 2. We can imagine that this is the reason for the serious increasing in the rewriting costs. When the rewriting probabilities are large, we should consider other protocols.

Finally, we show the effect of the delay restriction on the optimization of file allocation. In Fig. 8, we show the property of the total delay vs. the local-global differences of the communication delay $RDnf$ for different values of the maximum total delay D_{max}, i.e., 200, 100. We see the total delay are not affected by the restriction when $D_{max} = 200$. However, when $D_{max} = 100$, the restriction becomes to have influence on the total delay in the case $RDnf$ is more than 5.25. In this case, the total delay in the optimal file allocation that minimize the total cost may exceed the maximum (D_{max}). We show this effect of the restriction on the file allocation in Fig. 9. In the case $RDnf$ is more than 5.25,

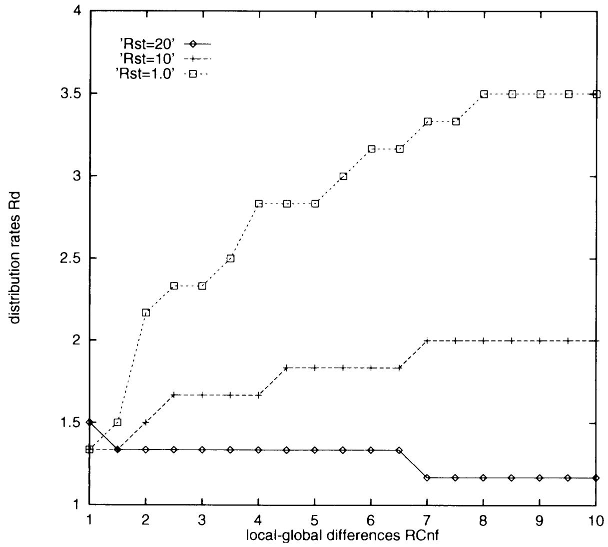

Fig. 6 A distribution property about $RCnf$ when $Pw = 0.5$ ($RDnf = 5.0, Cst = 0.5$).

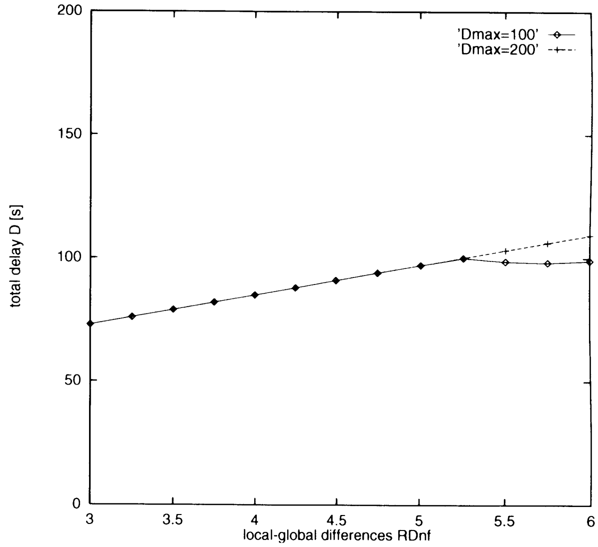

Fig. 8 A delay property ($RCnf = 3.0, Rst = 1.0, Pw = 0.1, Cst = 0.5$).

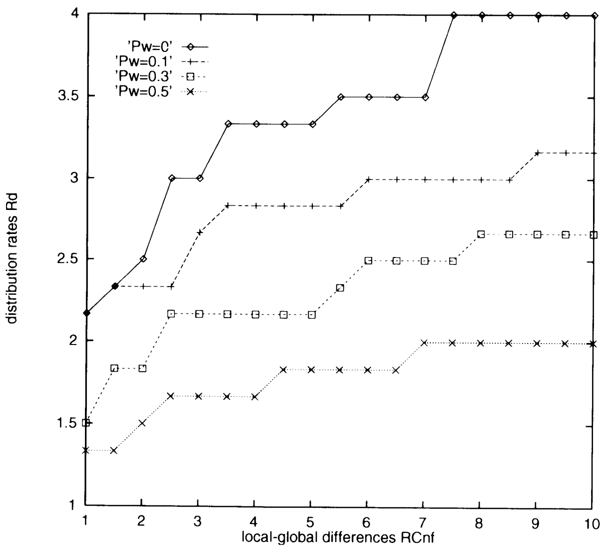

Fig. 7 A distribution property about $RCnf$ for different values of Pw ($Rst = 10, RDnf = 5.0, Cst = 0.5$).

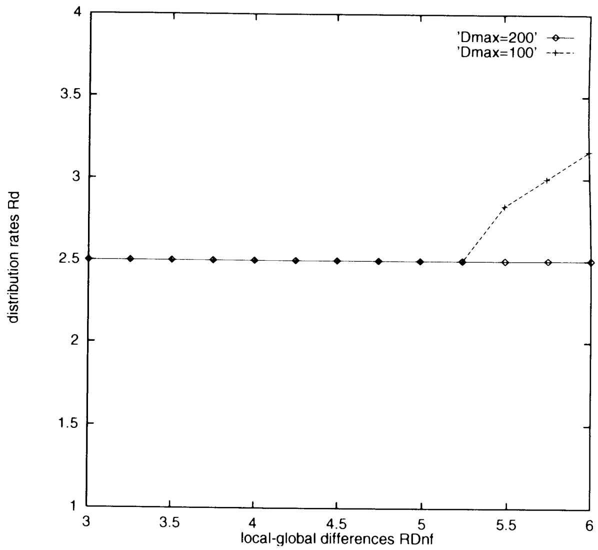

Fig. 9 A distribution property about $RDnf$ ($RCnf = 3.0, Rst = 1.0, Pw = 0.1, Cst = 0.5$).

files are more distributed to reduce the communication delays. When $RDnf = 6$, each file is storaged in more than three servers. In the case $RDnf > 6$, There is no solution in which the total delay does not exceed the maximum. This figure shows that files should be distributed, when the maximum total delay is small.

In the above analysis, we set simple system parameters. We wish to analyze the other multimedia models in future by the same method.

5. Conclusions

In this paper, we have optimized file allocation, such that the total cost is minimized subject to the total delay in distributed information network system. For considering this optimization problem in heterogeneous network environment, we have presented the new model of the system that covers wide range of multimedia network applications, and have formulated this problem as a 0–1 integer programming.

In distributed systems, the optimal file allocation to minimize the total cost is dependent on a trading-off between the communication costs and the storage costs. As the numerical results, the larger the local-global differences of the communication cost grow, the more files should be distributed due to increasing in the communication costs. On the other hand, the larger the storage costs are, the more files tend to be centralized to reduce the total cost. Also, we have shown the effect of file rewriting.

When the rewriting probabilities are large, the files should be centralized to reduce the total cost for the increasing in the rewriting costs. Moreover, we have shown the allocation of files should be distributed when the delay restriction is very severe.

As you may see in numerical results, we show the general tendency in distributed systems quantitatively. The system model presented here is very useful for evaluating various elements in constructing of a distributed system.

The issues remained for future work are as follows.

- To find out more useful formulae for the design of the optimal file allocation from the numerical results.
- To examine the sensibility of a number of system parameters in this model.
- To apply some general optimization methods like the branch and bound for this model to deal with more large scale systems.
- To adopt other rewriting protocols when the rewriting probabilities are large.
- To consider the system models including the reliability of systems.

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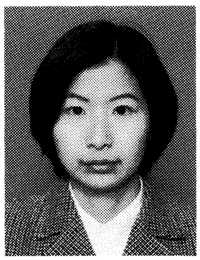

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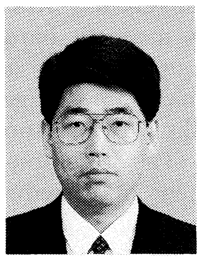

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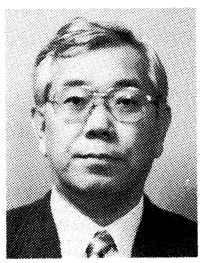

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