Multicast Group Partitioning Algorithm using Status of Receivers in Content Delivery WDM Network

Kyohong Jin† and Jindeog Kim††

ABSTRACT

Content Delivery Network(CDN) is a mechanism to deliver multimedia content to end users on behalf of web content providers. Provider's content is distributed from content server to a set of delivery platforms located at Internet Service Providers(ISPs) through the CDN in order to realize better performance and availability than the system of centralized provider's servers. Existing work on CDN has primarily focused on techniques for efficiently multicasting the content from content server to the delivery platforms or to end users. Multimedia contents usually require broader bandwidth and accordingly WDM broadcast network has been highly recommended for the infrastructure network of CDN. In this paper, we propose methods for partitioning a multicast group into smaller subgroups using the previous status of receivers. Through the computer simulation, we show that proposed algorithm are useful to reduce the average receiver's waiting time and the number of transmissions.

콘텐츠 전달 WDM망에서 수신기의 상태를 고려한 멀티캐스트 그룹화 알고리즘

진교홍† · 김진덕††

요 약

CDN은 콘텐츠 제공자(CP)의 멀티미디어 콘텐츠를 사용자에게 신속하고 안전하게 전달하여 주기 위한 망이다. 콘텐츠 제공자의 콘텐츠는 콘텐츠 서버에서 인터넷 서비스 제공자(ISP)에 위치한 여러 개의 전달플랫폼(Delivery Platform)에 보다 나은 성능을 위해 CDN을 통하여 분배된다. 현재 CDN에 관련된 연구방향은 주로 콘텐츠 서버에서 전달플랫폼이나 사용자에게 보다 효율적으로 멀티캐스트 서비스를 하여 주는 방법에 있다. 멀티미디어 콘텐츠는 광대역의 대역폭을 필요로 하므로 WDM 방송망이 CDN의 인프라망으로 적극 검토되고 있다. 따라서 본 논문에서는 CDN을 위한 WDM 방송망에서 멀티캐스트 서비스를 제공하기 위한 멀티캐스트 그룹화 알고리즘을 제안하였다. 제안된 알고리즘은 멀티캐스트 그룹을 수신기의 이전 상태를 고려하여 작은 서브그룹으로 나누는 방법이며, 이를 통해 수신노드의 지연시간과 송신노드의 전송횟수를 줄이고자 하였다.

Key words: 멀티캐스트 스케줄링, WDM, CDN

1. Introduction

Application of content delivery network(CDN), one of the hot topics in the networking and the biggest IP trends going, is quickly branching out. The CDN is a network optimized to deliver specific content, such as static web pages, transaction-based web sites, streaming media, or even real-time video or audio. Its purpose is to quickly give end users the most current content from the

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† 동의대학교 멀티미디어공학과 조교수
†† 동의대학교 컴퓨터공학과 조교수

Content Provider (CP)s server system. In other words, the goal is to push content as close to the user as possible to minimize content latency, jitter and to maximize available bandwidth speed. Fig. 1 shows a typical content distribution system.

As shown in Fig. 1, the CP makes various types of content and stores them at content server. The content according to the customers demand is delivered to delivery platforms, geographically distributed cache servers located at Internet Service Provider (ISP) facilities. When user requests some contents to CP, the specific contents are delivered from the delivery platform not from the content server.

Recently, as the rich media content like audio and video streaming over the Internet is becoming more and more popular, the broader bandwidth of CDN becomes necessary. Since the fiber optic technology becomes available and supports a few Gbps in a single data channel, the WDM (Wavelength Division Multiplexing) broadcast network is highly recommended to a solution of CDN. Also, because the CDN should deliver the contents frequently from the content server to several delivery platforms in multicast manner, the architectural advantage of WDM broadcast network would be well matched to distribution service of CDN.

Generally, basic WDM broadcast network is configured with single-hop star topology composed of passive coupler and several wavelengths(channels) are operated in one optical fiber. A wavelength supports over 1Gbps bandwidth typically. However

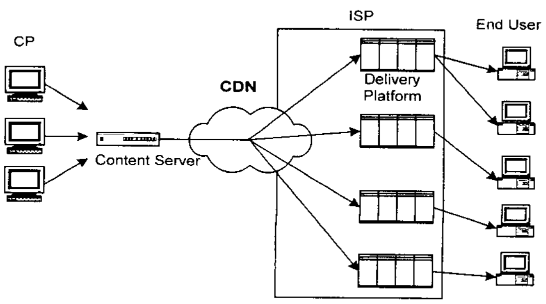

Fig. 1. CDN in Content Distribution System.

the number of wavelengths is limited and usually less than the number of nodes(typically, the node is equipped with a transmitter and a receiver, both of which my be wavelength tunable), thus the MAC(Medium Access Control) protocol is needed to operate the wavelengths and transmitter/receiver efficiently[1-3].

The MAC protocols to support the unicast service in WDM single-hop broadcast network are researched in [4-8] and MAC protocols for the unicast service with variable-sized message are studied in [9-13]. And the scheduling algorithms to deliver the multicast message are proposed in [14-17].

The multicast service can be implemented by unicast scheduling algorithm. However unnecessary multiple transmissions of a multicast message may result in a waste of bandwidth. To reduce the number of transmission, multicast service transmits only one message to all destinations, but this may result in excessive receiver waiting times. By partitioning a multicast transmission into multiple subgroups, an efficient balance between the number of transmission and the receiver waiting times may be achieved. Several multicast scheduling algorithms with the feature of partitioning multicast group are proposed in [14-17].

In [14], greedy heuristics are proposed. One of them, the EAR(Earliest Available Receiver) schedules a transmission start time by the source node to the first receiver, which becomes free. which becomes free. If additional receivers become available during this transmission, a transmission by the source to these receivers is scheduled immediately after the completion of the first one. In [15], random scheduling algorithms are studied. The random scheduling algorithm selects C nodes out of N nodes and schedules the multicast transmissions. If two or more nodes attempt to transmit message to the same destination node, the receiver selects one message among the transmitted messages with equal probability. It is shown that, if the number of C of channels is small, then network performance is limited by insufficient bandwidth. However, if the number of channel is relatively large, performance is limited by the occurrence of destination conflicts, and thus, employing multiple receivers per node can significantly increase the throughput and decrease the average delay. Unlike in [15], the [16]'s algorithm are designed for a centralized architecture in which a master scheduler maintains complete information about the state of the network, and instructs transmitters and receivers to tune to the appropriate channels. And in [17], the virtual receiver concept was developed as a novel way to perform fanout splitting that overcomes the overhead incurred when a partitioning and scheduling decision has to be made for each packet.

As described above, the existing multicast scheduling algorithms attempt to reduce the delay time through partitioning multicast group into several subgroups. However most of those algorithms do not consider the receivers tuning latency and previous status of receiver. If partitioning algorithm used the previous status of receiver, the preceding tuning process of receiver could be eliminated and accordingly the receivers waiting time and the number of transmissions could be reduced. Therefore, in this paper, we propose a heuristic multicast group partitioning algorithms that partition receivers into subgroups using the information of receivers previous status. And also we try to minimize the transmission delay of multicast message.

The rest of this paper is organized as follows. The system model is described in the next section. The partitioning problem is explained and the proposed heuristics are presented in section 3. The heuristics are tested on randomly generated test cases in section 4, and finally some concluding remarks are given in section 5.

2. System Model

The typical CDN network based on the WDM broadcast network consists of a passive star coupler and N nodes[3] as shown in Fig. 2. Each node connects to the passive star coupler via a fiber link consisting of a pair of fibers. There are W+1 communication channels in the system, where W N. One of the channels is used as control channel that is shared by all nodes. The rest of the channels are data channels that are used for data transmission. Each node is equipped with one fixed transmitter, one fixed receiver and one tunable transceiver. The fixed transmitter and fixed receiver are on the control channel. The tunable transceiver is used on the data channels.

When the content server is going to transmit a multicast message to a set of delivery platforms, the following procedures are performed typically in WDM broadcast network.

① If the content server has a multicast message to transmit to a set of delivery platforms, the transmitter attached to content server sends a control packet on the control channel. The control channel is divided into slots and assigned to each node by TDMA fashion. The control packet contains the length of message and the addresses of destination nodes(receiver of each delivery platform).

② When the receiver of delivery platform which belongs to destinations receives the control

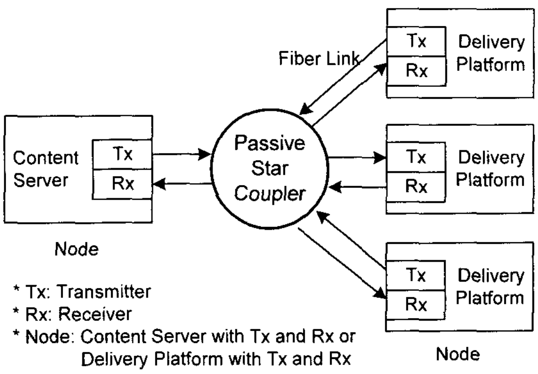

Fig. 2. System Model based on WDM Broadcast Network.

packet, it responds with the available time for next receiving and the data channel number being used through the assigned slot on the control channel.

③ Then the transmitter located at the content server runs a multicast partitioning algorithm by using the control packet delivered on the control channel. The multicast partitioning algorithm partitions the destinations into a few numbers of subgroups.

④ After that, the transmitter sends a multicast message to each subgroup until all destinations are finished to receive.

A number of multicast scheduling algorithms have been developed and they are generally including the multicast group partitioning algorithm. The multicast group partitioning algorithm plays an important roll in the scheduling algorithm and makes the average receivers waiting time and the number of transmission processes smaller.

The next section shows the heuristic multicast group partitioning algorithms proposed in this paper.

3. Proposed Algorithms

In this paper, two heuristic algorithms are proposed to resolve the multicast group partitioning problem. Before describing the algorithms, we present the multicast group partitioning problem is NP-complete. This works are based on the EAR [14]. The EAR algorithm is a greedy heuristic that schedules a transmission from the first available receiver. If additional receivers become available during this transmission, a transmission by the source to these receivers is scheduled immediately after the completion of the first one. However, the EAR does not consider the previous status of receivers and accordingly the tuning latency of receivers is included in every transmission scheduling.

The objective of partitioning multicast group into several subgroups is to schedule a separate transmission for each subgroup for minimizing the average receiver waiting time. Followings are assumed to simplify the partitioning problem.

- Source nodes transmitter and at least one data channel is available before the first receiver in the multicast destination group becomes available.
- Before transmission scheduling, the data channel number of receiver previously used is known to all nodes in the network.

The first is valid assumption by noting that multicast messages use an equal amount of transmitter and channel resources, but consume a higher amount of receiver resources, since each transmission is received by multiple receivers. Thus receivers are likely to be the bottleneck of the network. The second assumption is reasonable, since every node has a fixed transmitter and a fixed receiver to exchange the control packet to each other for planning transmission time. The problem can be formalized by following parameters:

- L: Length of the multicast message
- G: Multicast group size
- τ: Tuning latency of transmitter and receiver
- P_i, i = 1,2,·,G: Time when receiver at the destination node i finishes to receive a previous message before tuning to transmitters data channel for this time scheduling. P_is are ordered such that $P_1 \leqq P_2 \leqq \ldots \leqq P_G$.
- X_j, j = 1,2,·,G: Time when receiver at the destination node j becomes available to receive after tuning to transmitters data channel. X_js are ordered such that $X_1 \leqq X_2 \leqq \ldots \leqq X_G$ and the following relation stands up; $X_j = P_j + \tau$.

The output using above parameters, S_j, j=1,2,...,G is j-th scheduling time to transmit a message. The minimum average receivers delay time(ω) is given by

$$\varpi = \frac{1}{G} \cdot \sum_{i=1}^{G} \min_{j \ni S_j \geq X_i} (S_j - X_i) \qquad (1)$$

And the equation (1) can be extended as below using the Xj = Pj + τ.

$$\varpi = \frac{1}{G} \cdot \sum_{i=1}^{G} \min_{j \ni S_j \geq P_i - \tau} (S_j - P_i - \tau) \quad (2)$$

If the tuning latency(τ) is deleted from equation (2), then the minimum average delay time of receiver would be reduced. Our algorithms are able to remove the by using the previous status of receivers.

The transmission starting time S_j, j∈{1,2,...,G} has two constraints, such that

$$S_G \geq X_G > P_G \qquad (3)$$

$$S_j + L \leq S_{j+1} \text{ (for j=1, 2, ..., G-1)} \qquad (4)$$

The constraint in (3) guarantees that every receiver is able to have at least one chance to be scheduled. The constraint in (4) is due to the fact that there is only one transmission from occurence at the source. This prevents more than one transmission from occurring at the same time.

If $S_j < X_1$, then any transmission scheduling is not occurred because no receivers will be ready in time to receive and also if $S_j \geqq X_G + L$, then the earlier scheduling($\leqq S_j-1$) may be applied. Since the term between X_is is not fixed value and it could be less than the message length, there will be available receivers during the transmission of a message. The equation (5) shows this situation.

$$S_1 = X_1$$

$$S_j + L > X_i \text{ (where } 2<i\leqq G,\ 2\leqq j\leqq G,\ i\geqq j) \quad (5)$$

Example of equation (5) is following. If L is 5 and the available time of multicast destinations in a certain request of message transfer are (X_1, X_2, X_3, X_4, X_5) = (1,2,4,7,10), then the first transmission is scheduled at S_1(=X_1). And the next transmission scheduling(S_2) is occurred at time 6(=X_1+L). Therefore the transmission for receivers X_2, X_3 schedules at S_2 because of $S_2 \geqq X_2$ and $S_2 \geqq X_3$.

From the equation (5), we can conclude that the multicast group partitioning problem is to find a minimum-transmissions. Thus, if the minimum-transmissions problem can be solved, the transmission-number problem can also be solved but not vice versa. Therefore, the minimum-transmissions problem is at least as hard as the transmission-number problem. If the transmission-number problem is NP-complete, the minimum-transmission problem is also NP-complete. The transmission-number problem can be proved to be NP-complete by a reduction from the minimum-cover problem defined in [18] which is NP-complete.

Based on the above conclusions, we present two heuristics. The heuristic multicast partitioning algorithms proposed in this paper partition the multicast group into subgroups and transmit multicast message according to the status information of receivers.

3.1 PTL

PTL(Partitioning with Tuning Latency) is a greedy algorithm. In order to partition the multicast group, PTL generates a few pseudo groups. Pseudo group consists of one or more receivers, and the receivers in this group are scheduled separated with other pseudo groups. The pseudo group is configured by the time extent, message duration time(L) and tuning latency(τ). The first pseudo group starts at the P_1, and if there is such P_i, $P_i \leqq P_{i-1}+L+\tau$, i=2,...,G, then the P_i belongs to the pseudo group. The first pseudo group is ended at the time of P_{j-1} where $P_j > P_{j-1}+L+\tau$. And the next pseudo group starts at P_j. Until all receivers belongs to one of the subsequent pseudo groups, this process goes on. After configuration of pseudo groups, receivers in a pseudo group tune their receiver to the last receivers data channel in the pseudo group. Therefore the data channels used in the pseudo groups can be different each other.

After tuning the receivers in a pseudo group, PTL schedules the first transmission to the earliest available receiver in a pseudo group. The next transmission is either scheduled immediately after the first transmission if any of the remaining receivers become available during the first transmission, or, if no receivers became available during first transmission, whenever the next receiver becomes available. And after scheduling of pseudo group, the transmitter changes the data channel to corresponding next pseudo groups data channel.

The PTL is designed to minimize the delay time of each receiver by using the tunable transmitter when the term between P_is are longer than the L+τ. The running time for this heuristic is *O*(G).

Fig. 3(a) shows the finished time of previous transmission(P_i) and data channel number having been used(W_j). And Fig. 3(b) presents the configuration process of pseudo groups. In figure 3(b), the pseudo group #1 covers the P_1 and P_2, and P_3, P_4, and P_5 belongs to pseudo group #2. The nodes at P_1 and P_2 tune their receivers to data channel W_3 and P_3, P_4 and P_5 to W_1. After configuration of pseudo groups, the first transmission, S_1 starts at X_1. During the first transmission, X_2 becomes available. The second transmission starts immediately after the first transmission. Since X_3 is belonging to the second pseudo group, transmitter changes the data channel to W_1. The third transmission starts at X_3 and during this transmission the X_4 and X_5 became available. The last transmission includes the X_4 and X_5. As shown in the figure 3(c), the multicast group is partitioned as with (X_1), (X_2), (X_3), and (X_4, X_5).

3.2 M-PTL

M-PTL(Modified-PTL) algorithm is modified version of the PTL algorithm to decrease the transmission-number. The procedure of calculating the X_i is exactly same with that of PTL, but scheduling is occurred only once at the time of final receivers available time in each pseudo group. The running time for this heuristic is *O*(G).

Like in PTL algorithm, Fig. 4(a) shows the finished time of previous transmission(P_i) and W_j indicates the data channel number used at P_i. And Fig. 4(b) shows the configuration procedure of pseudo groups. The first pseudo group covers P_1 and P_2, and the second includes P_3, P_4 and P_5. The members of the first pseudo group tune their receivers to W_3 and the members of the second tune to W_1 and accordingly the all X_is are calculated.

As shown in Fig. 4(c), after generating the pseudo groups, M-PTL algorithm schedules the transmission at last X_i in each pseudo group. Since X_1 and X_2 belong to the pseudo group #1, the transmission S_1 starts at X_2 with data channel W_3, and at the X_5 the transmission S_2 begins with W_1.

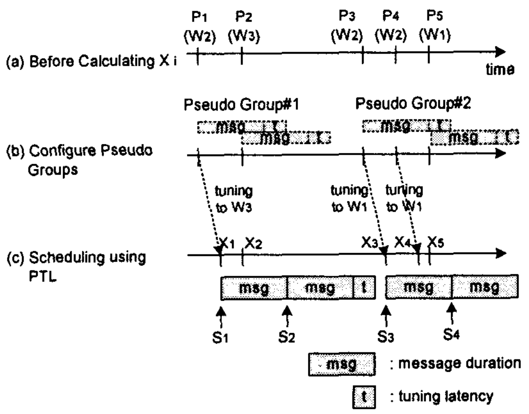

Fig. 3 PTL Algorithm.

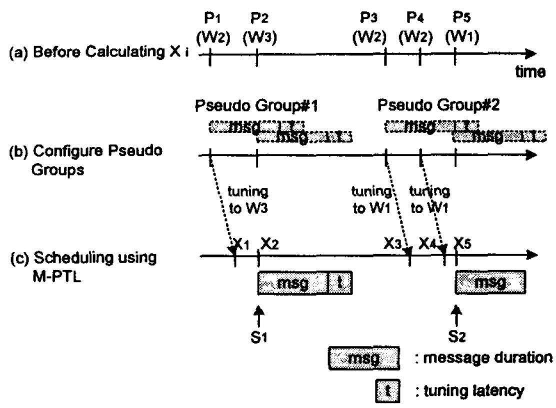

Fig. 4 M-PTL Algorithm.

Therefore the subgroups are composed of (X_1, X_2), (X_3, X_4, X_5) and the transmission-number is minimized.

4. Simulation Results

The PTL and M-PTL algorithms were tested on a number of randomly generated test cases. Each test case consisted of generating $P_1, P_2, ..., P_G$ randomly according to a geometric distribution with parameter ρ, fixing L and G. In our simulation the ρ is set to 0.5(ρ=1 is the case in which all receivers are become available at the same time, while ρ= 0 is the case in which the receivers become available at intervals infinitely spaced apart). Also the data channels number previously used at receivers is generated randomly. The EAR algorithm[14] was included in performance analysis to be compared with proposed algorithms.

Simulation system is considered as like in the Fig. 2 with following parameters.

Table 1. System Parameters for Simulation

Parameter	Description
N(=50)	The number of nodes in the WDM network.
W(=50)	The number of data channels used in the WDM network
Control Channel	In the network, one control channel is existed to exchange the nodes status information. This control channel is separated from the data channels.
Fixed Tranceiver	Each node station has one fixed transmitter and one fixed receiver that are tuned to the control channel.
Tunable Tranceiver	Each node has one tunable transmitter and one tunable receiver that can be tuned to any of the data channels.
G	Multicast group size, G, is uniformly distributed over (1,2,...,N).
τ	We assume the tuning time(τ) of transmitter and receiver is much smaller than message length.
P_i, W_{Pi}	Each node maintains P_i and W_{Pi}, i=1,2,...,N. W_{Pi} means the data channel number used to previously receive a message. W_{Pi} is initialized randomly.

The goal of the simulation experiment is to investigate the receivers average delay time and the number of transmissions as multicast group size is growing. The receivers delay time is defined as the amount of time that a receiver must wait before it begins to receive a message. The delay time is measured from the point at which the receiver finishes the last scheduling. It is supposed that the bandwidth of one data channel is 1Gbps, tuning latency is 10sec(when using the acousto-optic elements) and the message length is 1500 bytes and 3000 bytes. Fig. 5 shows the results of average delay time according to the number of destinations in multicast group where L is message duration time of 1500 byte-long message.

Since the PTL and M-PTL algorithms consider the previous status of receivers, it is not necessary receivers tuning in every time. And between pseudo groups the transmitter tunes to receivers data channel, they also decrease the average delay time. However in M-PTL, as multicast group size grows to the number of nodes, the average delay time becomes long because the number of pseudo group is gradually decreasing. By the way, in Fig. 5 as the multicast group size is growing over 40, the average delay time of PTL gets worse than the EAR's. Becasuse the multicast group size gets increasing, the interval of the receivers is decreasing, then the PTL algorithm delays the scheduling time of each pseudo group.

Next, the number of transmissions is measured

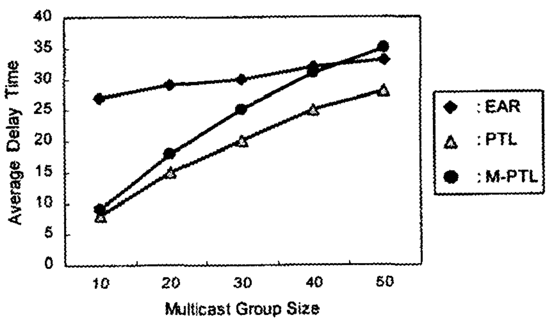

Fig. 5. Average Delay Time of Receivers(Message Length=1500B).

by how many transmissions are performed until all receivers in multicast group finish the message receiving. This number is equal to the number of subgroup and is an important measurement parameter of multicast group partitioning algorithm. Fig. 6 shows the number of transmissions according to the number of destinations in multicast group where L is message duration time of 1500 byte-long message.

As shown in Fig. 6, the number of transmission in PTL is slightly smaller than that of EAR with such a reason that in EAR all receivers have to be tuned to transmitters data channel before scheduling, but in PTL, the last receiver in a pseudo group does not have to be tuned. Also in the M-PTL, the transmission is occurred only once in each pseudo group and so the number of transmissions in M-PTL is smaller than the others.

Fig. 7 and 8 shows the results of average delay

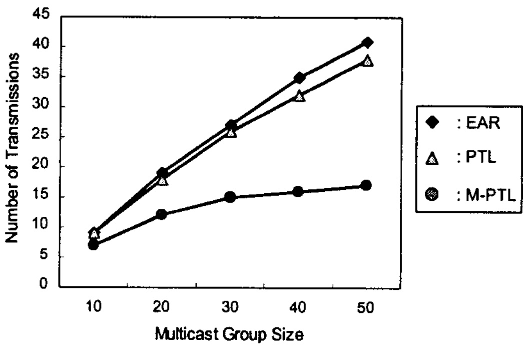

Fig. 6. Number of Transmissions(Messge Length = 1500B).

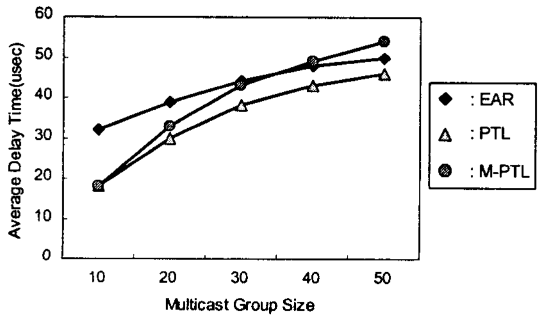

Fig. 7. Average Delay Time of Receivers(Message Length = 3000B).

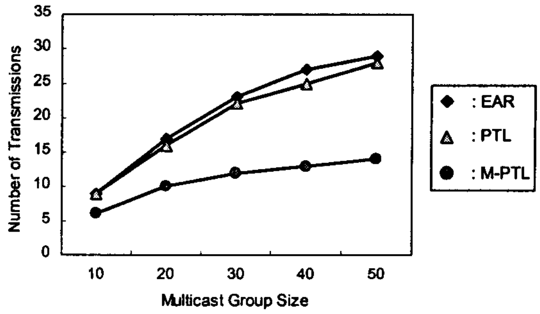

Fig. 8. Number of Transmissions(Message Length = 3000B).

time of receiver and the number of transmissions where L is message duration time of 3000 byte-long message. The average delay time is increased when L becomes long. Because the transmitter could send only one message at any time, the remained receivers must wait for an amount of increased message duration. And as shown in Fig. 8, while the L becomes long, the number of transmissions is decreased. Since the pseudo groups are configured using the message duration time and tuning latency, the number of pseudo group is decreased and then the number of transmissions is also diminished.

The average delay time of receiver becomes long as the message length becomes from 1500 byte to 3000 byte, because the message transmission time becomes long. However, the number of transmissions becomes small, because the number of pseudo group is decreasing.

5. Conclusions and Further Study

The purpose of CDN is to quickly give delivery platform of ISP or end users the most current content in a highly available fashion. To support the multimedia contents in CDN, the WDM broadcast network is a straightforward approach to implement wider bandwidth. And also using the topological advantage of WDM broadcast network, the multicast services in CDN are well supported.

Multicast service can be implemented by unicast scheduling algorithm. However unnecessary multiple transmissions of a multicast message may result in a waste of bandwidth. To reduce the number of transmission, multicast service transmits only one message to all destinations, but this may result in excessive receiver waiting times. By partitioning a multicast transmission into multiple subgroups, an efficient balance between the number of transmission and the receiver waiting times may be achieved.

Heuristic algorithms proposed in this paper reduce the average delay time of receivers and the number of transmissions. Since the PTL and M-PTL consider the previous data channel number used at the last scheduling, they reduce the average delay time and the number of transmission using the pseudo groups. In particular, the M-PTL sends only one message in each pseudo group, it minimize the number of transmissions. Therefore the proposed algorithms could be used as the solution of the partitioning problem in CDN where multicast service is frequently occurred.

As seen in the previous sections, the heuristics presented only provide the number of transmissions and the time at which each transmission should be scheduled. They do not provide the channels on which the transmissions should take place. To resolve this problem, we will research about the multicast scheduling algorithm in CDN.

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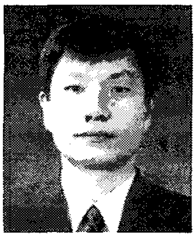
진 교 홍

1991년 부산대 컴퓨터공학과(공학사)
1993년 부산대 대학원 컴퓨터공학과(공학석사)
1997년 부산대 대학원 컴퓨터공학과(공학박사)
1997년~2000년 국방과학연구소 선임연구원
2000년~현재 동의대학교 멀티미디어공학과 조교수
관심분야 : 컴퓨터 네트워크, 광통신망, 인터넷응용



김 진 덕

1993년 부산대 컴퓨터공학과(공학사)
1995년 부산대 대학원 컴퓨터공학과(공학석사)
2000년 부산대 대학원 컴퓨터공학과(공학박사)
1998년~2001년 부산정보대학 정보통신계열 전임강사
2001년~현재 동의대학교 컴퓨터공학과 조교수
관심분야 : 공간 데이터베이스, 공간 색인, 모바일 데이터베이스

교 신 저 자

진 교 홍 614-714 부산광역시 부산진구 가야동 산24번지 동의대학교 멀티미디어공학과