Workshop: *Computer Networks*

Title: *LSRAM: A Lo-Su Resource Allocation Mechanism over DOCSIS Cable Network*

Abstract: With the emerging of newly deployed multimedia services, an alternative solution must be found to replace the tradition access network. Cable network supports great amount of client users and adequate bandwidth and therefore becomes an elegant solution for modern multimedia applications. However, the bandwidth-sharing characteristic and the lack of bandwidth management scheme in cable network result in some issues. Hence, in this paper we have proposed a management scheme called Lo-Su Resource Allocation Mechanism (LSRAM) to enhance the bandwidth management in cable network. Our mechanism is very simple, easy-implemented, fairly and flexibly assigns bandwidth to each user, and efficiently increases total network throughput.

Authors: Chin-Ping Tan* (m9001522@knight.fcu.edu.tw)

Kuo-Chi Chu+ (chukc@sparc4.ee.ncku.edu.tw)

Wei-Tsong Lee* (wtlee@fcu.edu.tw)

*Department of Information Engineering and Computer Science,
Feng Chia University, Taichung, Taiwan, R.O.C.

+Department of Electrical Engineering, National Cheng Kung University,
Tainan, Taiwan, R.O.C.

Contact Author: Chin-Ping Tan

Address: Dept. of Information Engineering and Computer Science, Feng-Chia University. (100 WENHUA RD., SEATWEN SECTION, TAICHUNG 407, TAIWAN, R.O.C.)

Telephone: +886-4-24517250 x 3721

Fax number: +886-4-24516101

Email: m9001522@knight.fcu.edu.tw, picobird_ccp@pchome.com.tw

Index Terms: Cable network, Data-over-Cable Service Interface Specifications (DOCSIS), Bandwidth management scheme, Lo-Su.

LSRAM: A Lo-Su Resource Allocation Mechanism over DOCSIS Cable Network

Abstract – Recently, with the emerging of newly deployed multimedia services, an alternative access network must be found to replace the traditional Public Switched Telephony Network (PSTN) in order to meet the strict requirements of these services. Cable network supports great amount of client users as well as sufficient bandwidth and therefore becomes an elegant solution for modern multimedia applications. However, the bandwidth-sharing characteristic and the lack of bandwidth management scheme in cable network result in some problems, for example, everyone must contend for transmission opportunity and may not fairly use the bandwidth. Hence, in this paper we have proposed a management scheme called Lo-Su Resource Allocation Mechanism (LSRAM) to further enhance the bandwidth management in cable network. Our mechanism is very simple, easy-implemented, fairly and flexibly assigns bandwidth to each user, and efficiently increases total network throughput.

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1. INTRODUCTION

With the improvements of computer and network technologies, Internet has almost become a necessity in our modern lives. Internet has been deployed extensively these years and makes a lot of changes to the world. It accelerates the growth of many new kinds modern applications and more and more services have been introduced to us, for instance, the voice over IP (VoIP) and video on demand (VoD) services. For accessing these real-time multimedia applications, a strict network quality is required for better experience, which is, a smother telephone talking or video watching.

To achieve this goal, cable network is an elegant solution. For customs, it provides sufficient bandwidth for more decent network experiences. For Internet Service Providers (ISP), the ability of supporting a large amount of users as well as the fact that it is based on the widespread traditional analog cable network make it having an easy installation environment, low investment costs, and a vast amount of potential customs.

Currently the most popular protocol used in cable network is DOCSIS protocol [1]. According to its definition, cable network is a central-controlled, bandwidth-sharing network where all client users share the total network bandwidth. Before data transmission, Cable Modem (CM) contends for contention slots (CS) in order to send a request to Cable Modem Termination System (CMTS) for reserving bandwidth.

Although the whole network is administrated by CMTS, the lack of bandwidth management scheme results that every user needs to contend the transmission opportunity and may not fairly share the bandwidth, that is, someone may hold a large portion of bandwidth while others only get small pieces if they always lose in the contention stage. Also, too many contentions will severely deteriorate the network performance, for example, the increment of delay time [2]. Therefore, how to manage and justly assign the bandwidth becomes a critical issue especially in a large cable network.

In this paper we present a bandwidth allocation scheme - LSRAM - to fairly assign network bandwidth for each client user according to certain precedence conditions. Our mechanism uses Lo-Su matrix [3], which is a matrix that the sum of each row, column, and diagonal is the same, to fairly allocate bandwidth, share the unused bandwidth for others, and efficiently improve the total network utilization rate. The LSRAM is very simple, easy-implemented, and only needs a slightly modification in CMTS to fit the DOCSIS protocol.

The rest parts of this paper are organized as follows. In the next section, we will introduce the cable network in detail. In Section 3, our LSRAM architecture, all inside functioning blocks, basic concepts, and operations will be revealed. An example of how the LSRAM be used in real life and what we can benefit form it is given in

Section 4 and we conclude in Section 5.

2. CABLE NETWORK

Currently, DOCSIS protocol is the most popular standard in cable network and accepted by many vendors. In order to be compatible with the current cable network, we follow the DOCSIS protocol to design our bandwidth management scheme. In this section, we discuss the operation of DOCSIS protocol first.

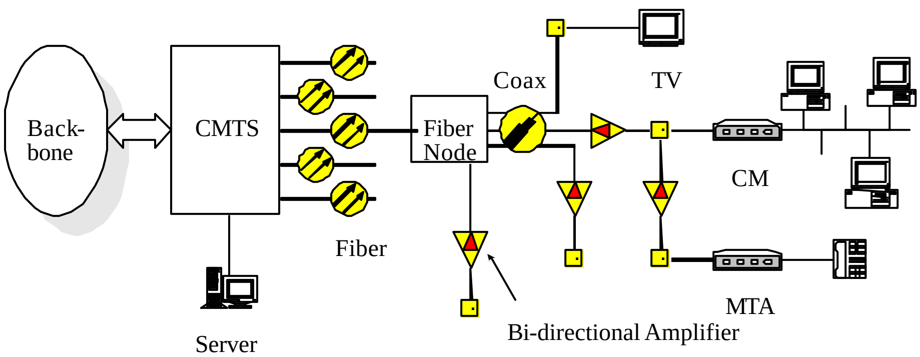

Figure 1. Cable network architecture.

Figure 1. is the architecture of cable network in DOCSIS protocol; the whole network is connected by optical fibers and coaxial cables. Cable network is a central-controlled network, where CMTS takes charge of all client users and each CM follows the instruction of CMTS for data transmission. CMTS assigns at least one Service ID (SID) to each CM and hence it can identify data packets of CMs according to the SID. In cable network, bandwidth is divided into upstream and downstream channels; CMs use upstream channels to transmit data while CMTS uses downstream channels to send control messages and data to CMs. By using the bandwidth

allocation Map (MAP), CMTS notifies CMs the purpose of each mini-slot during a certain period in upstream channel; and according to information in MAP, CMs transmit their requests or data packets within certain mini-slots. In the newly published DOCSIS 2.0 protocol, a single upstream channel can supply bandwidth with 30Mbps and a downstream channel supplies 40Mbps. Hence, with such great amount of bandwidth, cable network can easily satisfy most of the modern applications and services.

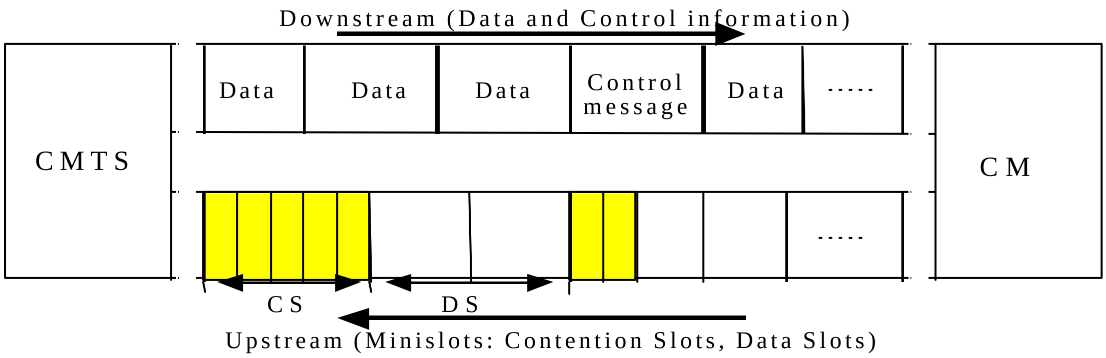

Figure 2. The Medium Access Control (MAC) Layer of cable network.

Figure 2. shows the operation of DOCSIS protocol. Before any data transmission, CM must send a bandwidth request through CS to CMTS for accruing bandwidth. As CMTS permits that request, then it will reserve Data Slots (DS) for CM to transmit data. Besides, because the upstream channels are shared by all CMs, collisions will occur if there are several CMs who want to send bandwidth requests by a same CS.

Although cable network is central-managed, every CM can still send bandwidth requests at will. When there are too many bandwidth requests in the network at a same time, performance drop which mentioned in previous section will occur and sometimes a CM may hold too much bandwidth and let others hard to send their data. Hence, a bandwidth management scheme is strongly desired for better performance.

In next section, we will introduce our LSRAM mechanism, which can efficiently manage the total throughput of each user, increase network utilization rate, and fairly allocate bandwidth for everyone.

3. The LSRAM Architecture and Operations

In this section, we present our LSRAM architecture and operations. The functioning of our mechanism is located in CMTS side and we have added some units into CMTS to implement our LSRAM. Modification is only needed in CMTS and CM need not be touched. First of all, we explain the main units of our LSRAM and then describe all these units' functions and operations.

3.1. Introductions of Main Components

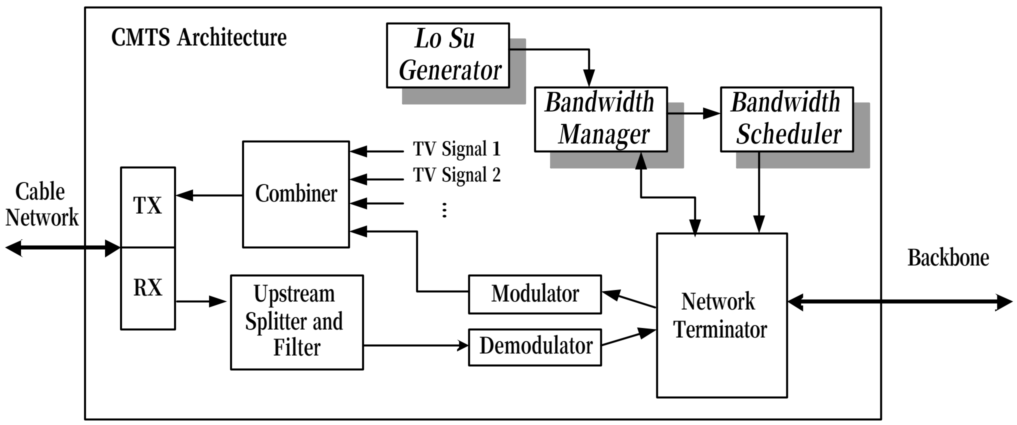

Figure 3. The CMTS architecture with LSRAM implemented.

In Figure 3., three important units are involved in the CMTS; they are Lo-Su Generator, Bandwidth Manager, and Bandwidth Scheduler.

✍✍ **Lo-Su Generator**

The Lo-Su Generator is used to generate a bandwidth allocation matrix. The earliest origin of Lo-Su concept is from old China, and later the same idea is also appeared in Europe and called Magic Square instead of Lo-Su matrix [3]. Lo-Su is a matrix where the sum of every column, row, and diagonal is equal to each other. Figure 4. is an example of 5x5 Lo-Su matrix.

	Period 1	***Period 2***	***Period 3***	***Period 4***	***Period 5***
CM_1	11	18	25	2	9
CM_2	10	12	19	21	3
CM_3	4	6	13	20	22
CM_4	23	5	7	14	16
CM_5	17	24	1	8	15

Figure 4. A 5x5 Lo-Su matrix

For generating a 5x5 Lo-Su matrix, we assume that m_{ab} means the entry in row **a**, column **b** in the matrix. To begin with, we put 1 in the bottom line of the rows and the middle line of the columns, that is, entry m_{53}; and then we get that, a=5 and b=3 in the initial stage. Then assigning the succeeding numbers according to rules listed below [3],

$$\begin{cases} m_{(a=a+1,\ \text{if}\ a>5,\ a=1)(b=b+1,\ \text{if}\ b>5,\ b=1)} & \text{, if the next entry is empty} \\ \text{or} & \\ m_{(a=a-1,\ \text{if}\ a<1,\ a=5)(b)} & \text{, if the next entry is occupied} \end{cases}$$

After finishing the 5x5 Lo-So matrix, we can understand that the sum of each column, row, and diagonal is the same and the value is 65. Hence, if we label X-axis as time periods, Y-axis as CMs (A CM maybe connects a single PC, or even a LAN which includes hundreds of PCs.), and the value of each entry as the weight, then we find that all CMs will be assigned with same bandwidth in total because all rows are with the same total weight. Besides, the total network throughput during each time period are the same too due to all columns also have the same total weight. Moreover, assume that the total network bandwidth is 100Mbps; form the matrix in figure 4. we know the weight of CM_2 in time period 1 is 10 and the total weight is 65, hence, we can calculate the maximum available bandwidth of CM_2 in time period 1 is (10/65)x100 = 15.385Mbps. Consequently, the fairness of bandwidth assignment is easily achieved by Lo-Su concept. Further more, we may divide a day into more time periods and combine bandwidth of several rows for a single CM who needs more bandwidth resources and also pays a higher rent, and by this way, the bandwidth allocation can be very flexible according to user's precedence and time.

✍✍ Bandwidth Manager

The Bandwidth Manager is responsible to keep track of users' bandwidth requests, schedule them, share the unused bandwidth to others, and determine how much bandwidth should be given to each user.

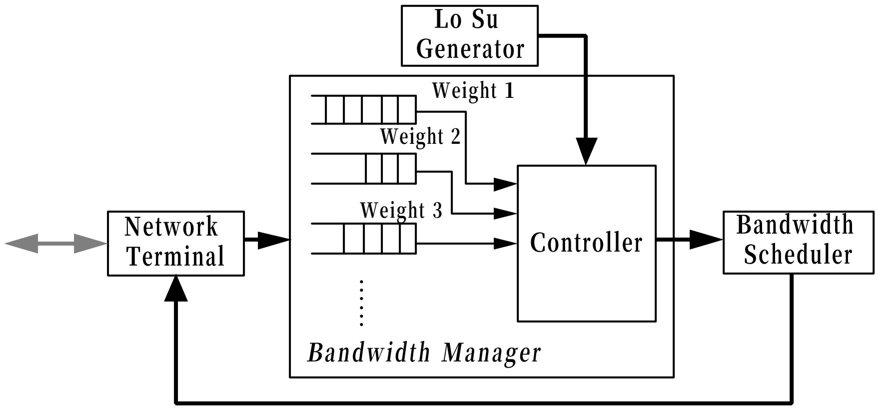

Figure 5. The Bandwidth Manager unit

Figure 5. shows the insider of the Bandwidth Manager. When Bandwidth Manager receives bandwidth requests from CMs, it first classifies these requests to different groups according to the SID of each CM and then assigns each group into corresponding queue. Then, the Bandwidth Manager inquires the bandwidth allocation matrix from Lo-Su Generator and assigns different weights to each queue in light of the current time period. Next, the Bandwidth Manager also checks if there are any unused bandwidth. The remnant bandwidth will be shared to other CMs who desire additional bandwidth. We should know that although we have made a Lo-Su matrix to describe the maximum available bandwidth of all CMs in each time period, the bandwidth used by a certain CM during a certain time period might not reach the maximum limit we have assigned to it. Hence, the remnant bandwidth resource can be shared to other CMs for more efficient bandwidth management and maximizing the total network throughput. Eventually, according to the final bandwidth assignment

statistics, the Bandwidth Manager determines how much bandwidth should be given to each CM. If a CM's required bandwidth exceeds the maximum available value in that time period, CMTS will only permit the maximum available bandwidth for that CM and deny the rest part of the required bandwidth.

✍✍ **Bandwidth Scheduler**

After processing all requests, Bandwidth Manager will inform Bandwidth Scheduler about the bandwidth assignment information. Then, Bandwidth Scheduler reserves DSs for CMs and notifies them through the MAP. As CMs get the MAP, they will know when to transmit data.

3.2 THE OPERATION

Here we illustrate the operation of our LSRAM mechanism in cable network. The operations consist of interactions of CM and CMTS. Figure 6. is the operation of data transmission and detailed steps are given below.

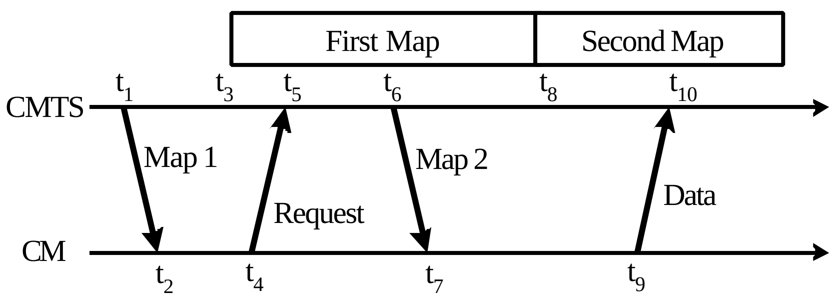

Figure 6. The operation of data transmission

1. The network manager configures the Lo-Su Generator to create a bandwidth

allocation matrix. As same as the example given in figure 4., we prefer the X-axis as time periods and the Y-axis as CMs. Assume that period 1 present 8:00~13:00, period 2 is 13:00~18:00, period 3 is 18:00~23:00, period 4 is 23:00~4:00, and period 5 is 4:00~8:00; then according to the network usage behavior of each CM, the manager assigns each CM into different row. For example, if CM_1 usually has a heavy network throughput in the night, the manager may associate it with row 2 to match its behavior. We have to notice that the Lo-Su bandwidth allocation matrix should be produced in advance and the manager must notify all CMs' administrators of the bandwidth allocation matrix and may ask them to slightly adjust their network usage behavior in order to achieve better network throughput and performance.

2. At time t1, CMTS sends MAP1 to CMs to describe the usage of each mini-slot in upstream channel during time t3 ~ t8.
3. CM receives MAP1 at t2 and knows the usage of each mini-slot during time t3 ~ t8, and then at t4 it sends a bandwidth request to CMTS for acquiring bandwidth.
4. As CMTS gets the request message at t5, the Bandwidth Manager puts that request into a certain queue according to the SID of that CM, and then inquires the bandwidth allocation matrix, calculates if there are any remnant bandwidth, allots unused bandwidth to it, and finally determines if the request is acceptable and

passes it to the Bandwidth Scheduler.

5. The Bandwidth Scheduler reserves DSs for CM and sends a notification message to it through MAP2 at t6.
6. As receiving MAP2 at t7, the CM knows its DSs begin at t10.
7. At time t9, CM transmits its data so that they will arrive at CMTS at t10.

4. AN EXAMPLE

We give an example here to simulate possible scenery, show how our mechanism works in a real life application and what we can benefit from it.

Assume that a network manager is now going to manage the network traffic of four departments in a campus which built by cable network. These four departments are,

- Dormitory: Basically, most of the students have to attend classes from morning till evening, and come back after dinner and get free time to surf Internet for web browsering, file downloading, Internet game playing, and so on. Consequentially, in common case, the network throughput of dormitory during the day is relatively light yet becomes heavy in the night.
- Distance-learning broadcast center: The distance-learning broadcast center broadcasts the live class video via the Internet to students who may locate on other schools for attending the class and hence needs respectable amount of bandwidth too. According to current schedules, most of the live video classes are

assigned from 8:00 to 19:00. Also, the broadcast center replays class videos in the midnight, but only few important courses are chosen and hence the required bandwidth is small.

✍✍ Administrative departments: Administrative departments work during the daytime and needs bandwidth for official document transmission, VoIP phone talking, video conferencing between each teacher or direct, and some bandwidth required operation for school business.

✍✍ Data exchange center: It is responsible to exchange science documents as well as files with other colleges and backup important archives and records. Current policy is that it continuously exchanges and backups data from morning till midnight and gets rest during 2:00~8:30.

Figure 7. shows the average network traffic per day of these four departments before applying our LSRAM mechanism.

Time period / Dept.	8:30~12:00	12:00~15:30	15:30~19:00	19:00~22:30	22:30~2:00	2:00~5:30	5:30~8:30	TOTAL
Dormitory network	16%	18%	26%	42%	62%	20%	10%	194%
Data exchange center	24%	24%	28%	36%	36%	4%	6%	158%
Distance-learning broadcast center	36%	44%	42%	16%	8%	4%	4%	154%
Administrative department	34%	42%	30%	14%	4%	2%	2%	128%
TOTAL	110%	128%	126%	108%	110%	28%	20%	

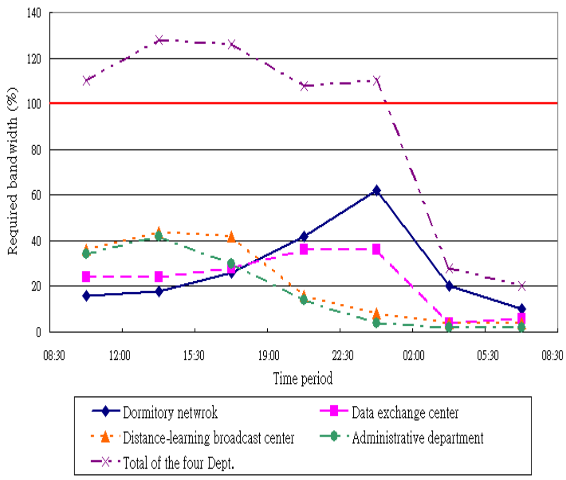

Figure 7. Average required bandwidth of four departments in each time period before applying LSRAM.

From figure 7. we can understand that the total required bandwidth of these four departments in time period 8:30~12:00, 12:00~15:30, 15:30~19:00, 19:00~22:30, and 22:30~2:00 exceeds what the network can support. In other words, each department must contend for bandwidth in these time periods while there are still lots of unused bandwidth in time period 2:00~5:30 and 5:30~8:30. Figure 8. indicates the gained bandwidth of each department in each time period before using LSRAM and figure 9. draws the result of gained/required bandwidth ratio according to figure 7. and 8.. Obviously, the bandwidth utilization rate is not fully optimized.

Time period / Dept.	8:30~12:00	12:00~15:30	15:30~19:00	19:00~22:30	22:30~2:00	2:00~5:30	5:30~8:30	TOTAL
Dormitory network	13%	13%	20%	40%	56%	20%	10%	172%
Data exchange center	22%	19%	21%	33%	33%	4%	6%	138%
Distance-learning broadcast center	33%	37%	34%	14%	7%	4%	4%	133%
Administrative department	32%	35%	25%	13%	4%	2%	2%	113%
TOTAL	100%	100%	100%	100%	100%	28%	20%	

Figure 8. Average gained bandwidth of four departments in each time period before applying LSRAM.

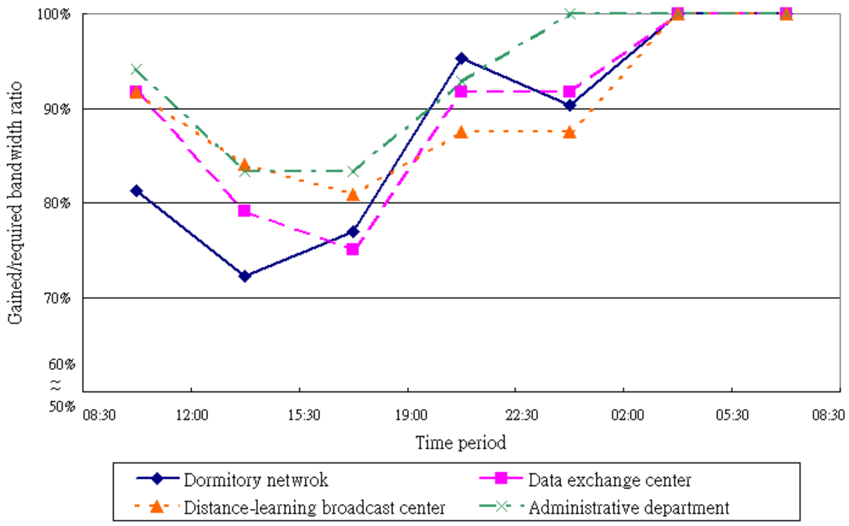

Figure 9. The gained/required bandwidth ratio of each department before applying LSRAM.

Now using LSRAM to manage the network. First, by analyzing the network traffic of these four departments, the network manager decides to generate a 7x7 Lo-Su matrix. X-axis presents time period and a day has been divided into seven time periods. Next, assigning rows for each department. Considering making minimum changes to each department's network usage behavior which mentioned above, the network manager assigns row 1 and 2 to distance-learning broadcast center, row 3 and 4 to dormitory, row 5 to data exchange center, and row 6 and 7 to administrative departments. Figure 10. shows the final 7x7 Lo-Su matrix.

	8:30~ 12:00	*12:00~ 15:30*	*15:30~ 19:00*	*19:00~ 22:30*	*22:30~ 2:00*	*2:00~ 5:30*	*5:30~ 8:30*
Distance-learning	22	31	40	49	2	11	20
broadcast center	21	23	32	41	43	3	12
Dormitory network	13	15	24	33	42	44	4
	5	14	16	25	34	36	45
Data exchange center	46	6	8	17	26	35	37
Administrative	38	47	7	9	18	27	29
departments	30	39	48	1	10	19	28

Figure 10. The final 7x7 Lu-So matrix

After generating and defining Lo-Su matrix, the network manager notifies each department's network administrator of the Lo-Su matrix and asks him to make some changes to their network usage behavior. For example, due to data exchanging and backup are not very time-critical, hence the network manager asks the data exchange center to process their work in the midnight instead of in daytime. The manager also asks the distance-learning broadcast center to move some courses in the morning and afternoon to the evening and night. Students in dormitory are also recommended to download files in the midnight if possible. In addition, Administrative departments are required to finish their work as early as possible before 19:00. Figure 11. indicates the new bandwidth requirements of each department after changing their network usage behavior according to Lu-So matrix which the network manager gives to them.

Time period / Dept.	8:30~ 12:00	12:00~ 15:30	15:30~ 19:00	19:00~ 22:30	22:30~ 2:00	2:00~ 5:30	5:30~ 8:30	TOTAL
Dormitory network	12%	16%	25%	38%	52%	38%	13%	194%
Data exchange center	23%	7%	6%	10%	27%	37%	48%	158%
Distance education center	25%	30%	40%	43%	8%	4%	4%	154%
Administrative Department	37%	45%	30%	8%	4%	2%	2%	128%
TOTAL	97%	98%	101%	99%	97%	81%	67%	

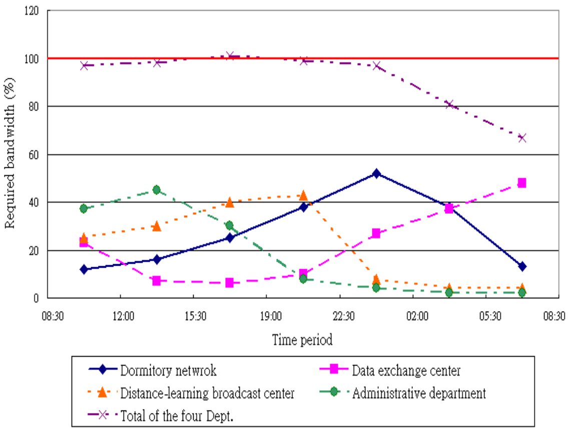

Figure 11. The new bandwidth requirements of each department after using LSRAM

Figure 12. presents the gained bandwidth of each department in each time period after using LSRAM and figure 13. sketches the result of new gained/required bandwidth ratio.

Time period / Dept.	8:30~ 12:00	12:00~ 15:30	15:30~ 19:00	19:00~ 22:30	22:30~ 2:00	2:00~ 5:30	5:30~ 8:30	TOTAL
Dormitory network	12%	16%	24.5%	38%	52%	38%	13%	193.5%
Data exchange center	23%	7%	5.5%	10%	27%	37%	48%	157.5%
Distance education center	25%	30%	40%	43%	8%	4%	4%	154%
Administrative Department	37%	45%	30%	8%	4%	2%	2%	128%
TOTAL	97%	98%	100%	99%	97%	81%	67%	

Figure 12. Average gained bandwidth of four departments in each time period after using LSRAM

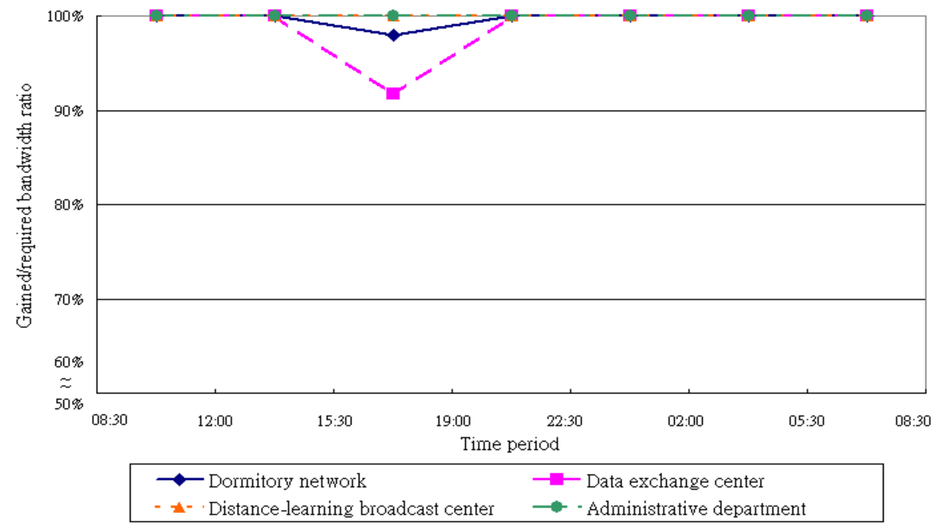

Figure 13. The gained/required bandwidth ratio of each department after using LSRAM.

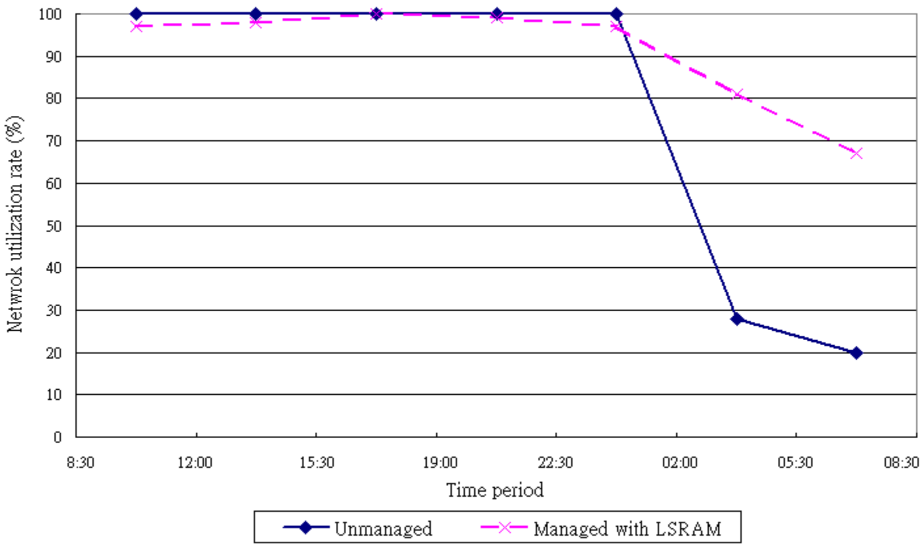

Figure 14. The comparison on total network throughput.

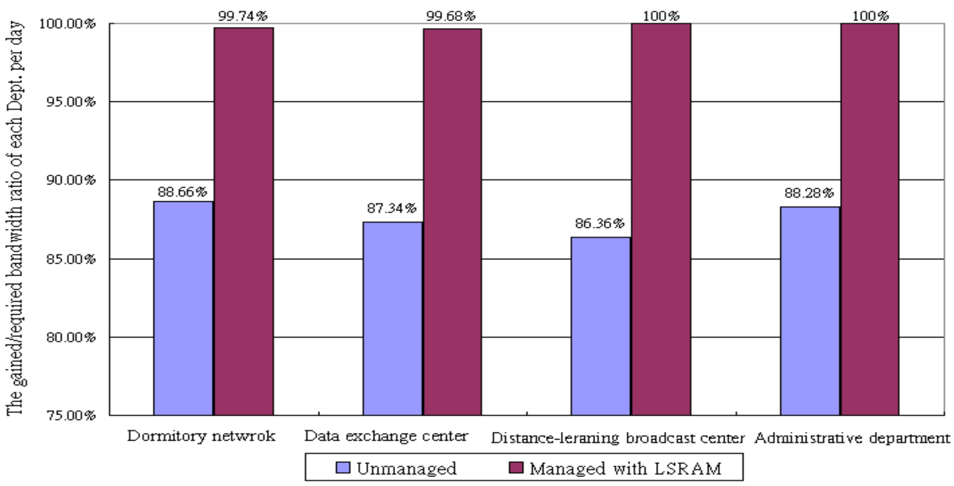

Figure 15. The comparison on gained/required bandwidth ratio of each department per day.

Comparing the results of figure 9. and 13, we see that the gained/required bandwidth ratio of the four departments in each time period have been increased impressively after using our LSRAM mechanism. Besides, figure 7. and 11. reveal that our LSRAM nicely redistributes the network traffic of each department, and figure 14. and 15. show the total network utilization rate has been efficiently improved.

5. CONCLUSION AND FUTURE WORK

Cable network is a considerable alternative for the modern multimedia applications. It supports great amount of client users as well as sufficient bandwidth and hence becomes a decent solution for those multimedia services. However, although cable network is a centralized network and all data transmissions must be granted by CMTS, the innate characteristic - bandwidth sharing - causes some issues. First of all, because users in cable network share the total upstream bandwidth, the more the users the less the bandwidth shared by each other. Also, the lack of bandwidth management scheme results that users may not fairly use the bandwidth even if they all pay the same rent. Moreover, the contention for transmission opportunity decreases network performance, for instance, the deterioration of round-trip delay time.

Hence, in this paper we have proposed a bandwidth management scheme called LSRAM to fairly and flexibly manage network bandwidth. LSRAM is located in

CMTS side and includes three main components; they are Lo-Su Generator, Bandwidth Manager, and Bandwidth Scheduler. Lo-Su Generator is used to create the bandwidth allocation matrix; Bandwidth Manager refers to the Lo-Su matrix and takes charge of bandwidth assignment; and Bandwidth Scheduler reserves transmission opportunity for CMs and notifies them. We have proffered a detailed introduction of these components and their interactions. Form the example given in Section 4, besides fairly and flexibly allocate bandwidth, our LSRAM mechanism can even efficiently improve individual and total network throughput and let each department get its required bandwidth as much as possible.

As the increasing amount of Internet users and new type multimedia services, such a management scheme of the precious network resources would be a critical subject in the future. Our LSRAM is quite workable yet could be further improved. Future work would be focused on meliorating the remnant bandwidth assignment policy to increase management efficiency.

6. References

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