Improving Efficiency of Timeslot Assignment for Non-realtime Data in a DVB-RCS Return Link: Modeling and Algorithm

Ki-Dong Lee, Yong-Hoon Cho, Ho-Jin Lee, and Deock-Gil Oh

This paper presents a dynamic resource allocation algorithm with multi-frequency time-division multiple access for the return link of interactive satellite multimedia networks such as digital video broadcasting return channel via satellite systems. The proposed timeslot assignment algorithm, called the very efficient dynamic timeslot assignment (VEDTA) algorithm, gives an optimal assignment plan within a very short period. The optimality and computational efficiency of this algorithm demonstrate that it will be useful in field applications.

I. Introduction

The digital video broadcasting (DVB) return channel via satellite (RCS) system is a geostationary earth orbit (GEO) satellite interactive network that provides multimedia services, including Internet traffic service [1], [2]. Companies and industries worldwide are developing broadband interactive satellite systems [2]-[4]. Recently, they have become commercially available [4] and network access demand is expected to increase. Therefore, strategies for achieving maximum use and minimum cost of the limited available radio resources have taken on increased importance.

Figure 1 shows a configuration of a DVB-RCS system called the Broadband Satellite Access Network (BSAN) system developed by the Electronics and Telecommunications Research Institute in 2002. In the figure, two kinds of satellite links are shown: the forward link and the return link. Satellite terminals attempt to log on and send capacity request messages and data via the return link at a transmission rate up to 4 Msps (mega symbols per second) whereas they are authorized by the hub and assigned additional amount of capacity upon their respective capacity requests, and they receive individual data and/or multicast data from the Internet and/or other servers via the forward link at a rate up to 45 Msps.

Because the available radio resources are very limited, one of the most important problems is to minimize the scheduling time and maximize the radio link throughout [4], [5], [8], [9].

For the return link in DVB-RCS systems, since there is

Manuscript received Sept. 11, 2002; revised Apr. 8, 2003.

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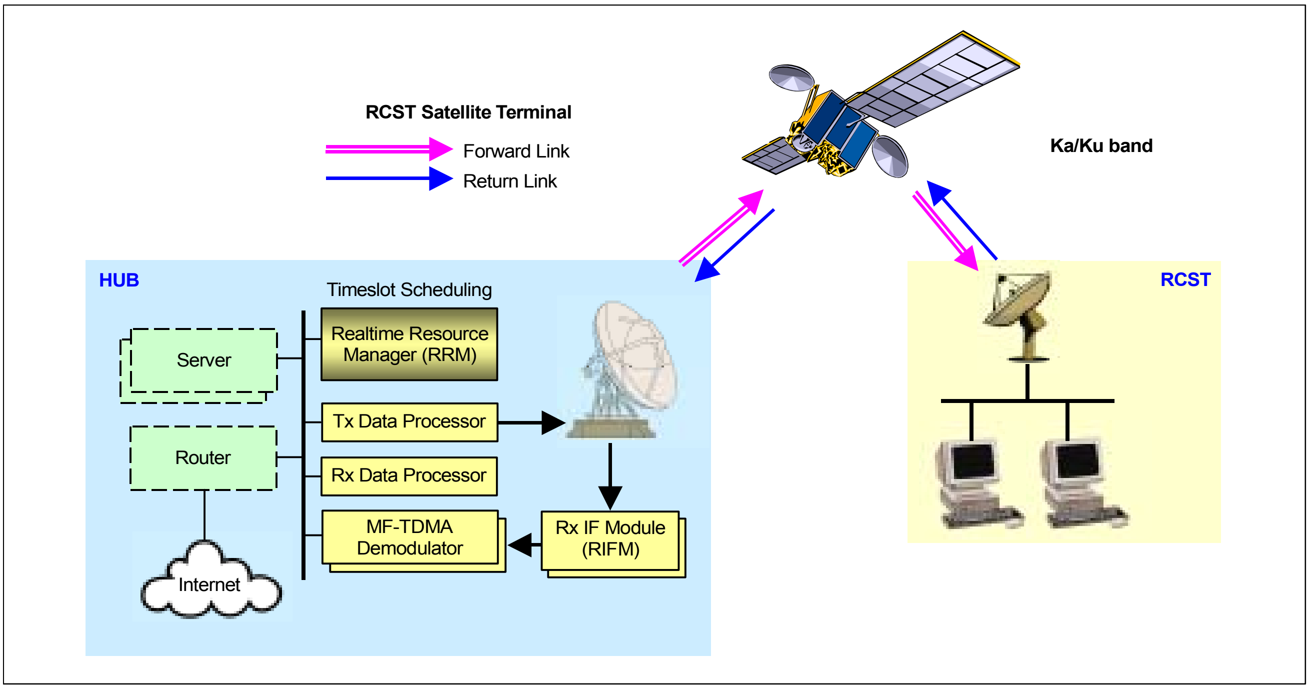

Fig. 1. An example of a DVB-RCS system configuration: the Broadband Satellite Access Network (BSAN) system developed by the ETRI, Korea (http://www.etri.re.kr/).

neither a broadcasting effect as in the forward link nor high reuse efficiency as in the present and emerging cellular systems, achieving high capacity with limited available radio resources is an important focus of investigation. The European Telecommunications Standards Institute (ETSI)'s standard [1] calls for a return link using a multi-frequency time-division multiple access (MF-TDMA) scheme. Thus, we are motivated to find an optimal timeslot schedule for each superframe in a fixed MF-TDMA return link so that the return link throughput is maximized [6], [7]. Introducing an economic concept-based penalty weight vector, we formulate the timeslot assignment problem as a binary integer-programming problem with a vast number of decision variables (e.g., more than 8,000,000 binary integer variables for the superframe pattern presented in [6]). To solve this problem with computational efficiency, we decompose the original binary integer-programming problem into two sub-problems, where the optimal assignment amount vector is determined in the first phase and a terminal burst time plan (TBTP) is determined in the second phase. Experimental results show that our method performs very well, i.e., it is very efficient. The optimality of the solution obtained by our proposed very efficient dynamic timeslot assignment (VEDTA) algorithm is shown in the appendix.

Our experimental and theoretical results demonstrate that this method successfully provides both solution efficiency and optimality. Thanks to the efficiency, which is suitable for interactive satellite networks, and the solution optimality, we believe that our method could be used to improve data throughput in the practical development of an interactive satellite multimedia network.

II. Model and Problem Description

1. System Model

We consider an interactive broadband satellite access network with one earth station (the Hub), a GEO satellite, and a number of immobile group terminals called return channel satellite terminals (RCSTs) (Fig. 1). The multiple access scheme in the return link (RCST to the Hub via satellite) is based on MF-TDMA [1]. The radio resources allocated to the return link are shared by multiple RCSTs. Let R be the set of logon RCSTs. The RCST $j \in R$ sends capacity request message(s) to the realtime resource manager (RRM). Upon receiving the messages, the RRM generates a TBTP table and sends it to the RCSTs. Upon receiving the TBTP table, each RCST reads the table to determine what timeslots are assigned. This procedure is executed every superframe.

Figure 2 depicts a unified capacity request and allocation procedure in an interactive satellite network using bandwidth-on-demand.

Figure 3 shows an example of a superframe structure in our MF-TDMA model [6]. We consider an MF-TDMA model in which a superframe, which is defined as a specific time-

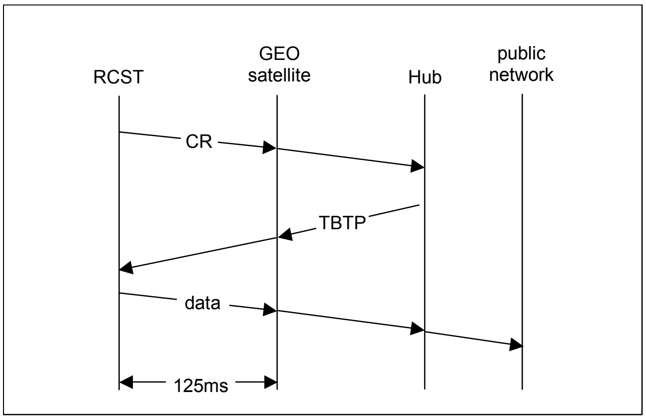

Fig. 2. Capacity request (CR) and allocation procedure in an interactive satellite access network.

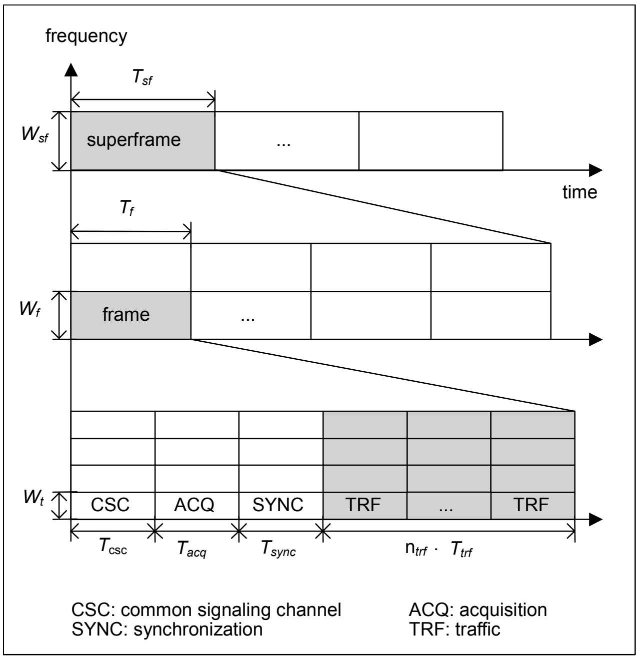

Fig. 3. An example of a superframe structure.

frequency block $T_{sf} \times W_{sf}$ (μs MHz) in the time-frequency domain, includes a group of frames less than M. A frame, which is defined as a specific time-frequency block $T_f \times W_f$, consists of common signaling channel timeslots ($T_{csc} \times W_t$), acquisition timeslots ($T_{acq} \times W_t$), synchronization timeslots ($T_{sync} \times W_t$), and traffic timeslots ($T_{trf} \times W_t$). An RRM, which is a submodule of the Hub, is responsible for traffic (TRF) timeslot scheduling of the return link. The RRM generates a TBTP table from the scheduling result. A TBTP table contains such information fields as Logon_ID, Assignment_Type, Start_Slot, and Assignment_Count. The Logon_ID field shows the identifier assigned to the terminal at logon time; the Assignment_Type field defines the repetitive nature of the assignment (i.e., one time assignment, repeating assignment, or assignment release); the Start_Slot field gives the number of the first timeslot in the block; and the Assignment_Count field gives one less than the number of timeslots assigned in the block.

There are two kinds of schemes: fixed-slot MF-TDMA and dynamic-slot MF-TDMA [1], [2]. A dynamic frame pattern design as presented in [7] belongs to the category of a dynamic-slot TDMA. Because this scheme requires a highly complex computation to solve an optimal frame pattern, many heuristic algorithms, such as the mean field annealing algorithm [7] and simulated annealing algorithm, have been proposed. In this paper, however, we develop an algorithm for a fixed-slot MF-TDMA scheme. This scheme can be implemented more simply and has a simpler computational complexity.

2. Problem Definition

We consider a penalty weight vector $\mathbf{v} = (v_1, \Lambda, v_{|R|})$ for the logon RCSTs to reflect the grade of service of each RCST in our optimal scheduling. Penalty weights are widely used in mathematical formulation [8]. The penalty weights are determined by various factors, such as average waiting time and average fraction of packet loss.

For a given TBTP table, the total penalty can be calculated with this penalty vector. Thus, the objective can be summarized as minimizing the total penalty. For example, if the penalty vector were a function of the average waiting time of packets, then the purpose of our scheduling would be expressed to minimize the average waiting time. According to the functional relation in defining the penalty vector, the objective will have different meaning.

3. Proposed Strategy

Figure 4 shows a timing diagram of the proposed TBTP table generation procedure during a superframe, and Fig. 5

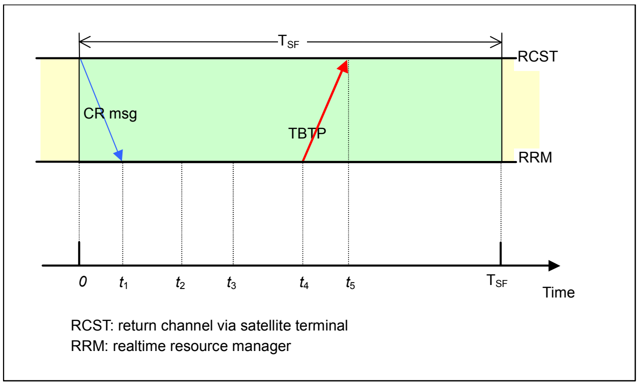

Fig. 4. A diagram of the terminal burst time plan (TBTP) table generation.

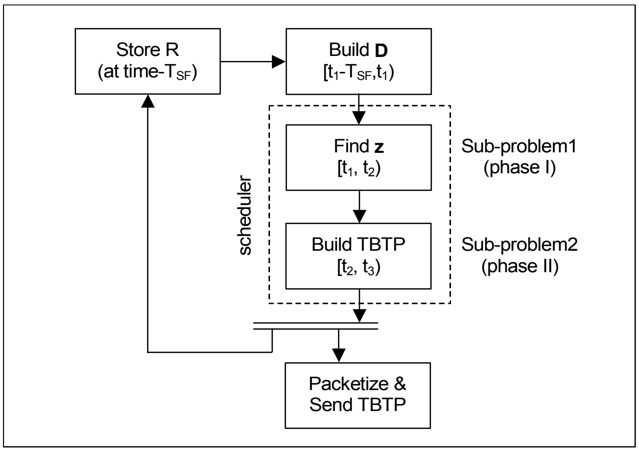

Fig. 5. The terminal burst time plan (TBTP) table generation procedure.

shows the proposed TBTP table generation procedure, including the timeslot scheduling. The RCST $j \in R$ sends a capacity request message to the RRM anytime it is necessary. The RRM accumulates the respective demands for the RCSTs $j \in R$ for the superframe duration T_{sf} and builds a demand vector **D** during $[t_0 - T_{sf}, t_0)$, where $t_0 = 0$ for the sake of convenience. When the RRM receives the last TRF timeslot of the current superframe (at time t_0), then the scheduler starts finding the optimal assignment amount vector **z**, where element z_j denotes the assigned amount of TRF timeslots to the RCST $j \in R$. The optimal assignment amount vector must be found by time t_2. Timeslot scheduling is executed (TBTP table generation) with this vector **z** by time t_3. During the interval $[t_3, t_4)$, the TBTP is packetized in a transport-stream packet format. Then the packets are transmitted with a packet identifier value to the RCSTs via a satellite. If an RCST receives the TBTP table (at time t_5), it analyzes the received TBTP table and waits for the timeslot(s) assigned to it. If the time interval $[t_5, T_{sf} + t_0)$ is too short for an RCST to read the schedule, the schedule cannot be used in the next superframe. To provide sufficient time for RCSTs $j \in R$ to read the schedule encoded in the received TBTP table, we must reduce the scheduling time, i.e., $[t_1, t_3)$.

III. Problem Formulation

1. Input Parameters

The resource allocation scheduler periodically requires updated information: the number of logon RCSTs (denoted by set R), the number of active return link demodulators (denoted by set A), and the capacity demands of logon RCSTs (denoted by vector $\mathbf{D} = (D_1, \Lambda, D_{|R|})$. The number of logon RCSTs must be reported to the scheduler every superframe, and the status of each return link demodulator must be checked before making every schedule. In addition, the capacity demand of each RCST is accumulated during a period equal to superframe duration T_{sf}.

2. Decision Variables

Our objective is to find an optimal layout of timeslot assignment in a superframe. The scheduling period is thus T_{sf}. In order to denote the assignment of each timeslot, we introduce a decision variable matrix $\mathbf{x} = [x_{ij}]$, where x_{ij} is unity if timeslot i is assigned to RCST j, and zero otherwise. For example, the number of binary decision variables is given by $|R| \sum_{m \in A} |S_m|$ and its upper bound is equal to 8,388,608 if we have 2,048 timeslots per frame, 32 available frames per superframe, and 128 logon RCSTs.

3. Problem Formulation

Reference [1] recommended five types of capacity requests. We consider continuous rate assignment and volume-based dynamic capacity, in which an RCST requests the volume units of payload size * *scaling factor*. The rate-based dynamic capacity, in which an RCST requests a bit rate in units of 2 kbps * *scaling factor*, is simply transformed to a certain capacity as if it had been requested as volume-based dynamic capacity. Free capacity assignment is no more than a problem in which free TRF timeslots, if there are any, are assigned. With a given symbol rate, a rate-based dynamic capacity request could be transformed into a volume-based dynamic capacity request with a capacity equivalent to the resource request. The total capacity demand of the respective types of capacity requests [1] generated by an RCST can be transformed into a certain number denoting the number of TRF timeslots required for its data transmission. This number for each RCST is the input parameter of our capacity assignment problem. Thus, in our capacity assignment problem, the total capacity demand for each RCST (in timeslots) is sufficient information but the respective demands for the five types are not required. If an RCST requests more capacity than the capacity available, a portion of the requested capacity will not be admitted and the residual capacity must wait to be admitted. However, if the capacity request messages of the logon RCSTs are dependent upon the buffer state (the size of packets waiting for transmission), it is not necessary for the RRM to know the amount of demand which is not satisfied every superframe. The RRM only has to know the demand generated for the previous superframe duration.

Let Y_j be the minimal capacity that must be assigned to a logon RCST. In our practical system, Y_j is used for assigning a certain capacity to a continuous rate assignment request with a higher priority. Let Q_j be the maximal capacity that can be assigned to a logon RCST. The problem of interest is how to allocate the available resources per superframe to the RCSTs in order to minimize the total penalty.

(CAP)

$$\text{Minimize} \quad g(\mathbf{x}) = \sum_{j \in R} \left[v_j \sum_{n \in A} \sum_{i \in S_n} (1 - x_{ij}) \right] \tag{1}$$

subject to constraints

$$\sum_{n \in A} \sum_{i \in S_n} x_{ij} \le \min\{Q_j, X_j + Y_j\}, j \in R, \tag{2}$$

$$\sum_{n \in A} \sum_{i \in S_n} x_{ij} \ge Y_j, j \in R, \tag{3}$$

$$\sum_{j \in R} x_{ij} \le 1, i \in S_m, m \in A, \tag{4}$$

$$\forall \ x_{ij} \in \{0,1\},$$

where v_j's are positive.

As shown in (1), the objective of the capacity allocation problem (CAP) calls for a weighted penalty when a certain amount of capacity is not assigned, where each RCST may have a different value of penalty weight v_j according to several factors, such as the registered service grade (e.g., a low priority service class or a high priority service class). Since $\sum_{n \in A} \sum_{i \in S_n} x_{ij}$ denotes the number of TRF timeslots assigned to RCST *j*, and $\sum_{n \in A} \sum_{i \in S_n} (1 - x_{ij})$ denotes the number of TRF timeslots that are not assigned to RCST *j*, thus, $v_j \sum_{n \in A} \sum_{i \in S_n} (1 - x_{ij})$ denotes the penalty caused by the amount not assigned to RCST *j*, and (1) denotes the sum of the respective penalties.

Constraint (2) implies that the number of TRF timeslots assigned to RCST *j* is not greater than the maximum capacity and the sum of the requested capacity and the minimum capacity. The number of TRF timeslots assigned to RCST *j* is greater than or equal to the minimum capacity. Constraint (4) means that no TRF timeslot can be assigned to more than one RCST.

Since we can separate the constant term from the objective of (CAP) as follows:

$$g(\mathbf{x}) = \overbrace{\sum_{j \in R} v_j \sum_{n \in A} |S_n|}^{\text{a constant term}} - \overbrace{\sum_{j \in R} \left[v_j \sum_{n \in A} \sum_{i \in S_n} x_{ij} \right]}^{g_1(\mathbf{x})}, \tag{5}$$

(CAP) is reformulated as (CAP′).

(CAP′)

$$\text{Maximize} \quad g_1(\mathbf{x}) = \sum_{j \in R} \left[v_j \sum_{n \in A} \sum_{i \in S_n} x_{ij} \right] \tag{6}$$

subject to the same constraints as (CAP).

IV. Solution Method

Table 1 shows the number of binary decision variables for each case of parameter values. A vast number of binary decision variables may give rise to a very long computation time, causing inefficiency of timeslot scheduling. Thus, it is necessary to investigate a simple and efficient method to solve (CAP′).

Table 1. Number of decision variables.

$\frac{W_{sf}}{W_f}$	$\frac{W_f}{W_t}$	$\frac{T_{sf}}{T_f}$	n_{trf}	$\lvert R \rvert$	Number of binary decision variables
2	4	16	500	10	640,000
2	4	16	500	50	3,200,000
2	4	16	508	100	6,502,400
2	4	16	508	128	8,323,072

1. Decomposition of (CAP′)

(CAP′)'s vast number of decision variables causes a heavy computational load. Each TBTP table per superframe must be generated within a desired time. To alleviate the processing burden, we decompose the original problem (CAP′) into two sub-problems [8]. One problem is to find an optimal assignment amount vector $\mathbf{z}$. The other problem is to find a TBTP table with the vector $\mathbf{z}$. According to (CAP′), the amount of TRF timeslots assigned to RCST *j* is $z_j = \sum_{m \in A} \sum_{i \in S_m} x_{ij}$. Thus, the problem to find an optimal $\mathbf{z}$ can be formulated as (P($\mathbf{z}$)).

(P(**z**))

$$\text{Maximize} \quad f(\mathbf{z}) = \sum_{j \in R} v_j z_j \tag{7}$$

subject to constraints

$$z_j \le \min\{Q_j, X_j + Y_j\}, j \in R, \tag{8}$$

$$z_j \ge Y_j, j \in R, \tag{9}$$

$$\sum_{j \in R} z_j \le \sum_{m \in A} |S_m|, \tag{10}$$

$$\forall \ z_j \in \mathbf{Z}^+ \cup \{0\}.$$

The additional capacity requirement of RCST *j* is given by $y_j = z_j - Y_j$. With this vector, we rewrite (P(**z**)) as (P$_1$(**y**)).

(P$_1$(**y**))

Maximize
$$f_1(\mathbf{y}) = \sum_{j \in R} v_j y_j \tag{11}$$

subject to constraints

$$y_j \le \min\{Q_j - Y_j, X_j\}, j \in R \tag{12}$$

$$\sum_{j \in R} y_j \le \sum_{m \in A} | S_m | - \sum_{j \in R} Y_j, \tag{13}$$

$$\forall y_j \in \mathbf{Z}^+ \cup \{0\}.$$

2. VEDTA Algorithm for (P$_1$(**y**))

We present the VEDTA algorithm for (P$_1$(**y**)) and prove that the VEDTA algorithm finds an optimal solution of (P$_1$(**y**)). The procedure of the VEDTA algorithm is shown below:

```
Step 1 (Sort $\{v_j\}$)
$J_0 := \{\}$.
FOR($k$:=1; $k$ <=$| R |$; $k$ ++) {
    $j_k := \arg\max \{v_j, j \in R - J_{k-1}\}$;
    $J_k := J_{k-1} \cup \{j_k\}$;
}

Step 2 (Find an optimal $\mathbf{y}^*$)
$n := \max\{c \mid \sum_{k=1}^{c} y_{j_k} \le \sum_{m \in A} | S_m | - \sum_{j \in R} Y_j\}$;
If $n = | R |$, then $y_j^* := \min\{Q_j - Y_j, X_j\}$ $\forall j \in R$;
Else,
    $y_j^* := \min\{Q_j - Y_j, X_j\}$ $\forall j \in J_n$;
    $y_{n+1}^* := \sum_{m \in A} | S_m | - \sum_{j \in R} Y_j - \sum_{j \in J_m} \min\{Q_j - Y_j, X_j\}$;
    $y_{j+1}^* := 0$, $\forall j > n$;

Step 3 (Find an optimal $\mathbf{z}^*$)
$\mathbf{z}^* := \mathbf{y}^* + (Y_1, \Lambda, Y_{|R|})$
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We relax the integer constraint on vector $\mathbf{y}$. We show that without the integer constraint, the VEDTA algorithm finds an integer optimal solution given that Q_j, X_j, and Y_j are integers.

Proposition 1: The VEDTA algorithm finds an optimal solution.
Proof: See the appendix. □

If there are free TRF timeslots, they may be additionally assigned to logon RCSTs as free capacity assignments. Capacity assigned in this category is intended as a bonus capacity, which can be used to reduce delays in any traffic that can tolerate delay jitter.

V. TBTP Table Generation Procedure

In the ETSI DVB-RCS standard [1], frames of a superframe are numbered from 0 (lowest frequency, first in time) to N (highest frequency, last in time), ordered first in time, then in frequency, where N is less than or equal to 31. In a frame, time slots are numbered from 0 (lowest frequency, first in time) to M (highest frequency, last in time), ordered first in time, then in frequency, where M is less than or equal to 2,047. In our TBTP table generation procedure, we use a similar numbering system as follows. In a superframe, TRF timeslots are numbered from 0 (lowest frequency, first in time) to $\sum_{m \in A} | S_m | - 1$ (highest frequency, last in time), ordered first in time, then in frequency. The TBTP table is then built up iteratively.

```
Step 1 (Initialization)
slot_counter := 0;  $\mathbf{x} := \mathbf{0}$;
Step 2 (Iteration)
FOR($k$ := 1; $k$ <=$| R |$; $k$ ++) {
    FOR($i$ := slot_counter; $i$ <= $j_k$; $i$ ++) {
        $x_{i,j_k}$ := 1;
    }
    slot_counter += $z_{j_k}$;
}
```

VI. Performance Analysis and Discussions

1. Optimality

The objective shown in (1) denotes the (weighted) throughput (in timeslots), where a certain RCST may have a higher priority than the others so that it can have more TRF timeslots than the others. In this sense, our optimization problem on CAP is to maximize the throughput. Thus, we can safely conclude that our algorithm attains the maximum throughput by Proposition 1.

2. Computational Efficiency

Our algorithm has a linear complexity with respect to $| R |$, $| A |$, and $| S_m |$, respectively. This means that each factor affects the computational complexity within a range of a linear complexity. In addition, our algorithm requires a small amount of memory in a computing machine. This is a merit of our algorithm for practical implementation.

3. Computational Results and Discussions

Figure 6 shows the clusters of TRF timeslots assigned to the respective RCSTs. As shown in the figure, the cluster of each RCST is numbered from 1 (lowest frequency, first in time) to $|R|$ (highest frequency, last in time), ordered first in time, then in frequency. According to the characteristics of the hub, an RCST cannot use more than one carrier at the same time (it uses multiple carriers, but a single carrier at a given timeslot). If $Q_j \le n_{trf} \cdot (T_{sf} / T_f)$, it can be simply shown that our TBTP table generation algorithm always finds a feasible TBTP table that does not violate the certain constraint of "using multiple carriers, but a single carrier at a given timeslot."

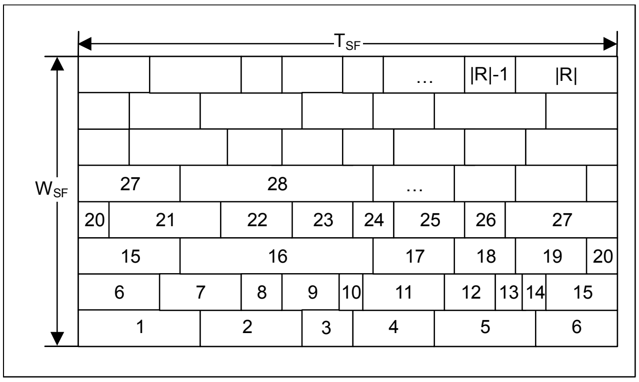

Fig. 6. A visualized example of a terminal burst time plan (TBTP) table for a superframe (number: RCST index).

We show the computational results of our algorithm using randomly generated demand vectors. Table 2 shows the superframe pattern, the available resource status, and the number of logon RCSTs. Table 3 presents the times elapsed in Phase 1 (finding **z**) and Phase 2 (finding **x**), which demonstrates the computational efficiency of our method.

VII. Concluding Remarks

We developed a method for efficient timeslot scheduling in an interactive broadband satellite access network [1], [2] so that the system throughput is maximized. The timeslot assignment problem was formulated as a binary integer programming problem [9], which has more than 8,000,000 decision variables. We employed a problem decomposition technique [9] that achieved a remarkable decrease in computational burden. In an interactive satellite access network, realtime resource allocation scheduling is impossible because of round-trip delay, i.e., it takes a certain period of time (e.g., about 500 ms in GEO satellite networks) for a terminal to receive a capacity allocation message generated by a Hub station. Computational results show that the proposed algorithm solves the formulated problem within a short period of time, much shorter than the designed superframe duration. Owing to this efficiency, the proposed optimization approach can be used for throughput performance improvement in interactive satellite access networks.

Table 2. Superframe pattern used in our example.

Item	Value
W_{sf} / W_f	2
W_f / W_t	4
T_{sf} / T_f	16
n_{trf}	508
$\|A\|$	3
	4
$\|R\|$	32
	64
	128
$\|S_m\|$	508*2*16

Table 3. Computational results (upper bound of elapsed time).

$\|A\|$	$\|R\|$	**z**	**x**
3	32	0.010	0.010
	64	0.010	0.010
	128	0.010	0.020
4	32	0.010	0.010
	64	0.010	0.010
	128	0.020	0.020

Time in seconds. Pentium III PC 1.0 GHz.

Appendix

We briefly describe how any feasible solution found by the VEDTA algorithm has optimality.

The optimality of the VEDTA algorithm can be proved by applying the concept of the simplex method or by using the complementary slackness theorem [8]. Thus, we try to prove it along a similar but different way. The outline of our proof is as follows.

Step 1: Linear programming (LP)-relaxation. Relax the integer constraint on **y** and consider an LP-relaxed problem.

Step 2: Feasibility check. Check if the solution obtained by the VEDTA algorithm is feasible.

Step 3: Local optimality check. Check if that solution is locally optimal.

If there is no feasible direction improving the objective value of that solution, then the solution is locally optimal. There is no feasible direction in that solution, and a mathematical proof of an equivalent problem can be found in [10].

Step 4: Global optimality check. Since an LP is convex, a local optimum is a global optimum.

Since the feasible set of the original problem is a subset of the LP-relaxed problem, the global optimum of the LP-relaxed problem is the global optimum of the original problem.

Acknowledgements

The first author would like to thank the anonymous reviewers for their valuable comments to improve this work. This work is a partial result of the Broadband Satellite Access Network (BSAN) system developed by the ETRI (URL http://www.etri.re.kr/). The every effort of all BSAN system developing members was helpful to the successful operation of the proposed algorithm in the BSAN system.

References

[1] ETSI EN 301 790 (V1.2.2): *Digital Video Broadcasting (DVB); Interaction Channel for Satellite Distribution Systems*,(also known as the 'DVB-RCS' specification).

[2] J. Neale, R. Green, and J. Landovskis, "Interactive Channel for Multimedia Satellite Networks," *IEEE Com. Mag*., Mar. 2001, pp. 192-198.

[3] Y.-H. Cho and H.-J. Lee, "Broadband Satellite Access Network (BSAN) System for Interactive Multimedia Services," presented in *ETRI-CRL 2nd Joint Conf*., Japan, Aug. 2001.

[4] SatNews Online, URL http://www.satnews.com/stories2/4nov 2001-3.html.

[5] Heyung Sub Lee, Un Gi Joo, Hyeong Ho Lee, and Whan Woo Kim, "Optimal Time Slot Assignment Algorithm for Combined Unicast and Multicast Packets," *ETRI J*., vol. 24, no. 2, Apr. 2002, pp. 172-175.

[6] K.-D. Lee, Y.-H. Cho, S.J. Lee, and H.-J. Lee, "Optimal Design of Superframe Pattern for DVB-RCS Return Link," *ETRI J*., vol. 24, no. 3, June 2002, pp. 251-254.

[7] G. Wang and N. Ansari, "Searching for Optimal Frame Patterns in an Integrated TDMA Communication System Using Mean Field Annealing," *IEEE Trans. Neural Net*., vol. 9, no. 6, 1998, pp. 1292-1300.

[8] K. Murty, *Linear and Combinatorial Programming*, Wiley, 1976.

[9] K.-D. Lee, H.-J. Lee, Y.-H. Cho, and D.G. Oh, "Throughput-Maximizing Timeslot Scheduling for Interactive Satellite Multiclass Services," *IEEE Commun. Lett*., vol. 7, no. 6, June 2003, pp. 263-265.

[10] K.-D. Lee, Y.-H. Cho, H.-J. Lee, and H. Jeong, "Optimal Scheduling for Timeslot Assignment in MF-TDMA Broadband Satellite Communications," *Proc. IEEE VTC Fall* 2002, vol. 3, Vancouver, Canada, 2002, pp. 1560-1564.

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