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Packet Scheduling in Interactive Satellite Return Channels for Mobile Multimedia Services Using Hybrid CDMA/TDMA

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Abstract — Developing an interactive satellite multimedia system, such as a digital video broadcasting (DVB) return channel via satellite (RCS) system, is gaining popularity over the world. To accommodate the increasing traffic demand, we are motivated to investigate an alternative for improving return channel utilization. We develop an efficient method for optimal packet scheduling in an interactive satellite multimedia system using hybrid CDMA/TDMA channels. We formulate the timeslot-code assignment problem as a binary integer programming (BIP) problem, where the throughput maximization is the objective, and decompose this BIP problem into two sub-problems for the purpose of solution efficiency. With this decomposition, we promote the computational efficiency in finding the optimal solution of the original BIP problem. Since 2001, ETRI has been involved in a development project, where we have successfully completed an initial system integration test on broadband mobile Internet access via Ku-band channels using the proposed resource allocation algorithm.

Index Terms — Packet scheduling, throughput, satellite, hybrid TDMA/CDMA, DVB-RCS.

ACRONYMS

CDU	CDMA demodulation unit
CR	Capacity request
DVB	Digital video broadcasting
ETSI	European telecommunication standard institute
MF-TDMA	Multi-frequency time division multiple access
RCS	Return channel via satellite
TCAP	Timeslot-code allocation problem
TBTP	Terminal burst time-code plan

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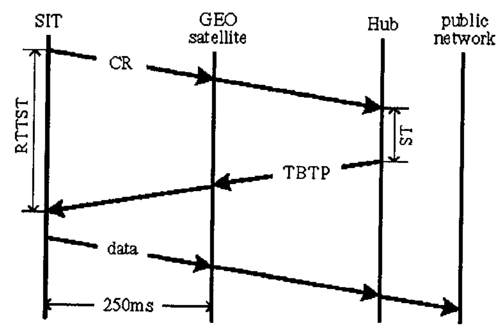


Fig.1 Capacity request (CR) and allocation.

I. INTRODUCTION

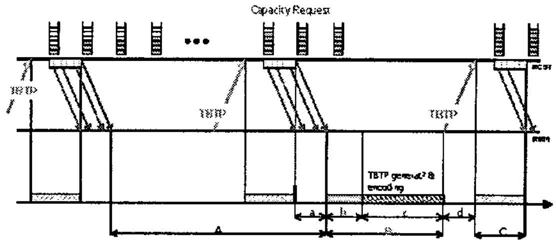
Developing an interactive satellite multimedia (ISM) network, such as digital video broadcasting (DVB) return channel via satellite (RCS) networks, has become one of hot issues. The DVB-RCS network is a geostationary earth orbit (GEO) satellite interactive network providing multimedia, including Internet traffic service [1], [2]. Worldwide companies and industries are developing broadband interactive satellite systems, and its commercial availability has been announced recently [2], [3]. Terminals of most DVB-RCS systems are immobile. However, mobile wireless communication should be provided for a wide marketability. Thus, we consider a mobility-supported interactive satellite system using hybrid TDMA/CDMA return channels over Ku-band. Such mobility-supported services using a GEO satellite over S-/L-band channels can be found (e.g, the Inmarsat). However, these are narrow band communication services (about 12Kbps is available) whereas our system using Ku-band channels is a broadband service (about 384Kbps is available) [4]. Several scheduling algorithms for DVB-RCS are found in the literature [5], [6]. However, these algorithms are based on MF-TDMA and thus we need a new algorithm for a mixed scheduling for timeslot and code assignment in this hybrid TDMA/CDMA scheme.

In order to accommodate increasing network access demand at the lowest possible cost, it is imperative to achieve high bandwidth utilization. In the return link of ISM systems, since there is 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 [7]. We consider a return link (terminal to hub via satellite) using a hybrid TDMA/CDMA scheme and develop a practical method for making an optimal timeslot-code assignment schedule for each superframe in a hybrid TDMA/CDMA return link so that the (weighted) throughput is maximized [5], [6], [7].

Introducing a penalty weight matrix for active terminals and multiple service classes, we formulate the timeslot-code assignment problem (TCAP) as a binary integer programming (BIP) problem. The penalty weight matrix can be dynamically specified according to the quality-of-service condition of each terminal, such as delayed service time, buffer overflow status, and so on. In order to solve the BIP problem with computational efficiency, we use the well-known *problem decomposition technique* [8]. As a result, the BIP problem is decomposed into two sub-problems, where the optimal assignment amount vector is determined in the first phase (solving the first sub-problem) and a terminal burst time-code plan (TBTP) is determined in the second phase (solving the second sub-problem). Performance analysis shows that the proposed method provides both solution efficiency and optimality. Thus, we believe that the proposed method can improve the return link throughput in practical ISM systems.

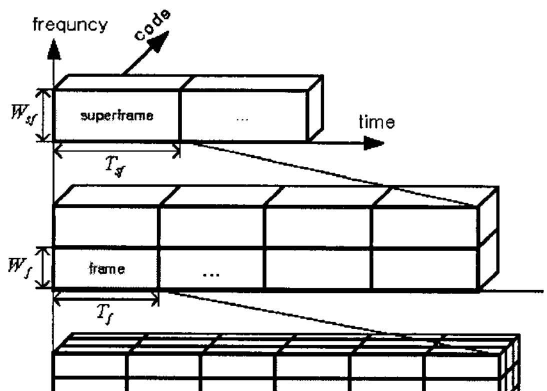
II. MATHEMATICAL FORMULATION OF TCAP

Our objective is to maximize the return link throughput for each superframe. The computational complexity is one of the most important requirements to meet the time constraint. Because the round-trip time in an interactive satellite network is about 500ms (return up/down links and forward up/down links), it is preferred to have as short scheduling time as possible in order to sensitively reflect fluctuating demands onto each TBTP.



1. Return Link Model

We consider an interactive satellite multimedia network with one earth station (hub), a GEO satellite, and a number of group terminals called satellite interactive terminals (SITs). As shown in Fig. 2, we consider a hybrid TDMA/CDMA model [1], where a superframe, which is defined as a specific time-frequency block $T_{sf} \times W_{sf}$ (μs MHz) in the time-frequency domain, includes a group of frames, and each frame, a specific time-frequency block $T_f \times W_f$, consists of physical random access channel (PRACH) timeslots ($T_{PRACH} \times W_t$), acquisition (ACQ) timeslots ($T_{acq} \times W_t$), synchronization (SYNC) timeslots ($T_{sync} \times W_t$), and dedicated data channel (DDCH) timeslots ($T_{DPCH} \times W_t$). The resources in our TDMA/CDMA return link, denoted by set S, are defined as available TRF timeslots.



2. Input Parameters and Control Variables

The scheduler periodically requires updated information such as the set of active SITs (denoted by set R, where the number of elements is limited by $R_{\max}$), and the capacity demands of active SITs during T_{sf} (denoted by matrix $\mathbf{D}=[D_k]$).

A four dimensional array $\mathbf{x}=[x_{ijk}^{l}]$ denotes the timeslot assignment: x_{ijk}^{l} is unity if code j during timeslot (l,i) is assigned to SIT k, zero otherwise. x_{ijk}^{l}'s are binary control (decision) variables of (TCAP).

3. Problem Formulation

Each SIT $k\in R$ has a capacity upper bound Q_k. The problem of interest is how to allocate the available resources per superframe to the SITs in order to minimize the total penalty.

$$g(\mathbf{x})=\sum_{k\in R}a_k\cdot\left(D_k-\sum_{l\in F}\sum_{i\in S}\sum_{j\in C}x_{ijk}^{l}\right) \tag{1}$$

As shown in (1), the objective of (TCAP) means a weighted penalty, where the respective penalty increases proportional to $\sum\sum\sum x_{ijk}^{l}$ by factor a_k if the assignment amount is less than the requested amount D_k. Constraint (2)) implies that the number of TRF timeslots assigned to SIT k is not greater than the maximum capacity Q_k and than the requested amount D_k. Each SIT k must be assigned a certain amount of capacity greater than or equal to the minimum capacity. Constraint (3) denotes a requirement that a given fraction of the demand should be assigned for each SIT. Constraint (4) means that every TRF timeslot cannot be assigned to more than one SIT.

(TCAP)
Minimize $g(\mathbf{x})$
Subject to constraints

$$\sum_{l\in F}\sum_{i\in S}\sum_{j\in C}x_{ijk}^{l}\le\min\{Q_k,D_k\},k\in R \tag{2}$$

$$\sum_{l\in F}\sum_{i\in S}\sum_{j\in C}x_{ijk}^{l}\ge\min\{Q_k,\alpha_k D_k\},k\in R \tag{3}$$

$$\sum_{l\in F}\sum_{i\in S}\sum_{j\in C}\sum_{k\in R}x_{ijk}^{l}\le 1,i\in S, \tag{4}$$

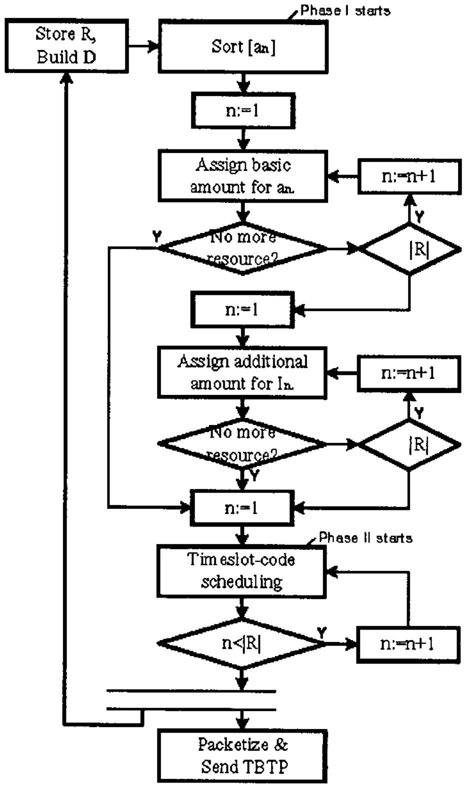
$$x_{ijk}^{l_1}+x_{ijk}^{l_2}\le 1,\forall i,j,k, \tag{5}$$

$$\forall\ x_{ijk}^{l}\in\{0,1\}$$

where a_k is a given threshold value denoting the minimal requirement on the fraction of assigned capacity out of requested capacity. For example, consider a case with $a_k=0.5$. It means that at least 50% of the demand D_k must be assigned to SIT k. These threshold values will be specified according to service providers' policies.

III. Solution Method

We employ a problem decomposition technique in order to reduce the computational burden to the packet scheduler. (TCAP) is divided into two sub-problems: the optimal amount of resources to allocate to each SIT is determined by solving the first sub-problem, and a timeslot-code allocation schedule (TBTP table generation) is made with the solution of the second sub-problem. The following figure presents the flow diagram of the proposed solution method.



IV. 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 simple algorithm has a linear complexity with respect to $|R|$, $|F|$, and $|S|$, respectively. This means that each factor affects the computational complexity within a range of a linear complexity. Also, our algorithm requires little amount of memory in a computing machine. This is a good point of our algorithm for practical implementation.

3. Computational Results and Discussions

Fig. 5 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 in time then in frequency. According to CDU characteristics, an RCST cannot use more than one carrier at the same time (using multiple carriers, but a single carrier at a given timeslot). If $Q_j \le n_{tf} \cdot (T_{sf} / T_f)$, it can be simply shown that our TBTP table generation algorithm always finds a feasible TBTP table that does not violate a certain constraint of "using multiple carriers, but a single carrier at a given timeslot".

We show computational results of our algorithms using randomly generated demand vectors. Table II shows the superframe pattern, the available resource status, and the number of logon RCSTs. Table II presents the times elapsed in Phase 1 (finding $\mathbf{z}$, i.e., the allocation amount for each SIT) and Phase 2 (finding $\mathbf{x}$), which shows the computational efficiency of our method.

TABLE I

Superframe pattern used in our example.

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

TABLE II

Computational results (upper bound of elapsed time)

$\|F\|$	$\|R\|$	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 sec. Pentium III PC 1.0GHz.

V. Concluding Remarks

We developed an efficient method for optimal packet scheduling in an interactive satellite multimedia network so that the system (weighted) throughput is maximized. The timeslot-code assignment problem was formulated as a binary integer programming problem, which has vast numbers of decision variables. We employed a problem decomposition technique so that a remarkable decrease in computational burden might be achieved. Extensive computational results (will) show that the proposed algorithm solves a throughput-maximizing timeslot assignment problem within a short period of time, much shorter than the designed superframe duration. Because of a fast convergence speed to the global optimum, we believe that the proposed optimization approach can be used for throughput performance improvement in practical interactive satellite multimedia networks.

Appendix

We briefly describe that any feasible solution found by the proposed algorithm has optimality.

The optimality of the proposed algorithm can be proved by applying the concept of the Simplex method [8] 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: (LP-relaxation) Relax the integer constraint on $\mathbf{y}$ and consider an LP-relaxed problem (LP: linear programming).

Step 2: (Feasibility check) Check if the solution by 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 at that solution, then the solution is locally optimal. There is no feasible direction at that solution, and an evidence can be found in [9].

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.

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