Resource Allocation in Variable Bandwidth MF-TDMA Satellite Communications

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Abstract

In modern satellite communication systems, because of the high efficiency and flexibility, multi-frequency time-division multiple access (MF-TDMA) becomes one of hot issues. In this paper we present a resource allocation algorithm for the variable bandwidth MF-TDMA model. The proposed algorithm uses new concept – Unit Block, as the basic unit of resource allocation, and gives an outstanding assignment plan within a comparatively short period of time.

1. Introduction

Time-division multiple access communication systems transmit the information in bursts, where each terminal access to the whole bandwidth with the maximum signal-to-noise ratio, but only for a short time period. When the network capacity has to be increased in a single frequency TDMA system, the information rate of all stations must be increased. This requires a higher EIRP and G/T for all terminals. This is a major drawback, which can be avoided by Multi-Frequency TDMA (MF-TDMA), where the system bandwidth is increased by adding further carriers, and the terminals transmit and receive on different frequency bands simultaneously. This leads to a two-dimensionally resource allocating problem in time-frequency domain, which is directly related to the QoS of the link.

In [1], two QoS measures, the bit error rate (BER) and the data rate, are used to evaluate the two steps resource allocation algorithm based on Markov model. In [2], Ki-Dong Lee find an optimal timeslot schedule for each superframe in a fixed MF-TDMA link and link throughput is maximized. But it is expected that the network access demand will increase and, all kinds of terminals with different signal bandwidth must work in one system compatibly. In this paper we present a resource allocation algorithm for the variable bandwidth case. Because the resource allocating problem is known to be NP-complete with vast numbers of decision variables, obtaining an optimal packing scheme requires a prohibitive amount of computation(e.g., more than 8×106 variables for the superframe pattern shown in [3]). In order to solve the problem with computational efficiency, we decompose and solve the original problem into three steps, where the fine sub-band bandwidth selection is determined in the first step, the assignment amount vector is determined in the second step and a burst time plan (BTP) is determined in the last step.

This paper is organized as follows. In Section 2, The variable bandwidth MF-TDMA system model is introduced. Our resource allocating algorithm is derived in Section 3, and Section 4, some results and conclusions are finally given.

2. SYSTEM MODEL

We consider an On-Board-Processing GEO satellite system whose return link is based on MF-TDMA scheme and various type satellite terminals marked STs which are mainly different in the bandwidth needed in normal working mode. The radio resource allocated to the return link is shared by STs. Let W_s be the whole return link bandwidth, and R be the number of STs. On satellite, there is a FPG module who receives the resource request messages from the STs, then generates the transmit burst time plan (BTP) which will be sent back to all the STs. The STs read the BTP to know what timeslots are assigned. Because different type STs have different working bandwidth, and here, we consider an atom bandwidth marked W_a which is the minimum bandwidth for STs. The valid request bandwidth must be 2^n multiple of W_a, where n is a positive integer. Fig. 1 shows an example of superframe pattern in our MF-TDMA model, acquisition timeslots and synchronization timeslots is not demonstrated.

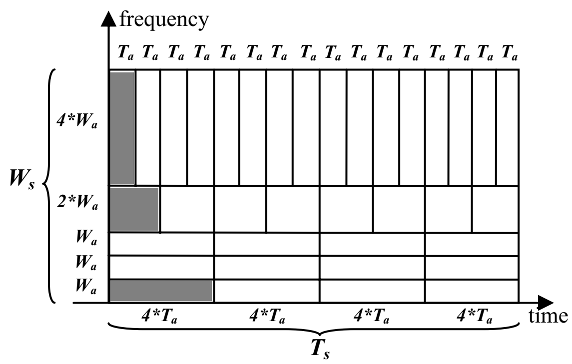

Figure 1. superframe pattern in our MF-TDMA model

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We consider an variable bandwidth MF-TDMA model, where a superframe, which is defined as a specific time-frequency block $T_s \times W_s$ ***(μs・MHz)*** in the time-frequency domain. We will take no account of the concept of ***Frame***, and look on ***Superframe*** as our research object. Here we give a important concept – ***Unit Block***, which is the basic unit of resource allocation regardless the STs' type(which have different working bandwidths). In the remainder part of the paper, we will use the unit blocks instead of timeslots. In Fig. 1, there are three dark blocks with the same area(marked A) in the time-frequency domain, and they are all unit blocks with different bandwidths. We consider the maximum bandwidth can be used is $W_s/2$, then, the atom burst length in the time domain is $2A/W_s$ (marked T_a). The burst length of STs must be 2^n multiple of T_a and must satisfy the product of the bankwidth and the burst length is A.

We consider some properties for the STs. i, the device NO.. T_i, the ST's type indicating different working bandwidth. M_i, the maximum number of unit blocks that the ***NO.i*** ST could be allocated. N_i, the minimum number of unit blocks that the ***NO.i*** ST should be allocated. X_i, the number of unit blocks requested. Y_i, the number of unit blocks allocated by the FPG. And, G_i, the weights of ***NO.i*** ST, which are determined by various factors such as average waiting time and PRI. Furthermore, we let $Z_i = X_i - Y_i$, which is the additional requested resource besides the essential minimum unit blocks, ($i \in R$).

3. PROPOSED METHOD

Our objective is to find an optimal layout of unit blocks assignment in a superframe. We consider the resource allocation delay is less than T_s, and the procedure is executed every superframe. At the beginning of every superframe(the period is about T_s /10) the STs send its resource request message to FPG, and the end of every superframe(the period is about T_s /4) is used by STs to read the BTP and prepare for new assignment of the next superframe. Thus, the scheduling period is usually must less than $T_s/2$.

When allocating unit block to the STs, the following restrictions are applied.

Restriction 1: The number of unit blocks assigned to STs is not greater than the maximum capacity and the requested capacity.

Restriction 2: The number of unit blocks assigned to STs is greater than or equal to the minimum capacity.

Restriction 3: A terminal can not use unit blocks that overlap in time to support multiple connections. This restriction will confine the value of M_i.

Restriction 4: Every unit block cannot be assigned to more than one ST.

To generate a BTP, we must maximize the sum of all ST's Fats whose value is the product of Y_i and G_i. As well as maximize ***F(y)*** without violating the 4 restrictions.

Maximum: $F(y) = \sum_{k \in N_T} \sum_{j \in R_k} G_j \times Y_j$

Subject to: $N_i \le Y_i \le \min\{M_i, X_i\}$

and other restrictions

If we view the unit blocks as a collection of bins, then the allocation of the unit blocks can be considered as a variant of the dynamic bin-packing problem. Because the this problem is known to be NP-complete, obtaining an optimal packing scheme requires a prohibitive amount of computation.

In order to alleviate the processing burden, we decompose the problem and solve it in three steps. The first step is to devide the W_s into several parts, which decides what bandwidth types we should used and how much these type bandwidths we must allocate. The second step is to find an optimal assignment amount vector $[Y_i]$. With the two steps above, we can get a maximum ***F(y)***. The last step is to find a BTP with the vector $[T_i]$ and $[Y_i]$.

A. The first two Steps:

In proposed algorithm, we combine the first two step together for convenience. This is the most important and complex step, and we will explain this step by a simplified example.

1) Firstly, allocating N_i unit blocks for each STs whose N_i is not equal to zero. Here we must allocate resource for all needed bandwidth types. Another method to guarantee the minimum resource is to change the weights of essential minimum number of unit blocks to a big enough number, and allocate the resource in 2) uniformly. We adopt the later method.
2) Secondly, sorting the STs' requested unit blocks according to G_i and the weight modification in 1), and fills the Table 1.

bandwidth													
W_s/4 (8)*	***NO.***	3	7	3	4	4	7	1	1	1	1	1	1
	G_i	∞	∞	9	7	7	6	5	5	5	5	5	5
W_s/8 (4)*	***NO.***	2	2	2	2	2	5	5	5	5	5		
	G_i	∞	∞	9	9	9	7	7	7	7	7		
W_s/16 (2) *	***NO.***	6	6	8	8	8	8	9	9	9	9	9	
	G_i	∞	6	6	6	6	6	6	6	6	6	6	

Table 1. An example table for demonstrate the proposed algorithm

∞:denote the big enough number in 1)

**: the number in the bracket is the number of unit blocks per carrier.*

Every unit block specified by $T_i(i \in R)$ is filled in the table with its device NO. and weights.

3) Thirdly, in the Table 1, the bandwidth get smaller along with the row number increasing. The first bandwidth type which has maximum working bandwidth, has 8(denote UN_1) unit blocks per superframe(select 8 is for convenience of drawing table, any bigger number can instead), hence we will process 8 unit blocks(as a processing unit) of every bandwidth type each time, and lay on different colors on the Table 1 depending on the value of $UN_1 \sim UN_3$. We use C(q,e) denote each color on the Table 1, q is the sequence number of bandwidth type and e is the color number of current bandwidth type. A colored processing unit is shown in Table 2.

$W_s/4$ (8)*	NO.	3	7	3	4	4	7	1	1
	G_i	∞	∞	9	7	7	6	5	5
$W_s/8$ (4)*	NO.	2	2	2	2	2	5	5	5
	G_i	∞	∞	9	9	9	7	7	7
$W_s/16$ (2)*	NO.	6	6	8	8	8	8	9	9
	G_i	∞	6	6	6	6	6	6	6

Table 2. A colored processing unit

4) Use the following algorithm to allocate resource.

/* maxfuc is an assistant function */
function maxfuc(K,L,Ls):**integer**
begin
if(L = 0) **then** result:= 0
else if(K = Ls) **then**

result $:= \sum_{i=1..L} SUMG\ (C(Ls, i))$

else
begin
tem:= ϕ;
for J:= L **downto** 0 do
tem:= tem ∪ maxfuc(K+1, (L−J)*2, Ls);
result:= max(tem);
end;
end;

max(T): Get the maximum number of set T;
SUMG(C): Return the sum of all unit blocks' G_i in color C;

For Table 2, we can use the pseudo codes below to allocate time-frequency resource.

/* pseudo codes of allocating time-frequency resource for Table 2 */
Ls = 3; allocSet = ϕ;
While(Table 2 is not empty and remainder resource still can be used by Table 2)**do**
begin
maxW = maxfuc(1,1.Ls);
Uset <= the unit blocks set which corresponding maxW;
Put Uset into allocSet;
Eliminate Uset from Table 2;
Left align the remainder data of Table 2;
end;

Then, allocSet is the unit blocks which we should allocate.

B. Step three:

Firstly, we devide allocSet into some groups according to unit block's type, and each group's unit blocks have the same type. What should we do in this step is connecting all the unit block for each STs together(in other words, we get the [Y_i]). Then, we can allocate resource according to the groups one by one, and generate the BTP. This process is quite clear(Refer to [2] for detailed description).

Whether or not our algorithm is optimal, it is hard to give a mathematical proof, but, refer to [2] 's appendix, after the sub-band bandwidth selection in the first step, our algorithm can ensure that the resource allocation in each sub-band is optimal. Further more, in the first step, we allocate the optimal working bandwidth by making an enumeration of all the case. So we think our algorithm is optimal.

Most of the developments shown in this paper are being tested in Linux and MPC8250 hardware platform. The first two steps' elapsed time show in Table 3.

L	K	Ls	Elapsed time(in sec)
4	8192	2	0.0005
4	8192	4	0.003
8	8192	4	0.007
8	8192	6	0.040
8	8192	8	15.6

Table 3. Simulation results

- *Let the maximum working bandwidth is **Ws/L** containing **K** unit blocks, and **Ls** is number of bandwidth types.*
- *MPC8250 300MHz, Source code in C++.*

The proposed algorithm works well while the number of bandwidth types is not bigger then 6. If exceeding 6, because of the enumeration operation in the first two steps, the computational capacity increases rapidly.

4. CONCLUSION

We developed a resource allocation algorithm for the variable bandwidth MF-TDMA satellite communication systems. Because the resource allocating is known to be NP-complete problem, We employed a problem decomposition technique and solve the complex problem into three steps. Testing results show that the proposed algorithm solves the variable bandwidth case within a short period of time, while the number of bandwidth types is not too big. Owing to the efficiency and flexibility, the proposed approach can be used for throughput performance improvement in variable bandwidth MF-TDMA communication systems.

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