A Novel Algorithm Based on 2D Packing Algorithm BFD for Timeslots Assignment in MF-TDMA System

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***Abstract*—This paper presents a periodic heuristic algorithm to solve the timeslots assignment problem of multi-terminals in MF-TDMA system with star topology. The goal is to design an algorithm that allows the processing of a given traffic profile with some constraints and a maximum utilization of the total frequency channel capacity, using the minimum spectrum bandwidth. The MF-TDMA system is viewed as a collection of bins, and then the resource assignment problem for the uplink becomes combinatorialoptimization problem which can be seen as a two-dimensional (2D) dynamic bin-packing problem with additional constraints. In the paper, the RCP-fit and the Best-Fit-Decreasing algorithms are integrated as a basis, which is added some additional restrictions. Through the experiment and simulation compared with existing algorithm, the proposed heuristic algorithm can improve the utilization of limited timeslot resources.**

***Index Terms*—MF-TDMA, 2D packing, radio resource management, timeslots assignment**

I. INTRODUCTION

Multi-Frequency Time Division Multiple Access (MF-TDMA) is used as the mainstream system in the broadband multimedia satellite communications system. This system allows multi-terminals to communicate with a gateway using a set of carrier frequencies, each of which is divided intotime-slots. Thus, each frequency channel is divided into several timeslots that can be assigned to multiple connections. In order to achieve flexible assignment of resources in a MF-TDMA communication network, radio resource management decides the amount of timeslots for each bandwidth request of traffic connections from user terminals and deals with the mapping of the timeslots assignment to the specific frequency channels in a frame.

In the paper the MF-TDMA system is star topology with one hub on a satellite network, as shown in Fig. 1. And the satellite return link, which goes from the terminals to the hub, is the only shared medium that requires a Medium Access Control (MAC) protocol. As an example, the MAC protocol proposed by the second Digital Video Broadcasting - Return Channel Satellite standard (DVB-RCS2) is the MF-TDMA. On the hub, the resource assignment phase periodically processes the Capacity Request (CR) received from multi-terminals and build a Burst Time Plan (BTP), which indicates the amount of timeslots resources of each terminal with a given traffic until the next BTP reception.

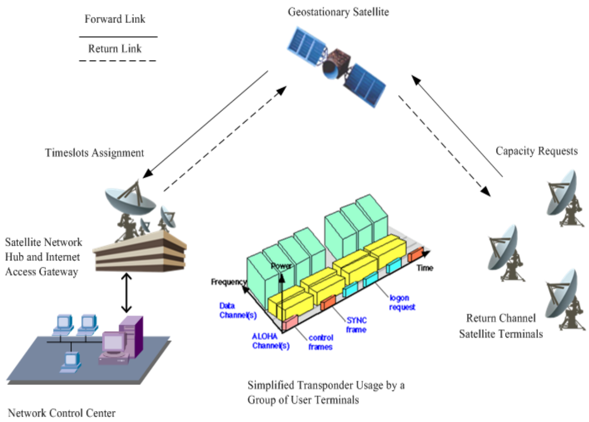

Figure 1. MF-TDMA satellite communication system

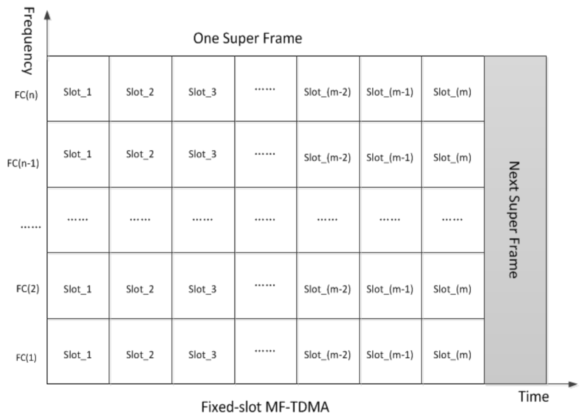

Figure 2. Fixed MF-TDMA frame structure

According to the frequency hopping ability of user terminal, MF-TDMA can be divided into fixed MF-TDMA and dynamic MF-TDMA. In Fixed-Slot MF-TDMA, the bandwidth and duration of successive traffic slots used by an RCST is fixed, which can be viewed as a 2-D array (as Fig. 2) in which the rows represent frequency channels and the columns represent timeslot indexes. In the fixed MF-TDMA system, a terminal can’t hop in different rate carriers in the process

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of continuous transmission, but only can hop between different frequency carriers which is at the same rate (as Fig. 3). In this paper use fixed MF-TDMA system as the research object.

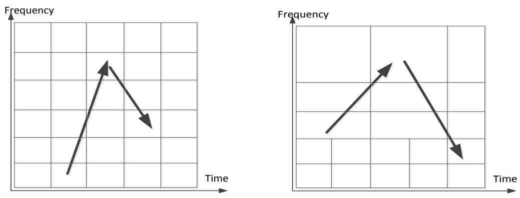

Figure 3. Static MF-TDMA (left) and dynamic MF-TDMA(right)

The structure of this paper is as follows: Section 2 performs a review of related literature; Section 3 presents the proposed algorithm to solve the problem; Section 4 shows some results obtained with the proposed algorithm; and Section 5 extracts some conclusions from the work.

II. Related Work

Researchers have come up with a number of strategies from various angles of view for timeslots assignment in satellite networks in existing bibliography. Below we present the proposals which is more beneficial for timeslots assignment in fixed MF-TDMA.

In Ref. [1], Navid considers the MF-TDMA timeslots assignment problem is a form of the knapsack problem which is NP-Hard and proposes a simple but poor robust packing algorithm. The packing algorithm perfectly packs any allocation that is completely packable in one pass. In case of not being fully allocated, it will only performa very small fragmentation rate (less than 3%). When packing everything at once, system performance can be improved by segregating equal bandwidth users into separate channel groups. If this is not possible, the situation that packs the capacity containing a larger number of small bandwidth will impact packaging efficiency. These efficiencies are quantified into a chart showing in the article. While there are a large number of small bandwidth users existing, more sophisticated packaging strategies are described in the paper to further improve the packing effectiveness. However, the author doesn't point out the restrictions in MF-TDMA system completely.

In Ref. [2], Shvodian *et al*. propose a Media Access Control (MAC) or Demand Assignment Multiple Access (DAMA) protocol for traffic with more than one priority level. At the beginning, Return Channel Satellite Terminals (RCSTs) compute the number of slots requested. Then they take the timeslots assignment into consideration with the priority of traffic. When there're more than one request exists in the same priority level, the Round Robin is taken. The timeslots assignment will be contiguous in time, but because timeslots are re-allocated and re-assigned every single super frame this protocol does not incur the fragmentation inefficiencies.

In Ref. [3], LEE, Ki-Dong, *et al*. develop a method for efficient timeslot scheduling in an interactive broadband satellite access network, which formulates the timeslot assignment problem as a binary integer programming problem with remarkable numbers of decision variables. Computational results of the dynamic timeslots assignment algorithm solve the formulated problem within a short period of time.

PARK, Jung-Min, *et al*. Ref. [4] address the problem of providing QoS connections over a MF-TDMA system and divide it into two parts: resource calculation and resource allocation. They treat the resource calculation phase as a disturbance prediction problem and presents a Markov model based scheme for solving it. The resource-allocation phase addresses the problem of allocating actual timeslots in the MF-TDMA Channel Structure (MTCS). MTCS is viewed as a collection of bins, and then the problem of allocating resources for the uplink can be considered as a variant of the dynamic bin-packing problem. The bin-packing problem belongs to the class of NP-hard problems, and therefore the existence of a polynomial time algorithm to solve the problem optimally is unlikely. As a result, a packing heuristic is proposed called reserve channel with priority (RCP-fit). Through analysis and simulation in the paper, they conclude that the Best-fit and First-fit algorithms can cause a certain degree of fragmentation that might prevent an item from being allocated. This problem can be improved by RCP-fit algorithm, of which the main idea is to reserves a frequency channel for each active RCST so that it can transmit all its bursts. But RCP-fit algorithm is especially effective when the uplink-traffic load is heavily dominated by a small number of terminals. This work is better presented in Ref. [5].

The literature Ref. [6] uses RCP-fit algorithm to select a carrier channel. The author presents a tree-based organizing method of timeslots for timeslots assignment in one frequency channel by using a Buddy-fit with Recursive Adjustment (BFRA) algorithm to optimize the utilization rate of the system for the efficient distribution of the MF-TDMA timeslots in carriers. This paper mainly contributes to propose the concept of Buddy-relation, which is that, if two blocks are the same size, the address of two blocks are consecutive and two blocks must be separated from a larger block.

III. Proposed Packing Algorithm

As Fig. 2 Fixed MF-TDMA Frame Structure shows, the Timeslots Assignment of MF-TDMA system is similar to a system where objects of different sizes are placed, moved, and removed from a finite capacity bin. The allocation, relocation will gradually increase fragmentation and limit the utilization of the available timeslots resource. According to the problem description, even though the capacity request arrive on-line, the assignments are periodic with the capacity request arrived up to the current time, so the channel fragmentation minimization problem can be modeled as an off-line 2D oriented strip packing problem (as Fig. 4) which is proved as a NP-hard problem Ref. [7]. The proposed 2D packing algorithm is a hybrid resource assignment that combine the RCP-fit AND Best-fit with some restrictions, aiming at improving utilization of timeslots resources.

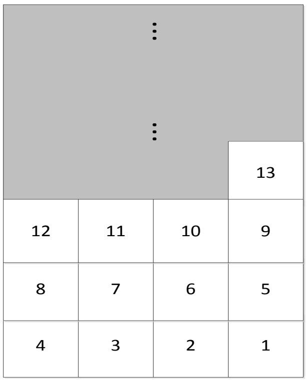

Figure 4. An off-line 2D oriented strip packing problem model

As the Best Fit (BF) algorithm is one of the most efficient off-line bin packing algorithms, and therefore is beneficial in the initial assignment of timeslots resource in an MF-TDMA communication system, and the additional advantage available while dynamically defragmenting an MF-TDMA communication system facilitates the usage of the Best Fit Decreasing (BFD) algorithm (work as Fig. 5). Although the added sorting step does lead to the increased run time cost of O(nlog(n)), the effectiveness of the BFD algorithm in reducing channel fragmentation is vastly improved over that of the non-sorted BF algorithm.

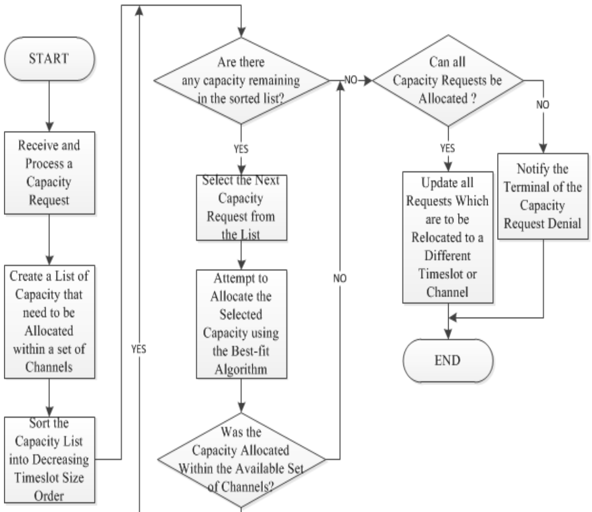

Figure 5. Best fit decreasing flow diagram

In this paper, in order to reduce the fragmentation of MF-TDMA communication system, and taking into account the simplicity and feasibility, the restrictions due to the hardware and operational limitations of the MF-TDMA system the system were modified on the basis applied in RCP-fit algorithm and BFD algorithm as follows:

(1) Timeslots used by a terminal can't overlap in time across several frequency channels to support multiple connections;

(2) One timeslot can only be assigned to one terminal;

(3) The timeslots assigned to a terminal cannot exceed the total number of the timeslots in one frequency channel;

(4) The set of timeslots requested by a terminal to support a given single connection must be contiguous on one frequency;

(5) Assignment of resources for a terminal is restricted on one frequency channel.

The restrictions (1) is as same as the original restrictions; the reason to set the restrictions (2) is that if the system repeatedly uses the same timeslot in a frequency channel, this causes mutual interference between terminals. So that the system can not effectively identify information; The restrictions (3) is based on how many the system resources can be used, limiting each terminal in the system can not be assigned timeslots exceeding the capacity one channel contained so that to improve the utilization of satellite bandwidth. The reason for restrictions (4) is to ease the assignment problem for the satellite resources and to simplify the routing in the payload. (5) is restricted mainly to reduce the amount of channel fragmentation to improve the efficiency of satellite bandwidth utilization. Whether the channel is reserved channel or unreserved channel, the timeslot resources it required are only allowed to use in one frequency channel. This will eliminate the impact which the restrictions (1) cause channel fragmentation, and effectively reduce the probability of generating fragmentation.

The proposed packing algorithm starts by packing timeslot which obey five restrictions and the principle for resource request is first-arrived, first-served. When request arrive, it is judged by system firstly based on RCP-fit algorithm. At the beginning RCP-fit can effectively reduce channel fragment, but with more requests coming from more RCSTs, the effect of RCP-fit weaken. At this time the system change to use BFD algorithm to pack large scales of timeslots request. The time to change algorithm is chosen by the utilization of channel resource which is shown as Fig. 5.

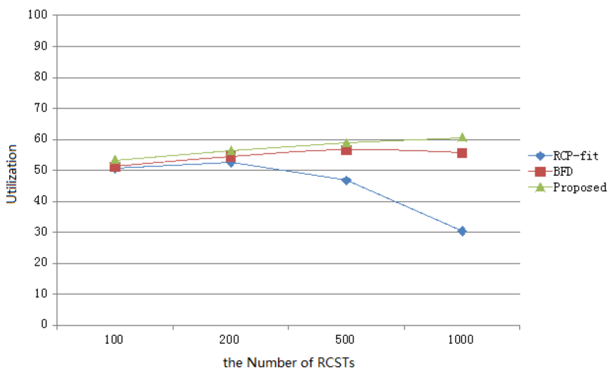

Figure 6. The average timeslots resources utilization

IV. Simulation

The system we apply here is described on the military satellite communication (MILSATCOM) Ref. [1] In this system, the total resource for a super frame (or a TBTP) consists of bandwidth B=48 and time T=72. Thus, all of the terminals share 3,456 timeslots (B•T) in the total system. The experiments have been executed over a standard laptop with an Intel Core 2 Duo CPU @ 2.4GHz and 6GB of RAM.

The simulation is set four groups with different numbers of terminals respectively as 100 RCSTs, 200RCSTs, 500RCSTs, 1000RCSTs. The simulation time of each group costs 120 minutes and every RCSTrandomly requests timeslots resources. The average timeslots resources utilization as a result of the simulation is shown as Fig. 6.

The experimental result shows that the RCP first-fit algorithm will decrease channel capacity utilization with the increase of numbers of terminals, and especially the performance of the 1000-terminals group fell sharply so that the debris rate is close to 70%, which accords with Ref. [5] that RCP-fit algorithm is only fit for a small amount of terminals. Through the employment of the BFD algorithm the average level of channel fragmentation is over 50% and the performance is less impacted than RCP-fit by increasing numbers of terminals, but because of the restrictions described before, the timeslots resources utilization rate still can not achieve 60%. Correspondingly, the performance of the proposed algorithm is the best of three algorithm and the utilization is over 60% when the terminal number is 1000. But as a fact that the assignment of timeslots is a 2D strip packing problem which is NP-hard, the fragmentation always exits and increase by terminal number. The Result shows that the proposed approach can effectively improve the utilization rate of timeslot resources in fixed MF-TDMA system and reduce the channel fragmentation which has better performance than BFD algorithm and RCP-fit algorithm by the increasing numbers of terminals. Thereby the proposed algorithm has more advantages at assignment of timeslot resources in MF-TDMA system.

V. Conclusion

This paper has shown the design and performance of a new heuristic to solve the resource-assignment problem on communications networks by integrating the RCP-fit and Best-Fit-Decreasing algorithms into assignment of timeslot resources within a fixed MF-TDMA system. In conjunction with the employment of the proposed algorithm, the network management system can overcome the aforementioned restrictions to the fixed MF-TDMA system and improve the utilization of limited timeslot resources. This algorithm is efficient in its approach of solving timeslots assignment problem, by adapting an existing Heuristic (BFDH) from the field of packing problems to achieve the communications networks resources management.

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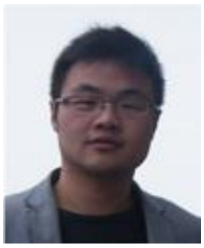

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