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Automated Telescope Scheduling

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Abstract. The Giant Metrewave Radio Telescope, commonly known as GMRT, is the world's largest low frequency radio telescope. Being a rare resource, efficient planning of GMRT is needed. Planning consists of scheduling a pre-selected large collection of scientific proposals up to half a year in advance. Scheduling becomes complex due to the variety of astronomical, equipment and logistical constraints. The goal is to schedule each observation to appropriate time slots so that constraints violation is minimized. We have developed a scheduler software named GSCHED to assist in scheduling and to increase the utilization of GMRT.

1. Introduction

Radio telescopes are used extensively by the scientific community for astronomical observations. Amongst the few radio telescopes available all over the world, GMRT is the world's largest low frequency radio telescope. GMRT operating frequencies are 150 MHz to 1420 MHz. The variety of observing modes enables it to make different kinds of observations [Jayaram Chengalur et al]. To efficiently schedule these observations is a challenging problem. Scheduling becomes complex due to the variety of constraints, like astronomical constraints, equipment constraints, logistical constraints, and people constraints. The challenge is to allocate each proposal to appropriate time slots, considering all the constraints. The first cut solution to the problem is obtained using linear programming and the solution is further repaired manually using heuristics, with the aid of a graphical user interface.

2. Literature Survey

Some work related to automated scheduling of other telescopes is described in the literature:

- LOFAR is the LOw Frequency ARray for radio astronomy. For the LOFAR scheduling problem, the potential use of evolutionary algorithms is examined [R. Grim et al]. The results state that valid schedules were not automatically generated. The best solution violated some of the constraints. In post processing, repairing of the already generated schedule to create a valid schedule was done.

- ROentgen SATellite (ROSAT) scheduling problem was modeled as a generalized assignment problem [J. Nowakovski et al]. Here, the problem was solved dropping the integrality constraint on the decision variables. The solution was improved using various heuristic approaches.

- For the Hubble Space Telescope [Miller et al], neural network and constraint satisfaction based techniques were used for scheduling. The repair heuristics were based on the neural network architecture.

From the literature survey, it is clear that the common strategy is to obtain a first cut solution using optimization techniques followed by repair using heuristic techniques. We adopt a similar approach for the GMRT scheduling problem. In the following sections we describe observations with GMRT, scheduling constraints, our model formulation and computational results.

3. Observations with GMRT

An astronomer submits a scientific observing proposal to GMRT. The proposal contains different sources to be observed, and the frequency band and integration time for each source. GMRT Time Allocation Committee short lists suitable proposals through peer review and allots suitable telescope time to them. The goal of scheduling is to allocate short listed proposals within the available time, such that constraint violation is minimized.

3.1. Scheduling Constraints

The following constraints were implemented in our scheduling model:
1] Each source has a particular rise and set time at the GMRT location. The source must be up during the scheduled time.
2] Sun is a strong emitter of radio waves. Thus while observing an object, the angular distance between the position of sun and target object should be more than 20 degrees.
3] Each astronomer may specify his/her preferred and non-preferred dates. All observations need to be allocated taking these date preferences into account.
4] The cycle must start with allocations for local observers first. Foreign observers are scheduled in the second month or later of the observing cycle.
5] Maintenance and system testing are done weekly. No observations can be scheduled during the maintenance time.

3.2. Problem Formulation and Description

The objective of GMRT scheduling problem is: To allocate the ‘n’ proposals to ‘m’ time slots, such that the overall cost of constraint violation is minimized. The time slot is an arbitrary time period used for individual proposal assignment. The cost is an arbitrary penalty assigned to each constraint violation. Cost indicates the level of importance of each constraint. For each constraint, observation feasibility with respect to each time slot is checked. If the constraint is violated by an observation in that particular time slot a penalty value corresponding to that constraint is assigned. Thus a cost matrix of size n proposals by m time slots is generated for each constraint. $Cset$ is the summation of all constraint matrixes.

$$Cset_{ij} = \sum_{k=1}^{N} C_{kij} \tag{1}$$

i	index for observation and $i = 1, 2, 3, \ldots, n$
j	index for time slot and $j = 1, 2, 3, \ldots, m$
k	index for constraint number and $k = 1, 2, 3, \ldots, N$
C_{kij}	cost of assigning i^{th} observation to the j^{th} time slot for the k^{th} constraint
X_{ij}	proportion of the j^{th} time slot allocated to i^{th} observation

Objective: To minimize Z

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{m} Cset_{ij} X_{ij} \tag{2}$$

Constraints:

$$\sum_{j=1}^{m} X_{ij} = T_i \quad for \quad all \quad i = 1, \ldots, n \tag{3}$$

$$\sum_{i=1}^{n} X_{ij} \leq 1 \quad for \quad all \quad j = 1, \ldots, m \tag{4}$$

$$X_{ij} \geq 0 \tag{5}$$

The primary resource constraint for GMRT scheduling is the amount of observing time available. The first equality constraint enforces allocation of the complete time requested by each observer. The second constraint states that the fraction of the time slot allocated cannot be more than one. The goal is to allocate each proposal to the time slot with the least constraint violation cost.

4. Computational Results

The proposal data delivered to us after GTAC review is as follows: Proposal code, which is a unique code (string) given to each scientific proposal, the sources to be observed, time requested for each observation, right ascension and declination of each source, the observer type: local (within India) or foreign, preferred and not preferred dates by the astronomer. Some of the configurable input details required for scheduling other than the proposal data are as follows: scheduling cycle start and end date, date from which foreign observer can be allocated, maintenance and testing: start time and end time, etc.

A generalized program was developed in Fortran 90 which generates the objective coefficient matrix and constraint coefficient matrix for the given input data. We have used SLPRS subroutine in IMSL for solving the linear programming problem. The values of the decision variables are converted into readable format and various output analyses are done. In most of the cases, observations are scheduled at completely feasible slots. In the few cases where constraints are

Figure 1. Section of a GMRT schedule generated by the GSCHED software.

violated, we find that only the soft constraints are compromised. There are two problems associated with our linear programming solution, namely an observation may get split into more than one slot and observations of a single proposal are not scheduled contiguously. To tackle these problems, we automatically flag the observations/proposals which are most damaged. These are then 'repaired' manually using an intelligent graphical interface.

5. Summary

GSCHED was used by the GMRT planning and scheduling team for generating the observing schedules for GMRT Observing Cycle 15 (Figure 1). The use of GSCHED has helped speed up the process and optimally utilize telescope time. The concept of including all the practical constraints in cost matrix makes it possible to handle many real world scheduling problems. This concept was also utilized in other scheduling projects, for example: Database Migration, Project allocation to students, etc. Given the generic nature of our approach, we believe that GSCHED will be useful in scheduling of other telescopes too.

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