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EVALUATING SPACE NETWORK (SN) SCHEDULING OPERATIONS CONCEPTS THROUGH STATISTICAL ANALYSIS

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ABSTRACT

The Network Control Center (NCC) currently uses the NCC Data System (NCCDS) to schedule customer spacecraft communication requests for the Space Network (SN). The NCC/Request Oriented Scheduling Engine (NCC/ROSE), which implements an operational concept called flexible scheduling, is being tested as a potential replacement for the NCCDS scheduler in an effort to increase the efficiency of the NCC scheduling operations. This paper describes the high fidelity benchmark tests being conducted on NCC/ROSE, the evaluation techniques used to compare schedules, and the results of the tests. This testing will verify the increases in efficiency and productivity that can help the NCC meet the anticipated scheduling loads well into the next century.

INTRODUCTION

The SN provides communication and tracking services to low earth orbiting spacecraft, such as the shuttle and Hubble Space Telescope (HST). These services are provided via two operational geosynchronous Tracking and Data Relay Satellites (TDRSs) and a ground terminal in White Sands, New Mexico. The NCC at the Goddard Space Flight Center (GSFC) is responsible for the management of SN resources, including the resource allocation function. Currently, customers submit relatively inflexible requests for communications and tracking support to the NCC (e.g., 20 minutes of S-band single access (SSA) support on the east relay satellite between 1200 and 1230) via Schedule Add Requests (SARs). However, customers generally have more flexibility than they are capable of expressing in the SAR messages. When scheduling conflicts occur, the NCC scheduler calls the customer(s), and using their true flexibilities, negotiates a resolution. Due to security restrictions, the NCC is prohibited from releasing information concerning the composite schedule to the general customer population, making conflict resolution even more difficult.

With projected increases in the network loading by the end of the century, extensive manual conflict resolution will not be viable. Therefore an operational concept called flexible scheduling is being evaluated (Moe, et al., Sept. 1993). Under this concept, customers are capable of expressing their full range of flexibilities in their request messages. Flexibilities to be included in the messages are: variable service and event durations, flexible service and event start times, open resource selection between equivalent resources, and backup or alternative event specification. In addition, flexible requests may express the recurring nature of requests (e.g., a 15 to 20 minute SSA support on any relay satellite once every orbit). With flexible requests, the scheduling system has more latitude in how to schedule a request and avoid or resolve conflicts in an automated fashion. An added benefit is that conflicts are resolved as they are encountered, and not after other lower priority requests have been processed.

The Request-Oriented Scheduling Engine (ROSE) was designed as a general scheduling system capable of performing flexible scheduling (Weinstein, 1993). ROSE uses a scheduling language called the Flexible Envelope Request Notation (FERN) as an input format (Tong, 1993). Both FERN and ROSE are being adapted for use on the SN scheduling problem. ROSE is a candidate for replacing the current scheduling system and FERN is one of several candidate formats for replacing the current SAR messages (Meeks, 1994).

HIGH FIDELITY BENCHMARK

Part of the technology transfer process involves high fidelity benchmark tests to demonstrate the feasibility of using the NCC version of ROSE (NCC/ROSE) and the flexible scheduling concept under realistic SN scheduling scenarios (Moe et al, Nov. 1993). The benchmark tests are being conducted in two phases.

The purpose of Phase I tests is to verify that NCC/ROSE can perform SN scheduling. Specifically, NCC/ROSE must not schedule any requests in conflict based on SN scheduling constraints, and must not unnecessarily decline any request that could be legally scheduled. Phase I tests compare a schedule produced by the NCCDS to an NCC/ROSE generated schedule (neither schedule has undergone manual conflict resolution). A week of real requests submitted during a shuttle mission were used as inputs to both schedulers. The SARs were translated into FERN for input into NCC/ROSE. These requests reflect the current level of flexibility available in the electronic messages. Fig.1 illustrates the methodology used for the Phase I tests. Schedule run time, minutes of support scheduled, and number of events scheduled are the primary comparison metrics between the two schedules. The NCC/ROSE schedule also is converted back into inflexible requests and these requests are processed by the NCCDS. If the NCCDS does not reject any of these requests, then the NCC/ROSE schedule is a legal one.

The purpose of the Phase II tests is to evaluate the value added of flexible scheduling. For these tests, most of the customers capable of using flexible scheduling were interviewed in order to define their flexible requests. Flexible versions of the requests submitted for the test week were then generated. In order to support open resource selection and request recurrence, orbital data for the test week for these spacecraft were also collected as operational scheduling aids. In general, this data specified when the spacecraft could view which relay satellite, but also indicated other constraints that may be relevant to the requests.

The NCC/ROSE schedule generated with flexible requests is then compared to the NCCDS schedule after manual conflict resolution (Fig.2). The NCC/ROSE schedule again is converted into requests and submitted to the NCCDS for verification of a conflict free schedule. In addition, customers are interviewed to ensure that the conflict resolution options implemented by NCC/ROSE were acceptable. At the time of this writing, Phase II testing was ongoing.

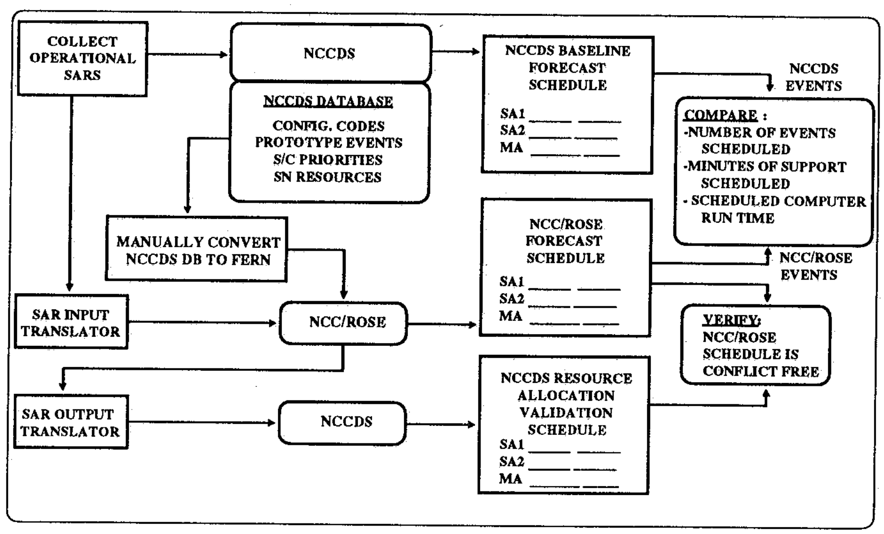

Fig. 1 - Phase 1 Methodology

NCC/ROSE can use two different algorithms to generate a schedule. Comparisons to the NCCDS are being made using both algorithms for Phase I and Phase II.

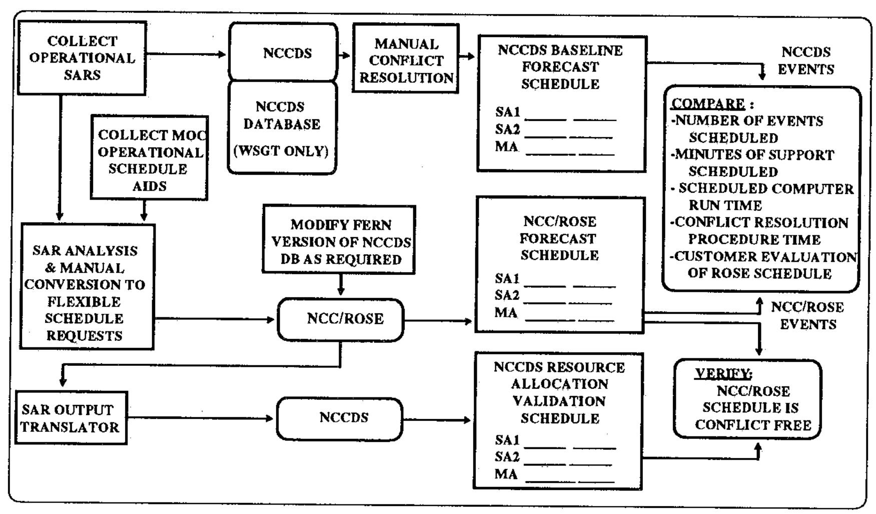

Fig. 2 - Phase II Methodology

EVALUATION TECHNIQUE

The evaluation method organizes the details of the comparisons between the NCCDS and NCC/ROSE schedules (Fig.1 and Fig.2). In addition, it characterizes the schedule differences via statistical evaluation metrics. When presented graphically, the metrics provide a composite view of schedule structure differences for all the SN customers and identifies anomalies for detailed analysis. Fig.3 shows an overview of the method used to make the comparisons.

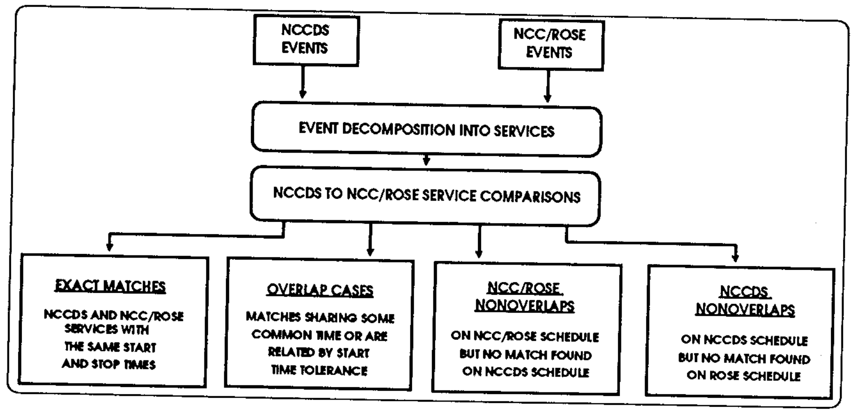

Fig. 3 - Schedule Comparison Method

The comparison method relies on the state transition diagram representation of the schedule shown in Fig.4 as a basis for generating the evaluation metrics. Each instance of a scheduled service is characterized by an ON transition state with an associated duration. The schedule period contains N instances.

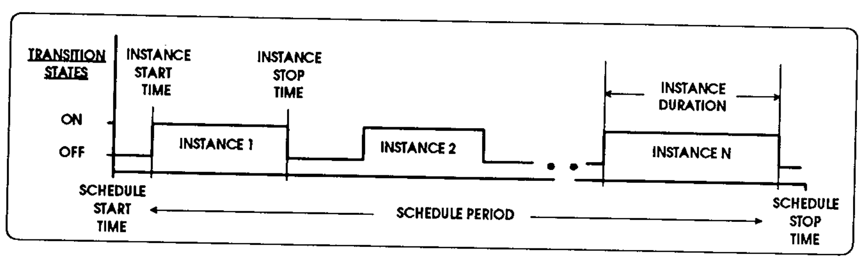

Fig. 4 - Representation of a Schedule

The NCCDS schedule consists of a series of events for all customers like the example HST events shown at the top of Fig.5. Each event contains one or more services. Event decomposition results in sets of customer service instances (bottom of Fig.5).

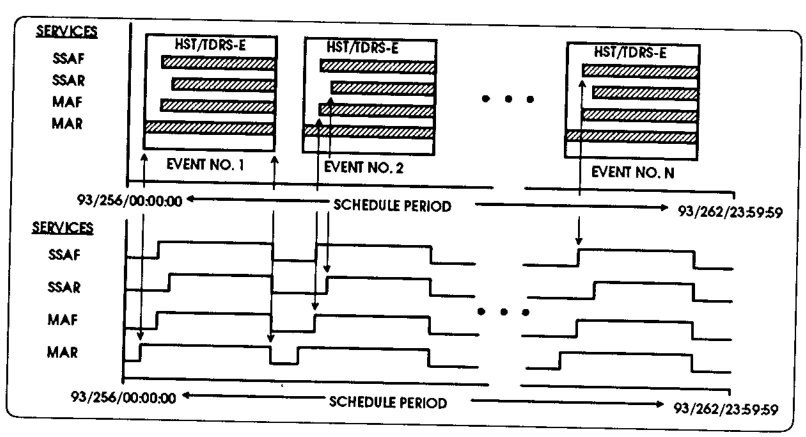

Fig. 5 - Event Decomposition into Services

Fig.6 shows the results of decomposing all of the NCCDS events into individual user resource schedules. The customer name, TDRS, and the TDRSS communication service requested identifies each schedule (e.g., STS, TDRS-E, SSAF).

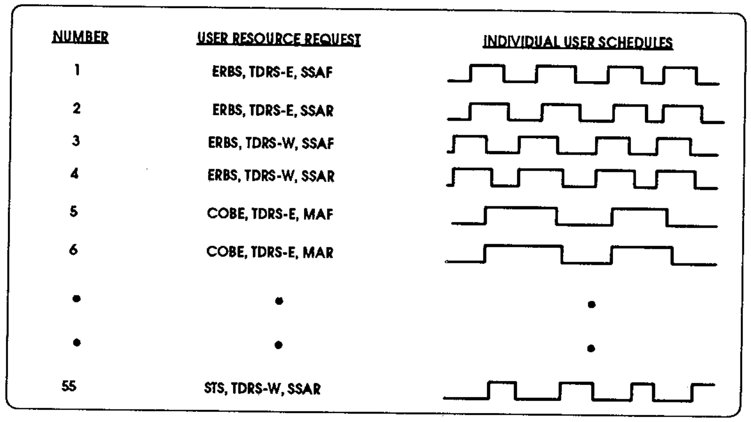

Fig. 6 - Decomposition by User Resource Requests

Fig.7 shows the criteria used in comparing the instances on the 55 NCCDS and NCC/ROSE user resource request schedules. Fig.7a through Fig.7c depict different match criteria while Fig.7d shows the no match criterion. Both overlap cases are the result

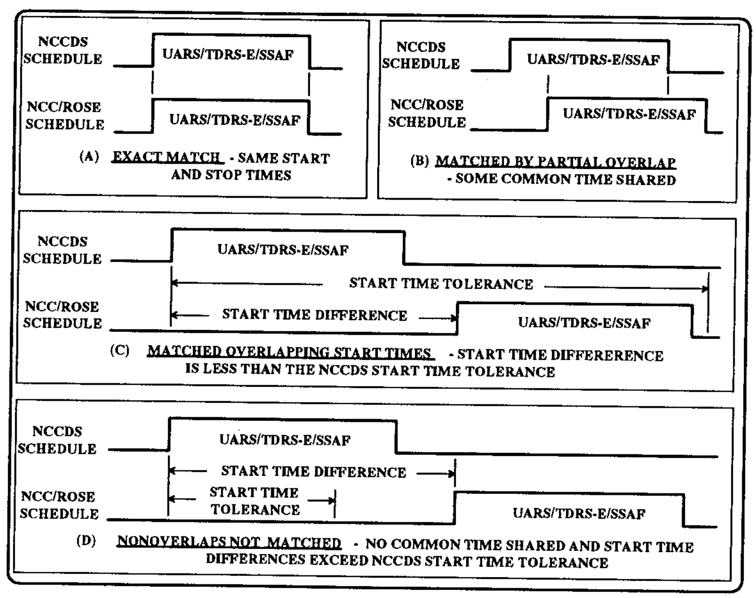

Fig. 7 - Service Instance Comparison Criteria

of exercising the NCCDS start time tolerances that allow an event to start anywhere in a specified time interval. Due to the open resource selection option, Phase II testing may produce overlap instances outside the SAR specified start time tolerance limits.

Instance counts and instance durations (Fig.4) form the basis of the evaluation metrics for each user resource request. Bar graphs provide a simultaneous view of all the customer metrics. The 55 user resource requests (Fig.6), listed in order of increasing priority, form the abscissa of each graph. The percentage of the NCC/ROSE instances matching those on the NCCDS schedule forms the ordinate. Vertical lines separate the eight SN customer metric groups. The bar graphs presented below in Figs.8 through 12 illustrate Phase I results. Each bar graph contains the comparisons between the NCCDS results and NCC/ROSE earliest possible and lookahead algorithm results.

Fig.8 presents the results of the exact match comparisons (Fig.7a) indicating that lower priority users are less likely to have exactly matching instances than the high priority users.

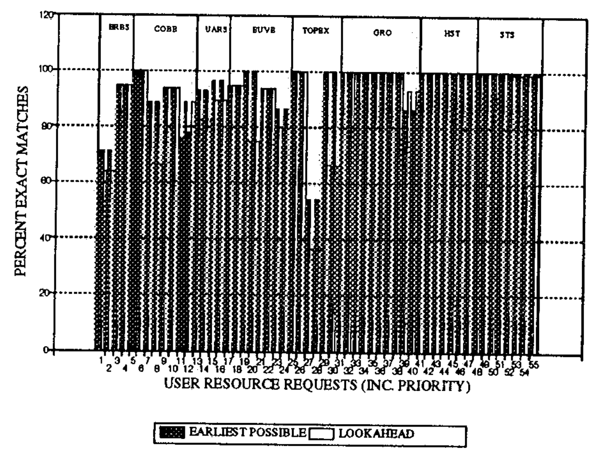

Fig. 8 - Exact Match Comparison Metrics

Fig.9 presents an assessment of instance start time differences for the overlap case results (Fig.7b and Fig.7c).

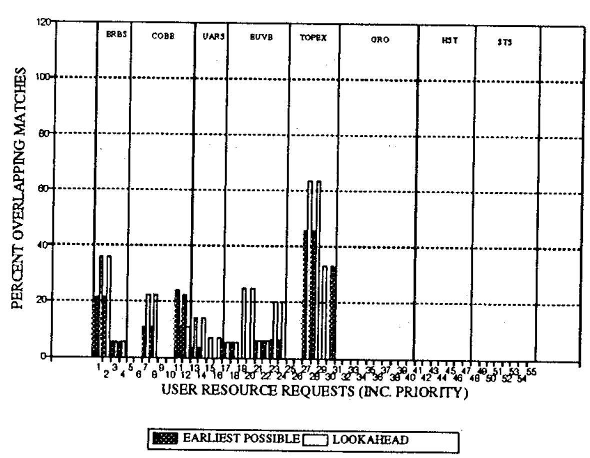

Fig. 9 - Overlap Comparison Metrics

Fig.10 shows the percent average start time difference metric for each user resource request. The ratio of average start time difference (Figs.7b and 7c) of all instances divided by the total of all the NCCDS instance durations (Fig.4) for a given user resource request forms the percent average start time difference metric. The average NCC/ROSE start time difference is either positive, negative, or zero, corresponding to an average late, early, or equal start time with respect to the NCCDS schedule, respectively. Fig.10 shows that the NCC/ROSE earliest possible algorithm scheduled on average all of the overlap start times earlier than the NCCDS. The lookahead algorithm realized both leading and lagging average start time differences.

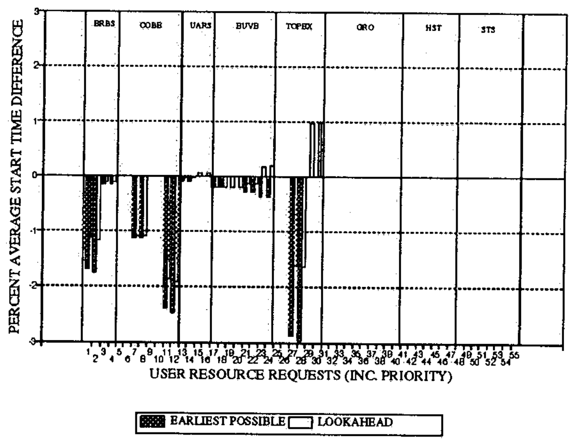

Fig. 10 - Average Start Time Difference Metrics

Fig.11 presents a composite of all the matching cases (Figs.7a, 7b, and 7c). This graph shows that the lower priority customers are more likely to have instances of a resource request dropped than high priority customers for both NCC/ROSE algorithms.

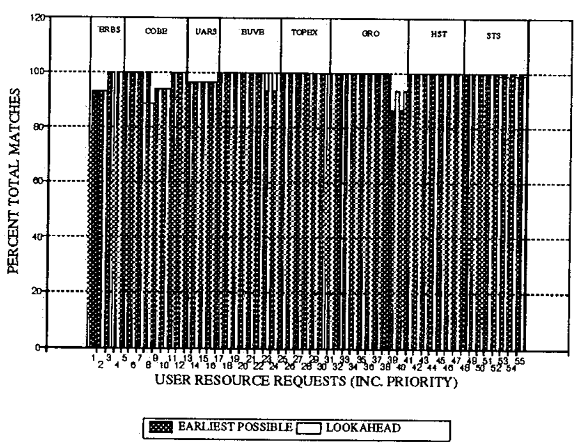

Fig. 11 - Exact and Overlapping Match Metrics

Fig.12 compares all of the NCC/ROSE scheduled instances (Figs.7a through 7d) to the NCCDS matching instances. COBE resource requests 11 and 12 for the lookahead algorithm exceed 100%, indicating that NCC/ROSE scheduled more instances than the NCCDS.

Replacing instance counts with instance durations (Fig.4) yields an analogous set of graphs corresponding to Figs. 8, 9, 11, and 12. The graphs compare the total time scheduled

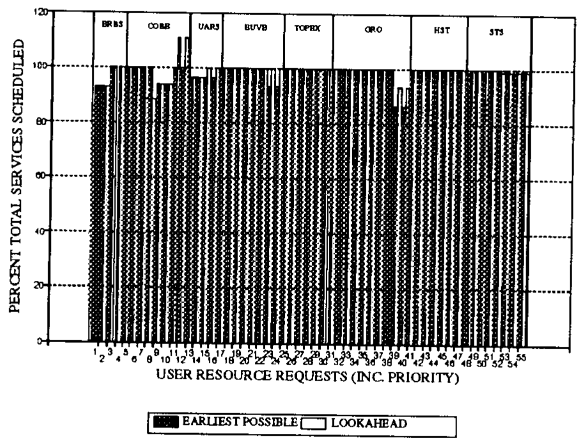

Fig. 12 - Total Instances Schedule Metrics

between the NCCDS and NCC/ROSE for each user resource request. Since the instance durations are not flexible for a given Phase I user resource request, the total service duration data is nominally proportional to the total instance data. This resulted in a set of percent time scheduled graphs that have virtually identical values in comparison to the instance scheduled graphs presented above. Flexible scheduling with variable instance durations will produce different results.

Phase II uses flexible requests for six of the eight SN customers. As such, the number of exact matches will decrease as the result of increased variability in instance start times and the added variabilities of instance duration, TDRS selection, and service selection. A shift from a highly populated exact match profile (Fig.8) to that dominated by large partial and nonoverlapping instance populations will accompany the transition from Phase I to Phase II testing.

PHASE I RESULTS

Table 1 shows a summary of the results of the NCCDS and NCC/ROSE scheduling operations for the earliest possible and lookahead algorithms (Kwadrat, 1994). NCC/ROSE scheduled the total number of events and total time within 1% of the NCCDS results for both algorithms.

Fig.13 shows two examples that illustrate the sources of the differences between the NCC/ROSE earliest possible and the NCCDS results presented in Table 1.

Fig.13a shows that an early EUVE start time selection by NCC/ROSE results in a conflict with a COBE instance. EUVE has a start time tolerance, COBE does not. The NCCDS uses the EUVE start time tolerance and the COBE instance is scheduled. Fig.13b shows the difference in antenna selection algorithms. NCC/ROSE places an HST instance on SSA antenna 1. The NCCDS placed the HST instance on SSA antenna 2. The NCC/ROSE schedule omits the inflexible COBE request due to a conflict with the HST and shuttle events, while the NCCDS places it on the schedule.

Table 1 - Summary of Phase I Comparisons

NCCDS TO NCC/ROSE COMPARISONS	ALGORITHM	
	EARLIEST POSSIBLE	LOOKAHEAD
TOTAL NCCDS EVENTS SCHEDULED BY NCC/ROSE	99.4%	99.2%
TOTAL NCC/ROSE EVENTS SCHEDULED BY NCCDS	100.0%	99.8%
TOTAL NCCDS TIME SCHEDULED BY NCC/ROSE	99.6%	99.1%
NCCDS RUN TIME * (MINUTES)	45.2	45.2
NCC/ROSE RUN TIME ** (MINUTES)	5.3	9.0

* INCLUDES LOADING AND SAVING ALL CONFIGURATION CODE PARAMETERS

** INCLUDES LOADING BUT NOT SAVING ONLY THOSE CONFIGURATION CODE PARAMETERS REQUIRED FOR SCHEDULING (10%)

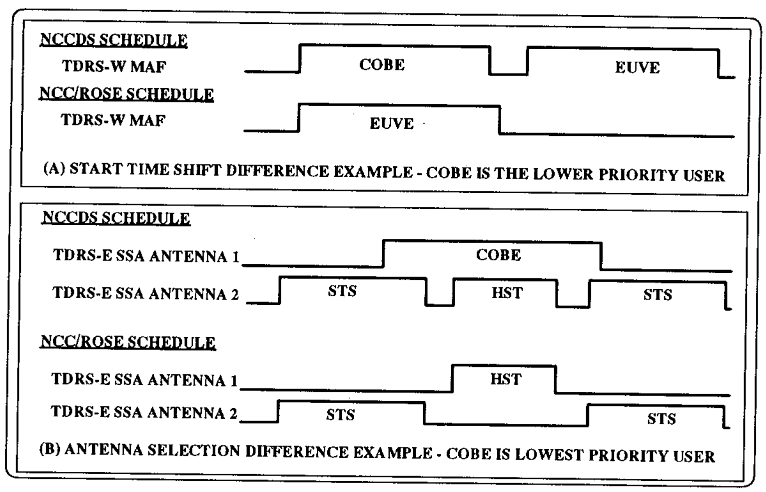

Fig. 13 - Earliest Possible Difference Examples

Heuristic algorithmic differences also account for differences in the lookahead algorithm results shown in Table 1. Fig.14 shows two examples that demonstrate the impact of heuristic differences. Fig.14a shows that NCC/ROSE used a UARS start time tolerance to permit the scheduling of ERBS.

The NCCDS elected not to shift the UARS instance, resulting in a rejection of the ERBS instance. Fig.14b shows COBE being scheduled by the NCCDS but not by NCC/ROSE. EUVE is the only event with a start time tolerance. NCC/ROSE chose not to use the EUVE start time tolerance in order to schedule COBE. In addition, the NCC/ROSE lookahead uses a resource utilization algorithm to select antennas based on current load assessments. The NCCDS does not use this algorithm. This difference produced scheduling results similar to those shown in Fig.13b.

A SUN Sparc 10 Workstation and a UNISYS mainframe are the host processors for NCC/ROSE and the NCCDS scheduling systems, respectively. The run times given in

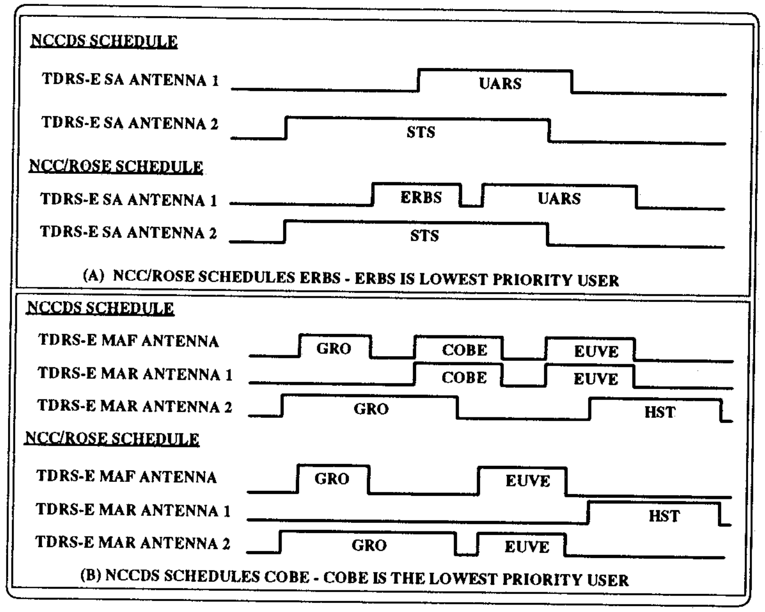

Fig. 14 - Lookahead Difference Examples

Table 1 are batch mode results. Configuration code processing differences between the NCCDS and NCC/ROSE are in part responsible for the run time differences.

PHASE II RESULTS

Phase II testing is in progress. The ERBS and COBE flexible schedule requests are operational. Due to a delay in the receipt of scheduling aids, the remaining six customers currently use the Phase I requests in the scheduling process. UARS, EUVE, GRO, and HST will also have flexible requests by the completion of Phase II testing.

Phase II schedules for the NCCDS included manual conflict resolution. There was an increase of 22% and 10% for ERBS and COBE instances, respectively, over the Phase I NCCDS schedule. Table 2 presents a summary of the preliminary Phase II ERBS and COBE results since they alone show the added effects of flexible requests on the NCC/ROSE schedule.

Table 2 - Phase II Preliminary Results

COMPARISONS	ERBS	COBE
NCC/ROSE TO NCCDS TOTAL INSTANCES SCHEDULED	80%	90%
NCC/ROSE TO NCCDS TOTAL TIME SCHEDULED	73%	90%

Fig. 15 shows the percent total NCCDS instances scheduled by NCC/ROSE for ERBS and COBE resource requests using the earliest possible algorithm. Fig.15 is the Phase II counterpart of Fig.12. Fig.15 contains MA and SSA ERBS resource requests. All of the Phase I ERBS resource requests were SSA. The NCCDS manual conflict resolution activities (Fig.2) and NCC/ROSE flexible service requests are responsible for the Phase II ERBS MA resource request metrics.

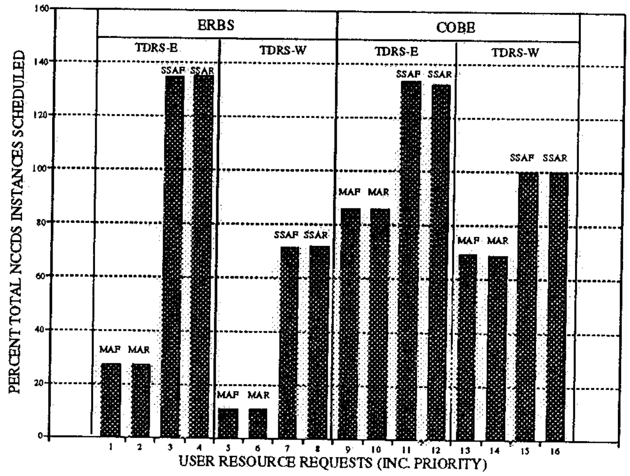

Fig. 15 - Total Instances Schedule Metrics

The number of ERBS and COBE SSA resource request instances have increased for both the NCCDS and NCC/ROSE results in making the transition from Phase I to Phase II. Fig.15 shows that for COBE at least NCC/ROSE appears to automatically choose, via flexible TDRS and service selections, more SSA scheduling on the alternate TDRS (the preferred alternative) in place of some of the MA selections made during NCCDS manual conflict resolution. The results for ERBS are less obvious and need further study.

Exactly matching instances form less than 1% of the Phase II ERBS and COBE comparisons. The Phase I exact matches (Fig.8) exceed 60% for both customers. This shows that the introduction of Phase II flexible requests significantly alters the NCC/ROSE schedule structure in comparison to the Phase I results.

As far as execution time is concerned, over 60 hours of NCCDS operator time were spent on manual conflict resolution. An NCC/ROSE run with flexible requests takes on the order of 5 minutes.

SUMMARY

The Phase I results verify that NCC/ROSE knows how to schedule SN services. All services that could be, were scheduled legally. However, the scheduling algorithms in NCC/ROSE are not quite as efficient as the algorithm in the NCCDS. Some improvements would probably be required prior to operational use.

The preliminary Phase II results are very promising. It was not expected that NCC/ROSE could perform conflict resolution as well as an NCCDS operator, but it might be able to resolve a significant portion of conflicts in an automated fashion. It appears that this is so. It is hoped that these findings hold up after all appropriate customers are switched to the flexible requests.

The process of performing the tests has itself provided several valuable lessons. First, this effort required the cooperation of many different organizations, both government and contractor. With proper coordination, this collaboration has gone quite smoothly.

Still many technical stumbling blocks were encountered. The most cumbersome of which was dealing with the multitude of data formats and media for the operational scheduling aids for each customer. A single standardized interface is required prior to operational implementation of the flexible scheduling concept.

An important lesson learned was that it is more difficult than it appears to create a recurring flexible request. For flexible scheduling to work in an operational environment, it is critical that customer's have the proper tools to create and test their recurring flexible requests prior to submission to the NCC.

For flexible scheduling to be truly successful, the SN customer community must also change their mode of operations to take advantage of the enhancements. The more customers that submit flexible requests, the more benefit will be reaped by the entire SN community. And as the loading on the network increases, the more profitable the flexible scheduling strategy becomes.

ACKNOWLEDGMENTS

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