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THE AUTOMATED CONFLICT RESOLUTION SYSTEM (ACRS)

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ABSTRACT—The Automated Conflict Resolution System (ACRS) is a mission-current scheduling aid that predicts periods of mutual interference when two or more orbiting spacecraft are scheduled to communicate with the same Tracking and Data Relay Satellite (TDRS) at the same time. The mutual interference predicted has the potential to degrade or prevent communications. Thus the ACRS system is a useful tool for aiding in the scheduling of Space Network (SN) communications.

I. INTRODUCTION

NASA's Network Control Center (NCC) schedules communications of orbiting spacecraft through the Tracking and Data Relay Satellite System (TDRSS). Since most TDRSS users operate with the same polarization and at the same or similar frequencies, there is a potential for communications "mutual interference" between users. Also known as self-interference, mutual interference has the potential to occur when two or more spacecraft are communicating with the same TDRS at the same time. Naturally, as the number of concurrently orbiting user spacecraft increases, so does the probability for mutual interference.

When mutual interference occurs, it has the potential to delay signal acquisition, cause data degradation, and even loss of lock for a user spacecraft. Thus it is critical, especially during manned flight missions, for the communications schedule to avoid periods of potential mutual interference. In order to mitigate the interference, the NCC created a requirement for a Network tool that predicts mutual interference.

Stanford Telecom developed ACRS to support satellite communications scheduling by NASA's NCC. ACRS is a mission-current tool designed to analyze communications problems arising when two or more orbiting spacecraft are scheduled to communicate with the same TDRS at the same time. ACRS provides an exhaustive in-depth look at the mutual interference potential between the many user spacecraft missions currently in operation. The detailed output charts produced, along with the suggested interference mitigation techniques, provide the NCC with an accurate tool for mission-current user scheduling and mutual interference prediction and mitigation.

The NCC uses ACRS outputs on a weekly basis to predict potential spacecraft mutual interference and on a daily basis during critical Shuttle mission support. A newly developed implementation of ACRS is currently undergoing operational prototype testing within the NCC Operations Control Room (OCR). This classified version of the software incorporates the actual NCC communications schedule and will be utilized in an ongoing fashion by the NCC operators to accurately predict potential interference periods during scheduling operations and mission planning. It is the analysis contained in this NCC OCR version of ACRS that is detailed in this paper.

II. THE ACRS SYSTEM

ACRS, as implemented within the NCC OCR, runs on an HP 9000 735 Unix workstation. The workstation is connected, via an eavesdropping LAN Probe, to the NCC Inter-Segment Network (ISN). This network connects the Flight Dynamics Facility to the NCC and carries all relevant SN schedule and orbital data in a real-time manner as it is generated. Using the LAN Probe, ACRS continually extracts the current orbital and schedule data and stores it in a specialized database system for later use. The data stored can then be used in the performance of ACRS analyses on past, present, or future mission data.

Specifying an ACRS analysis is done via a user-friendly graphical user interface (GUI) designed to the specifications of the NCC operators who use the system. Figure 1 shows a typical input screen from the ACRS analysis system. Whereas the specifics of operating ACRS will not be discussed in this paper, below is a brief listing of some of the many functions available to the ACRS operator. For details on how to operate ACRS in the NCC OCR, see [3]:

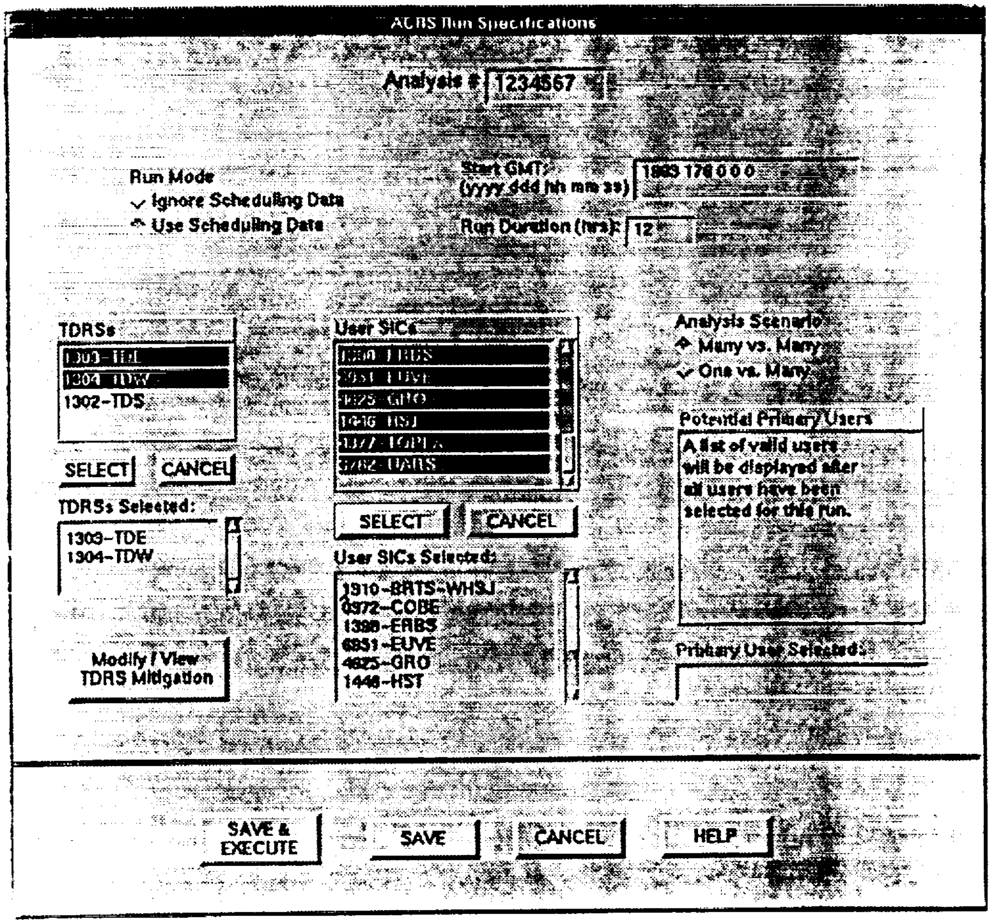
- Specify and run an ACRS analysis.
- View a list of previously executed ACRS analyses.
- View the outputs from any previously executed ACRS analysis.
- Backup the ACRS databases to tape.
- Restore the ACRS databases from tape.
- Backup ACRS analyses to tape.
- Restore an ACRS analysis output from backup tape.
- View/modify the ACRS orbital and SN schedule databases.
- Validate the data within the ACRS databases.

III. ANALYSIS OVERVIEW

ACRS provides a clear picture of communications interference caused by and to other orbiting satellites, calculating all periods of compromised return link TDRS communications for all users. In predicting impeded communications, ACRS analyzes three areas of operation:

- Data degradation
- Acquisition delay, and
- Loss of bit synchronization.

In order to accommodate mission-current analysis for the NCC and Payload Operations Control Center (POCC) distribution, ACRS is designed to process a large number of *interference combinations* in a short period of time. An interference combination is comprised of a pair of user communication links, one called the *desired link*, and the other the *interfering link*. ACRS is capable of rapidly processing all possible interference combinations of desired and interfering links. Interference periods are calculated for each communication link of each operating TDRSS user space-



Analysis # 1234567

Run Mode
✓ Ignore Scheduling Data
◆ Use Scheduling Data

Start GMT: (yyyy ddd hh mm ss) 1993 176 0 0 0

Run Duration (hrs): 12

TDRSs
1303-TDE
1304-TDW
1302-TDS

TDRSs Selected:
1303-TDE
1304-TDW

User SICs
1390-ERBS
6951-EUVE
4825-GRO
1446-HST
1377-TOPEX
3782-UARS

User SICs Selected:
1910-BRTS-WHSJ
0972-COBE
1390-ERBS
6951-EUVE
4825-GRO
1446-HST

Analysis Scenario
◆ Many vs. Many
✓ One vs. Many

Potential Primary Users
A list of valid users will be displayed after all users have been selected for this run.

Primary User Selected:

Figure 1. ACRS Analysis Screen

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craft versus all other links of all other operating TDRSS user spacecraft.

The inputs for ACRS include:

- Link characteristics for all of the communication links to be analyzed.
- Accurate orbital and SN schedule information for each user.
- TDRS receive antenna patterns.
- Analysis-specific run parameters.

The ACRS analysis involves a three-step process:

1) First, the required discrimination is calculated for each interference combination based on the worst case scenarios. This value indicates the necessary power differential for the uninterrupted operation of the desired link when the desired and the interfering links are in the same line of antenna boresight from TDRS.
2) This value is then used to calculate the interference threshold angle which is the computed difference between the TDRS-to-interferer and TDRS-to-desired look angles.
3) Finally, the databased interference threshold angles for each interference combination are compared on a timepoint-by-timepoint basis with the actual inter-user angles (see Figure 2) to produce an accurate summary of possible mutual interference between user links. When the actual inter-user angle is less than the interference threshold angle, interference is likely to occur.

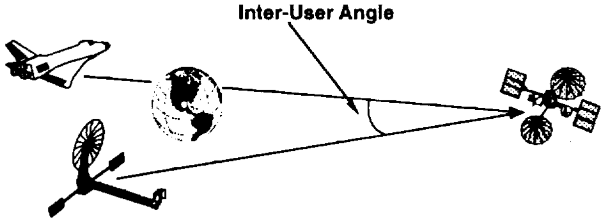


Figure 2. Inter-User Angle

Since ACRS has access (via the ISN) to the actual communications schedules, ACRS has the option to utilize these schedules in its mutual interference predictions. If the operator selects to consider the communications schedule data, ACRS will only predict mutual interference if both the desired and interfering user are scheduled to communicate with the same TDRS at the same time (subject to the above inter-user angle criteria). Alternately, if the communications schedule data is not used, ACRS will predict mutual interference if both the desired and interfering users are simply line-of-sight closest to the same TDRS (subject to the above inter-user angle criteria). Using the schedule data has the effect of dramatically reducing the predicted interference periods.

Each of the above analysis steps is depicted in Figure 3 and described in more detail in the sections below.

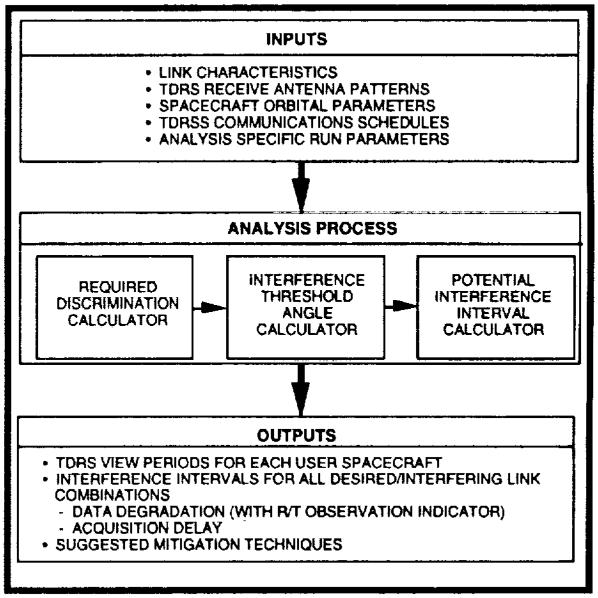


Figure 3. ACRS Analysis

IV. DETAILED ACRS ANALYSIS PROCESS

A. Calculation of Required Discrimination

The first step in the ACRS analysis entails determining the amount of discrimination required to avoid interference for each pair of desired and interfering links. This value is used as input to the Interference Threshold Angle Calculator. ACRS is presently set up for the calculation of three types of required discrimination thresholds. These thresholds are necessary to avoid:

1) Data degradation
2) Acquisition delay, and
3) Loss of bit synchronization.

For threshold calculations, desired channel energy-to-noise density (E_S/N_O) or equivalently, probability of error (P_e), is determined from requirements documents and Communications Link Analysis and Simulation System (CLASS, NASA GSFC Code 531.1) analyses that correspond to operation of the desired channel with zero margin. The actual desired channel E_S/N_O at the receiver is determined from CLASS link budgets. For each combination of links, the interfering power level, P_i/N_O, is then found that results in the desired channel operation at the zero margin level. The difference between the actual interfering power level and P_i/N_O is the required discrimination that would enable the desired channel to operate without interference. The actual interfering power level is determined from CLASS link budgets.

CLASS link budgets are updated regularly. The desired user's link budget includes losses due to pointing, Radio Frequency Interference (RFI), and hardware distortion that reflects the age of the TDRS satellite. Hardware distortion and pointing losses are not included in the interfering user's link budget thus resulting in a worst case interference scenario. Free space loss is calculated assuming the desired and interfering satellites are at the maximum distance from TDRS. Since the actual satellite geometries vary, the free space loss will only be accurate to within about .5 dB.

ACRS uses analytic and simulation packages to search for the interfering power level (P_i/N_O) that results in the P_e corresponding to desired channel operation with zero margin. Since hardware distortion losses are small (approximately .5 dB), the communications channel is assumed to be linear. With this assumption, a characteristic function approach can be used to find P_i/N_O. P_e is calculated from the characteristic function of the signal with interference and noise. The program searches for the interfering power level (P_i/N_O) that results in the P_e that corresponds to desired channel operation with zero margin.

In the case of data degradation, zero margin corresponds to P_e = 10-5 (10-4 for Shuttle S-band). P_e is calculated by integrating the characteristic function of the desired signal with mixed interference signal and noise, over all phases of the interfering signal. Averaging over all phases of the interfering signal is a reasonable approximation to the actual interference situation where different Doppler rates result in a time-varying phase of the interference signal relative to the desired signal.

For acquisition delay and bit synchronization, simulation and specified values from requirements documents are used to determine the desired carrier-to-noise density that results in operation with zero-dB margin. The characteristic function approach is then used to determine the P_i/N_O that results in desired channel operation with zero margin.

TDRSS signals are either BPSK or QPSK modulated. The I- and Q-channels of the desired signal are analyzed separately, whereas both I and Q channels of the interferer are included in the characteristic function. The characteristic function includes averaging of all phases of the interfering signal relative to the desired signal and also averaging the interfering chip polarities using Bernoulli trials. The channel noise is assumed to be Additive White Gaussian (AWG).

After simplifying, the characteristic function becomes

$$C(u) = e^{-u^2/4 + ju\sqrt{\frac{E_S}{N_0}}}$$

$$\frac{1}{2\pi}\int \cos\{u\,A_I\cos(\theta)\}\,\cos^{N_I}\{u\,B_I\cos(\theta)\}\,\sin\{u\,A_Q\cos(\theta)\}\,\sin^{N_Q}\{u\,B_Q\cos(\theta)\}\,d\theta$$

where

$\frac{E_S}{N_0}$ = energy-to-noise density of the desired symbol (I- or Q-channel

$$N_I = \left\langle\frac{T_S}{T_I}\right\rangle$$

The brackets indicate a floor function with the fraction rounded to the lowest integer.

T_S = the symbol duration of the desired (I- or Q-) channel.

T_I = interfering signal, I-channel, chip duration. If the desired signal is PN modulated, the interfering chip duration is the smaller of the interferer symbol duration and the desired PN rate.

T_Q = interfering signal, Q-channel, chip dura-

$$N_Q = \left\langle \frac{T_S}{T_Q} \right\rangle$$

tion.

= effective amplitude of the I-channel chip,

$$A_I = \sqrt{\frac{E_I}{N_0}\frac{T_I}{T_S}} \;;$$

interfering with the desired symbol.

= effective amplitude of the Q-channel chip,

$\frac{E_I}{N_0}$ = energy-to-noise density of an interferer I-channel chip.

$$A_Q = \sqrt{\frac{E_Q}{N_0}\frac{T_Q}{T_S}} \;;$$

interfering with the desired symbol.

= fractional part of an I-channel chip, inter-

$\frac{E_Q}{N_0}$ = energy-to-noise density of an interferer Q-channel chip.

$$B_I = \sqrt{\frac{E_I}{N_0}\frac{T_S}{T_I}} \left(\frac{T_I}{T_S} - N_I\right) \;;$$

fering with the desired symbol.

= fractional part of a Q-channel chip, interfer-

$$B_Q = \sqrt{\frac{E_Q}{N_0}\frac{T_S}{T_Q}} \left(\frac{T_Q}{T_S} - N_Q\right) \;;$$

ing with the desired symbol.

The total interference power, P_i/N_0, is related to E_I/N_0 and E_Q/N_0 by
where

$$\frac{E_I}{N_0} = \frac{P_i\,T_I}{N_0}\left(\frac{P_I}{P_i}\right)$$

$$\frac{E_Q}{N_0} = \frac{P_i\,T_Q}{N_0}\left(\frac{P_Q}{P_i}\right)$$

P_I = I-channel power of the interferer.

P_Q = Q-channel power of the interferer.

The characteristic function above assumes that the interference is tuned to the same frequency as the desired signal. If the interfering signal is off-tuned from the desired signal, then filtering may significantly reduce the interfering signal power. The interfering power that is not filtered is assumed to be centered at the carrier frequency of the desired signal.

TDRSS signals are either uncoded, 1/2 or 1/3 rate convolutionally coded. Using the characteristic function, the P_e can be determined for each of these cases. In the uncoded case the P_e is given by

The inner integral is a Fourier transform that is

$$P_e = \int_{-\infty}^{0}\int_{-\infty}^{\infty} C(u)\, e^{j u z}\, du\, dz$$

used to change the characteristic function into a density function. The outer integral is used to determine the Pe from the density function.

In the coded case, the decoder is assumed to consist of an eight level quantizer and Viterbi decoder. The Pe is calculated from a heuristic expression [1] based on the computational cutoff rate R_0. The parameter R_0 is given by
where

$$R_0 = -\log_2 \sum_{i=1}^{8} \left\{\frac{1}{2}\left(P(i/+1)^{1/2} + P(i/-1)^{1/2}\right)\right\}^2$$

P(i/+1)= the transition probability that the transmitted bit is positive and the ith quantizer level is received. Since the channel is assumed to be symmetric, a negative transmitted bit has the same transition probabilities as the positive bit, but in reverse order.

The optimum step size between quantization

$$P(i/+1) = P((9-i)/-1) = \int_{\text{ith quantizer interval}} \int_{-\infty}^{\infty} C(u)\, e^{j u z}\, du\, dz$$

boundaries for an 8-level quantizer has been determined for a Gaussian channel to be $\sigma/2$, where σ represents the standard deviation of the noise component at the output of the coherent integrate and dump detector.

The probability of error equation was developed heuristically, by adjusting constants so that the equation matched the results from a Gaussian noise channel simulation of a Viterbi decoder. The equation that results is shown below for both rate 1/2 and 1/3 constraint length 7 convolutional codes.

where

$$\ln(P_e) = \ln(K_1(R)) + \frac{K_2(R)}{R} \ln\left[\frac{2^{1-R_0}-1}{1+e^{a(R_0-b)}}\right]$$

R = code rate
a = 3.017
b = 1.602
K1(1/2) = 102.3　K1(1/3) = 42.284
K2(1/2) = 5.834　K2(1/3) = 5.918

Averaging over all phases of the interfering signal as described above is a reasonable approximation to the actual interference situation, where different Doppler rates result in a time varying phase of the interference signal relative to the desired signal.

B. Interference Threshold Angle Calculator

The Interference Threshold Angle Calculator computes threshold angles required to meet the desired discrimination. These angles are the inter-user angles (see Figure 2) between the desired user spacecraft and the interfering user spacecraft, as viewed from TDRS. It is assumed that the desired user spacecraft is directly in line with the TDRS antenna boresight. For Multiple Access (MA), this means that the beam is formed in the direction of the desired user spacecraft. Thus, the computed threshold angle is the minimum angular difference between the TDRS antenna boresight and the TDRS-to-desired look angle necessary to attain the required discrimination. However, it should be noted that since discrimination versus angle-off-boresight is not a strictly increasing function, the required discrimination may also be achieved for some angles less than the threshold angle.

The actual discrimination is the sum of gain discrimination and polarization rejection. The gain discrimination is acquired from the TDRS Antenna Pattern Databases. Although the actual TDRS MA antenna pattern and associated gain discrimination will vary slightly with the position of the desired user spacecraft, the databased gain discriminations used by the ACRS model are accurate to within .2 dB for spacecraft altitudes under 1000 kilometers. Polarization rejection is only applicable if the signals from the desired and interfering user spacecraft are oppositely polarized.

Three types of threshold angles are computed, all of which are worst-case scenarios: data degradation, acquisition delay, and bit synchronization loss. These three types of angles are computed for all possible desired/interfering link combinations, and are computed for each TDRS using the method described above. An output value of zero for a threshold angle indicates that interference cannot possibly occur for the link combination. These calculated threshold angles are used as input to the Potential Interference Interval Calculator.

C. Potential Interference Interval Calculator

The Potential Interference Interval Calculator uses actual TDRS and user spacecraft orbital data to compute TDRS view periods for, and potential interference intervals between active TDRSS users. All TDRS view periods computed are based strictly on line-of-sight visibility. Data degradation and acquisition delay interference intervals are computed, corresponding to two of the three types of threshold angles computed by the Interference Threshold Angle Calculator. Interference intervals are computed for all selected TDRSs. For a given TDRS, an interference interval is defined as an interval of time for which the following conditions hold:

1) Both the desired and interfering user spacecraft have line-of-sight visibility to the given TDRS.
2) The inter-user angle between the desired user spacecraft and the interfering user spacecraft as viewed from the given TDRS is less than the appropriate threshold angle.
3) If the analysis is to consider the actual communications schedules for the user spacecraft, those schedules must exist in the ACRS schedule databases and include overlapping desired and interfering user service periods for the given TDRS.

Before each run of the Potential Interference Interval Calculator, the analyst must specify several run parameters. The most important of these are:

1) Starting Greenwich Mean Time (GMT) of the run.
2) Duration of the run.
3) Which TDRSs are active for the run.
4) Which user spacecraft are active for the run.
5) Whether or not scheduling data will be considered for the run.

The orbital data for each active TDRS and user spacecraft is obtained from the Orbital Information Database (OID). The orbital data is continually updated by received orbital information from the ISN. The state vectors from the OID are propagated forward to the next vector or the end Greenwich Mean Time (GMT) of the run. The orbit generator used is one whose force model only includes the oblate Earth. Assuming the spacecraft does not maneuver, the state vector error is less than 10 seconds per week of propagation.

Between the start GMT and the end GMT of the run, spacecraft state vectors and all of the geometric calculations are performed at discrete time points, ten seconds apart. Thus the start and stop times of view periods or interference intervals are only accurate to the nearest 10 seconds.

In addition to start times, stop times, and durations, the Potential Interference Interval Calculator provides other outputs for each interference interval. For each interval, possible mitigation techniques, if any, are provided. A mitigation technique is listed for an interval if it is both a possible option and will prevent the interference from occurring. However, there is no guarantee that employing a suggested mitigation technique will not cause an interference problem with another link. Suggested possible mitigation techniques include changing the frequency, polarization, or supporting TDRS for the desired or interfering user.

Additionally, for all data degradation interference intervals, a flag is provided indicating whether or not the interference event will probably be observable in real-time at White Sands Ground Terminal (WSGT) or the NCC. This flag is set if the angle between the two user spacecraft is less than the appropriate bit synchronization loss threshold angle, predicting a loss of bit synchronization due to interference.

D. Solar Interference

ACRS predicts solar interference by treating the Sun in a manner similar to most other interfering user spacecraft. The Potential Interference Interval Calculator uses the desired user's position, the sun's position, and the appropriate Interference Threshold Angle to compute predicted intervals of solar interference which could cause data degradation, late acquisition, or loss of bit synchronization.

Computation of the interference threshold angles for solar interference differs from the standard computation as described in the section above on the Interference Threshold Angle Calculator. First, the required brightness temperature must be computed for each link of each desired user spacecraft. The required brightness temperature is defined as the brightness temperature which, when added to the normal system noise temperature, will reduce the desired user's link margin to zero. The link margins used are the same as those used in computing the required discrimination (see the section above on Calculation of Required Discrimination).

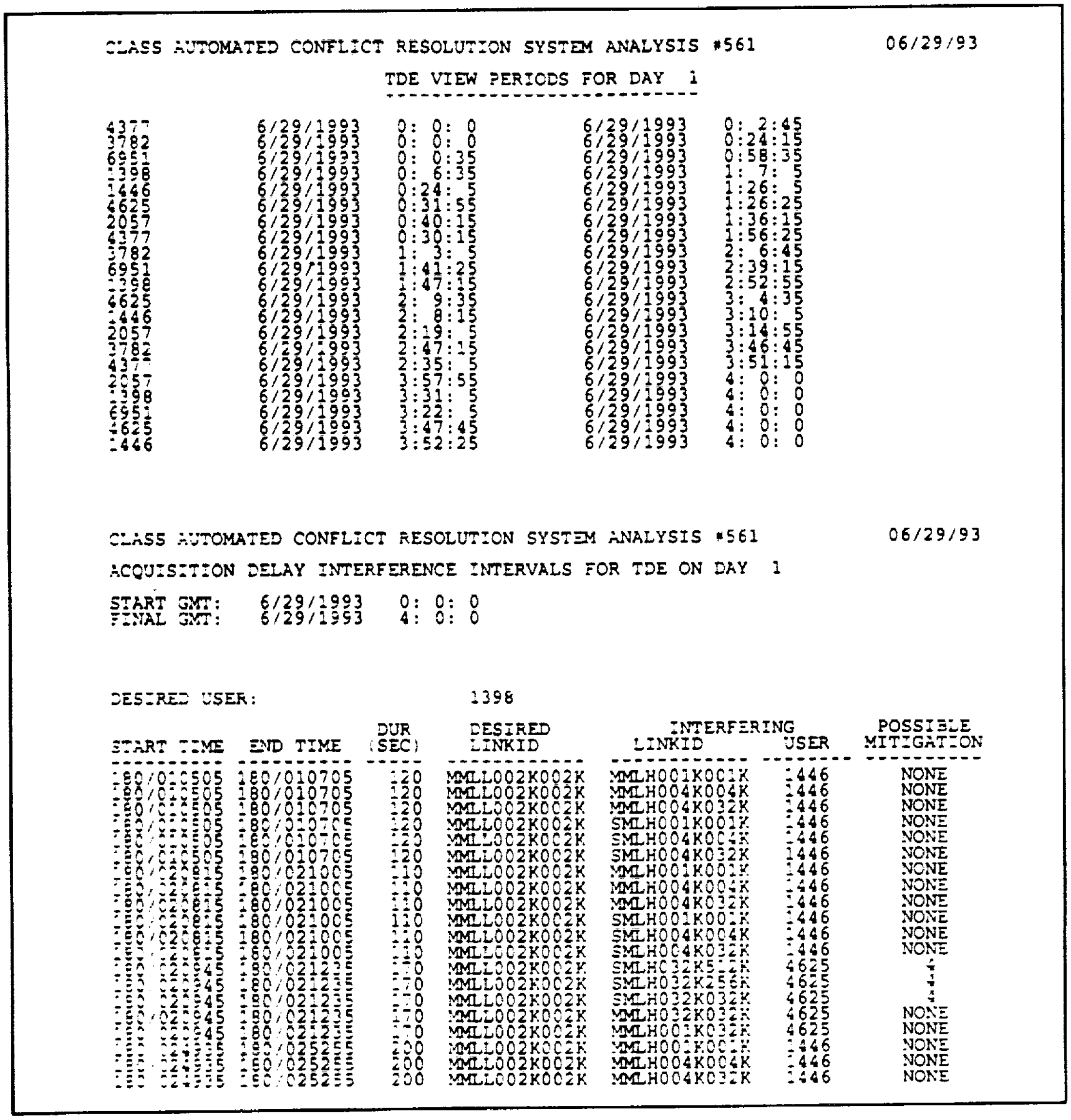
The required brightness temperature is then used to compute time-dependent solar interference threshold angles. This angle is defined as the minimum angular distance required between the TDRS receive antenna and the center of the sun to guarantee that the brightness temperature as seen by the TDRS antenna is less than the previously computed required brightness temperature. A different angle is computed for each month for each desired user spacecraft link. The time-dependence is necessary to allow for the different levels of solar activity at various times in the solar cycle. The solar interference threshold angle is computed by using a detailed model of the TDRS antenna pattern and a model of solar emissions in the appropriate frequency band during the desired month. The solar model is identical to that used in the CLASS Solar Interference Analysis package.

V. DESCRIPTION OF ACRS OUTPUT

The output produced for a given ACRS analysis run is a mutual interference summary chart which can be displayed on the screen or printed out on a local printer. A subset of one of these charts is shown in Figure 4. The summary charts are divided into 24-hour periods referenced as days. There are three tables displayed per TDRS for each day:

- TDRS view periods
- Acquisition delay interference intervals, and
- Data degradation interference intervals.

The view period table lists all of the user spacecraft considered and the date and time for the beginning and end of each mutual interference interval. The format of the acquisition delay and data degradation tables are, for the most part, the same. The desired user is identified followed by columns of information for each possible mutual interference occurrence. The first three columns identify the start, stop, and duration of the interference interval, respectively. The data degradation table contains an additional column identifying, with a double asterisk, the predicts of interference severe enough to be visible to the NCC or WSGT during real-time operations. The next column identifies the operational link of the desired user as defined in appendices attached to each ACRS output. The interfering Link ID and



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CLASS AUTOMATED CONFLICT RESOLUTION SYSTEM ANALYSIS #561            06/29/93
                       TDE VIEW PERIODS FOR DAY  1
                       ---------------------------

4377          6/29/1993   0: 0: 0          6/29/1993   0: 2:45
3782          6/29/1993   0: 0: 0          6/29/1993   0:24:15
6951          6/29/1993   0: 0:35          6/29/1993   0:58:35
1398          6/29/1993   0: 6:35          6/29/1993   1: 7: 5
1446          6/29/1993   0:24: 5          6/29/1993   1:26: 5
4625          6/29/1993   0:31:55          6/29/1993   1:26:25
2057          6/29/1993   0:40:15          6/29/1993   1:36:15
4377          6/29/1993   0:30:15          6/29/1993   1:56:25
3782          6/29/1993   1: 3: 5          6/29/1993   2: 6:45
6951          6/29/1993   1:41:25          6/29/1993   2:39:15
1398          6/29/1993   1:47:15          6/29/1993   2:52:55
4625          6/29/1993   2: 9:35          6/29/1993   3: 4:35
1446          6/29/1993   2: 8:15          6/29/1993   3:10: 5
2057          6/29/1993   2:19: 5          6/29/1993   3:14:55
3782          6/29/1993   2:47:15          6/29/1993   3:46:45
4377          6/29/1993   2:35: 5          6/29/1993   3:51:15
2057          6/29/1993   3:57:55          6/29/1993   4: 0: 0
1398          6/29/1993   3:31: 5          6/29/1993   4: 0: 0
6951          6/29/1993   3:22: 5          6/29/1993   4: 0: 0
4625          6/29/1993   3:47:45          6/29/1993   4: 0: 0
1446          6/29/1993   3:52:25          6/29/1993   4: 0: 0


CLASS AUTOMATED CONFLICT RESOLUTION SYSTEM ANALYSIS #561            06/29/93

ACQUISITION DELAY INTERFERENCE INTERVALS FOR TDE ON DAY  1

START GMT:    6/29/1993   0: 0: 0
FINAL GMT:    6/29/1993   4: 0: 0


DESIRED USER:                      1398

                          DUR     DESIRED            INTERFERING          POSSIBLE
START TIME   END TIME    (SEC)    LINKID          LINKID         USER    MITIGATION
----------  ----------  -----  ------------   ------------  --------  ----------
180/010505  180/010705   120   MMLL002K002K   MMLH001K001K    1446       NONE
180/010505  180/010705   120   MMLL002K002K   MMLH004K004K    1446       NONE
180/010505  180/010705   120   MMLL002K002K   MMLH004K032K    1446       NONE
180/010505  180/010705   120   MMLL002K002K   SMLH001K001K    1446       NONE
180/010505  180/010705   120   MMLL002K002K   SMLH004K004K    1446       NONE
180/010505  180/010705   120   MMLL002K002K   SMLH004K032K    1446       NONE
180/020815  180/021005   110   MMLL002K002K   MMLH001K001K    1446       NONE
180/020815  180/021005   110   MMLL002K002K   MMLH004K004K    1446       NONE
180/020815  180/021005   110   MMLL002K002K   MMLH004K032K    1446       NONE
180/020815  180/021005   110   MMLL002K002K   SMLH001K001K    1446       NONE
180/020815  180/021005   110   MMLL002K002K   SMLH004K004K    1446       NONE
180/020815  180/021005   110   MMLL002K002K   SMLH004K032K    1446       NONE
180/021045  180/021235   170   MMLL002K002K   SMLH032K512K    4625         4
180/021045  180/021235   170   MMLL002K002K   SMLH032K256K    4625         4
180/021045  180/021235   170   MMLL002K002K   SMLH032K032K    4625         4
180/021045  180/021235   170   MMLL002K002K   MMLH032K032K    4625       NONE
180/021045  180/021235   170   MMLL002K002K   MMLH001K032K    4625       NONE
180/024935  180/025255   200   MMLL002K002K   MMLH001K001K    1446       NONE
180/024935  180/025255   200   MMLL002K002K   MMLH004K004K    1446       NONE
180/024935  180/025255   200   MMLL002K002K   MMLH004K032K    1446       NONE
```

Figure 4. Sample ACRS Output

user are displayed in the following two columns. The final column contains any possible options for interference mitigation. These options are described in detail in an ACRS output appendix. (For detailed information on ACRS output formats, see [3]).

VI. CONCLUSION

As the number of TDRS user spacecraft increases, so does the potential for interference arising from two or more spacecraft communicating simultaneously with the same TDRS. ACRS is a new tool used for mission-current mutual interference prediction, and although it is still in the operational prototype stage, the implementation of ACRS in the NCC OCR is already being used as an aid for communications scheduling. Future enhancements to the program, already under development, include forward link mutual interference prediction and refined mutual interference algorithms based on the results of ongoing validations studies of ACRS outputs vs. actual observed mutual interference events. ACRS will help the NCC accomplish the ever more challenging job of scheduling uninterrupted communications for NASA missions.

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